

Methane and Carbon Dioxide Flux From
Ponds and Lakes of the
Hudson Bay Lowlands

By

James David Hamilton

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Submitted to the Faculty of Graduate Studies
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MASTERS OF SCIENCE

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AND LAKES OF THE HUDSON BAY LOWLANDS

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JAMES DAVID HAMILTON

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

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Abstract

Methane and carbon dioxide fluxes ponds and lakes in the Hudson Bay Lowland to the atmosphere from were measured from June to October 1990. The study area was located near the town of Moosonee, Ontario (51° 29' N; 80° 27' W). The study area was divided into four different sites; the Coastal Marsh, Coastal Fen, Interior Fen and the Kinosheo Lake Bog. The Kinosheo Lake bog was the furthest inland (114 km inland from the Coastal Marsh).

In early July, the average daily rate of methane flux from the ponds in the Kinosheo Lake area was 20 mg CH₄/m²/day, increasing to 50 mg CH₄/m²/day by the end of the month. The average daily flux of carbon dioxide was 900 mg CO₂/m²/day. The Coastal Fen and Interior Fen Ponds exhibited much higher fluxes of both CH₄ (averaging 160 mg CH₄/m²/day) and CO₂ (averaging 9000 mg CO₂/m²/day) than were measured at the Kinosheo Lake Bog. At all the sites the flux of CH₄ and CO₂ were highest in September.

Differences between ponds were much greater than the differences on different dates, i.e., ponds with higher rates tended to remain higher and vice versa. All 24 ponds and lakes sampled had concentrations of CH₄ and CO₂ which were consistently above atmospheric equilibrium and thus were sites of net carbon loss from the Hudson Bay Lowland.

Computer modelling suggests that CH₄ concentration is controlled by the combination of wind driven gas exchange and CH₄ oxidation. Carbon dioxide concentrations appear to be controlled by the combined effects of wind driven gas exchange and algal photosynthesis/respiration.

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Historical and Introduction

Atmospheric concentrations of both methane (CH_4) and carbon dioxide (CO_2) have been increasing since the Industrial Revolution (i.e 1700 A.D.) (see Chappellaz et al. 1990 for the most recent 160,000 year record of atmospheric CO_2 and CH_4 concentrations). Prior to the that time tropospheric concentrations of CH_4 averaged 0.75 p.p.m.v. (parts per million by volume) (Rasmussen and Khalil 1984). By 1990 the concentration reached 1.70 p.p.m.v. (Chappellaz et al. 1990) and is increasing at a rate of approximately 1.3%/year or 0.02 p.p.m.v./year (Rasmussen and Khalil 1984).

Pre-industrial tropospheric CO_2 concentrations averaged 260 p.p.m.v. (Raynaud and Barnola 1985). The concentration has now risen to 350 p.p.m.v. and continues to increase at 0.4% or 1.5 p.p.m.v., per year (Gammon et al. 1986).

The increasing concentrations of CH_4 and CO_2 are a growing concern as both of these gases have the property of being radiatively reflective or greenhouse gases. Greenhouse gases are gases that have the property of being transparent to incoming short-wave solar radiation but re-radiate much of the out going long-wave heat energy. Thus, an increase in their concentrations may have the effect of increasing the Earths temperature (Revkin 1988). Moreover the consumption of hydroxyl radicals (OH) by reaction with CH_4 results in a depletion of atmospheric OH and the increase of other greenhouse gases. Hydroxyl radicals are derived from the breakdown of ozone (O_3). Therefore the depletion of the OH

pool in the atmosphere will affect the tropospheric chemistry by depleting O_3 (Cicerone and Oremland 1988). Approximately 85% of the CH_4 input to the troposphere is consumed by this reaction. The end products of this process is CO_2 , H_2O , CO (which are all greenhouse gases) and H_2 (Cicerone and Oremland 1988).

At present CO_2 is causing the most concern because of it's greater concentration. However, CH_4 is a growing concern even though it is found in significantly smaller concentrations than CO_2 . It has 30x the radiative capacity of CO_2 on a mass basis (Revkin 1988). To illustrate this point Cicerone and Oremland (1988) have demonstrated that the radiative heating effect of increasing CH_4 from 0.7 ppm (pre-industrial revolution) to 1.7 ppm (1988 concentration) is half as large as that caused by the simultaneous increase of CO_2 concentrations from 275 ppm to the 1988 concentration of 345 ppm. The half life of CH_4 in the atmosphere of 8-10 years (Prinn et.al 1987) and is different from CO_2 which makes comparisons complicated.

Paleoclimatological studies have suggested that there is a strong relationship between CH_4 and CO_2 concentrations and climatic warming (Kuhn and Kasting 1983; Raynaud and Barnola 1985; Lindstrom and MacAyeal 1989; Broecker and Denton 1989). Ice core data suggests that the lowest concentrations of both CH_4 (.35 p.p.m.) and CO_2 (200 p.p.m.) occurred during the periods of maximum glaciation. When the earth's temperature

increased during the inter-glacial periods the pre-industrial maximums of both gases were observed (Chappellaz *et al.* 1990).

Hypotheses regarding past CO₂ changes usually involve how chemical processes in the world's oceans influence the atmospheric CO₂ concentrations and subsequently the glacial cycles (Broecker and Peng 1987; Broecker and Denton 1989). Raynaud *et al.* (1988) have hypothesized that the increase in CH₄ during interglacial periods comes from CH₄ production from wetlands, which increase in size during the glacial retreats. Thus CH₄ further contributes to the warming during the interglacial period.

At present, anthropogenic sources of both CO₂ and CH₄ are added to natural sources. With the data now available it is predicted that at the present emission rates the atmospheric CO₂ concentration will double the preindustrial concentration some time early in the next century. With this doubling there may be an increase in the earth's average atmospheric temperature of 1.5°C to 4.5°C (Understanding CO₂ and Climate, AES Report 1985). This would bring about many far reaching physical and socio-economic changes.

Both CO₂ and CH₄ are produced biologically, by the combustion of materials such as wood or fossil fuels, and by volcanic eruptions. Of the biological sources, production from northern wetlands may be the most sensitive to anthropogenic environmental impacts. These ecosystems have not been well studied and it is not known how these systems will respond to

anthropogenic influences.

The following is a review of the literature pertaining to the biogenic production of CH_4 and CO_2 from wetlands and the transport pathways that these gases follow to reach the atmosphere. A discussion of the methods by which gas exchange between water surfaces and the atmosphere may be determined is included.

I Microbial Production of CH_4 and CO_2

Biogenic CH_4 and CO_2 production result from anaerobic decomposition of organic material. CO_2 may also be produced from aerobic decomposition of organic carbon and CH_4 oxidation. Many environments provide conditions for both aerobic and anaerobic decomposition such as natural wetlands, lake sediments, rice paddies, and enteric fermentation of ruminants.

The primary pathway of CH_4 and CO_2 production in anaerobic sediments is the degradation of acetate into CH_4 and CO_2 (Hobson *et al.* 1974 and Lovely and Klug 1982). Another pathway is the reduction of CO_2 by H_2 to form CH_4 (Bryant *et al.* 1967).

Because organic matter is primarily in the form of large complex molecules such as carbohydrates, proteins and lipids, the methanogens must rely on other organisms to convert the organic material to a acetate, H_2 and CO_2 (Figure 1). The classic example of this association of methanogens with other

organisms is the association of *Methanobacterium bryantii* and the S-organism. In this case the chemoheterotrophic S-organism oxidizes ethanol to acetate and H_2 . *M. bryantii* then utilizes the excess H_2 to reduce CO_2 to CH_4 (Bryant et al. 1967). Another example is the fermentation of cellulose in the rumen. In the rumen, *Ruminococcus flavefaciens* ferments cellulose to acetate, formate, H_2 and CO_2 . *Methanobacterium ruminantium* can grow by using the H_2 and CO_2 directly to form CH_4 or by the breakdown of formate to H_2 and CO_2 (Latham and Wolin 1977).

The presence of methanogens in a culture influences the types of fermentation end products that are formed. In co-cultures of chemoheterotrophs and methanogens, methanogens can utilize the H_2 produced by the chemoheterotroph. This symbiotic relationship is known as interspecies H_2 transfer. Interspecies hydrogen transfer was first reported by Bryant et al (1967) and the first systematic verification was conducted by Iannotti et al. (1973). When interspecies H_2 transfer occurs there is a shift of the fermentation end products from volatile fatty acids to CH_4 and CO_2 (Mah 1982).

When chemoheterotrophs are grown in the absence of methanogens the fermentation end products that are produced are volatile organic compounds such as acetate, butyrate, propionate and neutral end products such as acetone, butanol and propanol. A small quantity of H_2 and CO_2 is also produced (Figure 1). In the presence of H_2 oxidizing methanogens, H_2 production becomes the major electron sink for the

chemoheterotrophs. Acetate becomes the major organic end product which can be further reduced to CH_4 and CO_2 (Figure 1)(Mah 1982). The relationship is a symbiotic one as the chemoheterotrophs benefit by the removal of inhibitory H_2 and other fermentation products by the methanogens while the methanogens benefit from a readily available supply of substrates produced by the chemoheterotrophs. All the organisms benefit from increased overall energy release (Iversen et al. 1987).

In anaerobic lake sediments and peat organic matter is also hydrolysed to the reduced fermentative end products acetate, H_2 , CO_2 (Yavitt et al. 1987). To a lesser degree proprionate, butyrate, valerate and formate are produced as products of incomplete decomposition and are eventually converted to acetate (Lovely and Klug 1982). Of these products acetate is the major precursor of CH_4 and CO_2 (Yavitt et al. 1987, Lovely and Klug 1982) by methanogenic bacteria. In anaerobic lake sediments CH_4 and CO_2 from non-respiratory pathways are produced in approximately equal quantities (Kelly et al. 1988)

II Methane Production from Lake Sediments

Most of the information available on natural populations of methanogens is from studies on aquatic systems. The major zone of CH_4 production in freshwater lakes is the sediment

(Strayer and Tiedje 1978, Lindstrom and Sommers 1984).

The amount of CH_4 produced varies with location within the lake as well as seasonally and geographically. Rudd and Hamilton (1978) showed that for a small eutrophic lake, the CH_4 production rates for well oxygenated epilimnetic sediments was $0.8 \text{ mmol/m}^2/\text{day}$ and $10.8 \text{ mmol/m}^2/\text{day}$ for anaerobic hypolimnetic sediments during summer stratification. During fall turnover the average CH_4 production rate for the total lake sediments was $4.8 \text{ mmol/m}^2/\text{day}$. During the winter the hypolimnetic sediments produced CH_4 at a rate of $12.1 \text{ mmol/m}^2/\text{day}$ after the hypolimnion became anoxic. Ellis-Evans (1984) found a similar pattern of methane production from lake sediments in freshwater maritime lakes in the Falkland Islands although not at the same magnitude as those found by Rudd and Hamilton (1978) for a north temperate lake. In these Antarctic lakes CH_4 was produced at a rate of only $0.11 \text{ mmol/m}^2/\text{day}$ for profundal sediments and $0.04 \text{ mmol/m}^2/\text{day}$ for littoral sediments during the winter. Rates decreased during the summer to $0.08 \text{ mmol/m}^2/\text{day}$ for profundal sediments and $0.03 \text{ mmol/m}^2/\text{day}$ for littoral sediments.

Kelly and Chynoweth (1981) have shown that CH_4 production from sediments is correlated with short-term temperature changes in laboratory core incubations. More importantly they have shown CH_4 production *in situ* correlates best to the rate of input of organic material and suggest that activity proceeds at a maximum rate even under long-term cold

conditions. CH_4 production decreases during summer stratification as the input of new organic material into the hypolimnion is slowed by the strong thermal gradient of the thermocline. The rate increases again in the fall as algal sedimentation increases during fall turn over and winter when there is a large amount of new organic material in the anoxic sediments.

A significant amount of the new carbon fixed by primary productivity is recycled as CH_4 in anaerobic sediments. Strayer and Tiedje (1978) found that 24-37% of the summer productivity was released from the sediments as CH_4 . Kelly and Chynoweth (1981) also found that approximately 40% of the organic input into the sediments was returned as CH_4 . Rudd and Hamilton (1978) found that 55% of carbon input into the lake was regenerated as CH_4 . This variation in the amount of CH_4 released probably reflects the difference in the contribution of respiratory processes to total decomposition in each of the lakes studied.

Another controlling factor in the rate of CH_4 production from sediments involves competitive interactions with other groups of bacteria. There is a large body of literature that shows that methanogens can be inhibited by all aerobic processes and by other anaerobes such as sulfate reducers (ex. *Desulfovibrio spp.*), through competition for the main sources for terminal electron donors such as CO_2 , H_2 and acetate (Abram and Nedwell 1978 and Smith and Klug 1981 and Lovely and Klug

1983). Oremland *et al.* (1982b) and Lovely *et al.* (1982) have shown that methanogenesis can occur simultaneously with sulfate reduction when the methanogens utilize other organic carbon substrates such as methanol or methionine. Naguib (1984) has also demonstrated this effect with incubations of cores from a eutrophic lake. Naguib amended sulfate reducing cores with acetate, H_2/CO_2 and methanol. Only the methanol enhanced CH_4 production.

III Methane Oxidation

CH_4 oxidation is a major form of loss of CH_4 within lakes. Rudd and Hamilton (1978) found that 60% of the CH_4 produced in lake sediments was oxidized before it could escape to the atmosphere, with most of the oxidation occurring during spring and fall lake turnover.

In freshwater systems during summer stratification CH_4 oxidation usually occurs near the aerobic/anaerobic interface as CH_4 oxidizers must fix N_2 and the N_2 fixation process is very sensitive to the presence of O_2 (Rudd *et al.* 1976, Rudd and Hamilton 1978 and Lindstrom and Somers 1984). However when the fall turnover occurs, ammonia (NH_3), which had been trapped below the thermocline, is mixed throughout the lake and the CH_4 oxidizers are no longer restricted to the aerobic/anaerobic interface as there is no longer a need to fix N_2 (Rudd *et al.* 1976). In laboratory incubation experiment

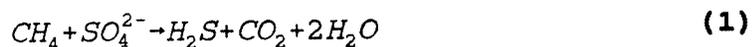
Rudd et al. (1976) demonstrated that CH_4 oxidation could be turned on or off with the presence or absence of N_2 fixation. When the dissolved inorganic nitrogen concentration in the culture was increased to 7 mM, CH_4 oxidation could proceed without N_2 fixation.

The amount of CH_4 oxidized varies seasonally as well as with changing lake characteristics between different lakes. Very little CH_4 oxidation occurs throughout the period of summer stratification as very little CH_4 diffuses across the highly stable thermocline. Rudd et al. (1976) and Rudd and Hamilton (1978) have shown that >95% of CH_4 oxidation occurs during the period of fall overturn and winter when the lake is uniformly mixed.

Of the CH_4 that is oxidized, approximately 50% is taken in by the cell for incorporation as new cell material and 50% is converted to CO_2 (Rudd and Hamilton 1978). Since the majority of CH_4 oxidation occurs during fall overturn, approximately 90% of the CO_2 produced escapes into the atmosphere as there is very little algal activity at this time in northern temperate lakes (Rudd and Hamilton 1978). Therefore CH_4 oxidation can significantly increase the export of CO_2 from the lake to the atmosphere.

In freshwater systems species such as *Pseudomonas methanitrificans*, *Methylomonas methanica*, *Methanomonas methanooxidans* have been implicated in CH_4 oxidation (Rudd and Taylor 1980).

Desulfovibrio spp. have been implicated in the oxidation of methane (Barnes and Golberg 1976, Iverson et al. 1987). Barnes and Goldberg (1976) demonstrated CH₄ oxidation is energetically feasible in marine sediments where sulfate concentrations are usually very high, >10 mM (Reeburgh and Heggie 1977) by the following pathway:



$\Delta G^\circ = -22.8$ kcal/mol.

In freshwater systems sulfate concentrations are very low, 1-10 M (Reeburgh and Heggie 1977) and therefore sulfate reducers likely play a minimal role in CH₄ oxidation in anaerobic environments. However, meromictic lakes are an important exception to this. Meromictic lakes are lakes that never or only rarely completely mix. In the bottom of these lakes there is a layer of increased salinity (the monimolimnion) that can have very elevated levels of sulfate and therefore are not truly "freshwater lakes". Sulfate reducers have been shown to oxidize significant quantities of CH₄ in these lakes (Iversen et al. 1987).

IV Natural Freshwater Wetlands

Aselman and Crutzen (1989) identify some 45 different types of wetlands, which they have grouped into six

categories; Bogs, Fens, Swamps, Marshes, Floodplain and Shallow Lakes. Of these six, only Bogs, Fens and Shallow Lakes are considered here. These three comprised the major ecological zones within the Hudson Bay Lowland site of the Northern Wetlands Study in which I took part. The following are the definitions used by Aselman and Crutzen (1989) to classify the wetlands:

1) Bogs

Bogs are peat producing wetlands where organic material has accumulated. The main distinguishing feature is that they are ombrotrophic, which means that the only moisture and nutrient input comes from direct atmospheric deposition rather than from upland runoff. Bogs tend to be nutrient poor and acidic. The major vegetation type consists of *Sphagnum* moss.

2) Fens

Fens are also peat forming environments. Fens are minerotrophic systems, receiving water and nutrients from ground water and/or runoff, in addition to direct precipitation. Fens are more productive than bogs. Vegetation tends to be a mixture of *Sphagnum* moss, grasses and sedges.

3) Shallow Lakes

Shallow lakes are defined as unstratified open bodies of water of only a few meters in depth. This category is considered in the world analysis of wetland area in Africa,

Europe and South America (Aselman and Crutzen 1989). In the northern latitudes of North America, fens, bogs and swamps are a combination of shallow lakes and mire (saturated soil) vegetation. When characterizing these regions with satellite imagery or aerial photography, small lakes are not often differentiated from the surrounding vegetated area due to the difficulty in separating very small lakes or ponds from the surrounding bog or fen surfaces.

This was a problem in the Northern Wetland Study as standing water covers approximately one third of the Hudson Bay Lowland (Roulet pers.com.)¹ but only lakes larger than 1 km can readily be distinguished by the satellite remote sensing available to the project. Aerial photographs improve the detection of ponds, but anything smaller than approximately 15m in diameter is not possible to detect. This made it difficult to develop a good estimate of water coverage and hence the flux, as carbon flux is very different between the terrestrial and aquatic ecosystems (the terrestrial systems exhibit a net uptake of carbon while the aquatic systems have a net loss of carbon (see discussion)).

4) Marshes

Marshes have saturated soils that do not accumulate peat and are dominated by grasses, sedges or reeds. They may be

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permanent or seasonal wetlands. Salt marshes have been excluded as they are not significant sources of CH_4 because of the high concentrations of SO_4^{2-} .

5) Swamps

Swamps are forested freshwater wetlands with waterlogged or inundated soils. There is little or no peat accumulation.

6) Floodplain

Floodplains are areas along lakes and rivers that are periodically flooded. There is considerable variation in vegetation.

The world wide area of wetlands has been estimated at $5.3 \times 10^6 \text{ km}^2$ (Matthews and Fung 1987) and $5.7 \times 10^6 \text{ km}^2$ (Aselmann and Crutzen 1989). The difference in estimates is due partly to the different interpretations of data by the two groups of authors. More importantly, the data given by Aselman and Crutzen are derived from more advanced satellite image technology and their estimates will be used in this discussion.

The wetland coverage in Canada is approximately $1.27 \times 10^6 \text{ km}^2$. Of these, 95% are comprised of bogs and fens (Aselmann and Crutzen 1989). Aselman and Crutzen (1989) list the area covered in Canada by fens as 3×10^3 - $673 \times 10^3 \text{ km}^2$, bogs 1×10^3 - $531 \times 10^3 \text{ km}^2$ and lakes within wetlands $6 \times 10^3 \text{ km}^2$.

There are two types of decomposition that occur in a bog or fen peat forming system: aerobic decomposition in the upper aerated layers and anaerobic decomposition deep in the peat. Carbon dioxide is produced in both layers, while CH_4 comes only from the deeper anaerobic layer. When input of new organic material exceeds removal, organic material will accumulate and peat will form (Clymo 1984). In northern latitude bogs accumulate organic matter at a rate of 0.1-0.2 cm/year (Mitsch and Gosselink 1986).

It has been estimated that the amount of carbon stored in the wetlands is approximately equal to the amount of CO_2 in the atmosphere (Gorham 1991). Methane from wetlands has greater radiative activity while it remains in the atmosphere as CH_4 , and is eventually oxidized to CO_2 . Therefore understanding the flux of both CH_4 and CO_2 to and from the wetlands is very important.

V Measurement of Gas Flux from Aqueous Wetland Surface

There are three possible methods available to estimate *in situ* gas flux rates across the air/water interface. These are (1) to measure the change in gas concentration within dynamic chambers placed over the water surface, such as those developed by Sebacher and Harris (1982), (2) to measure the

change in gas concentration in static chambers² floated on the water surface, and (3) to measure the difference in concentration between the water and atmosphere and then to calculate the flux using the Thin Boundary Layer or Stagnant Boundary Layer Model outlined by Liss (1973).

After an initial examination of all three methods, the Sebacher and Harris (1982) style of chambers was eliminated as too costly. The static chamber method, which is widely used for terrestrial flux measurements, was eliminated because problems associated with the elimination of wind (it is not known at this time if this is a problem or not), build up of gas concentrations in the air phase and (possibly) may change the natural flux during the measurement period. Such chambers have not been sufficiently studied to determine if this is a reasonable method for measuring flux from aquatic systems. Therefore it was decided that the Stagnant Boundary Layer Model would best suit the purposes of this work.

The theory of the Stagnant Boundary Layer Model (SBLM) for gas exchange was first developed by Whitman (1923) to explain the absorption of HCl gas across the air-liquid interface of an experimental system.

Liss (1973) explains how the work developed by Whitman can be applied to natural systems. The Stagnant Boundary Layer

²Static chambers are large inverted containers that are floated on the water surface in such a way the the edges of the container are sealed by placing the edges a few centimeters into the water.

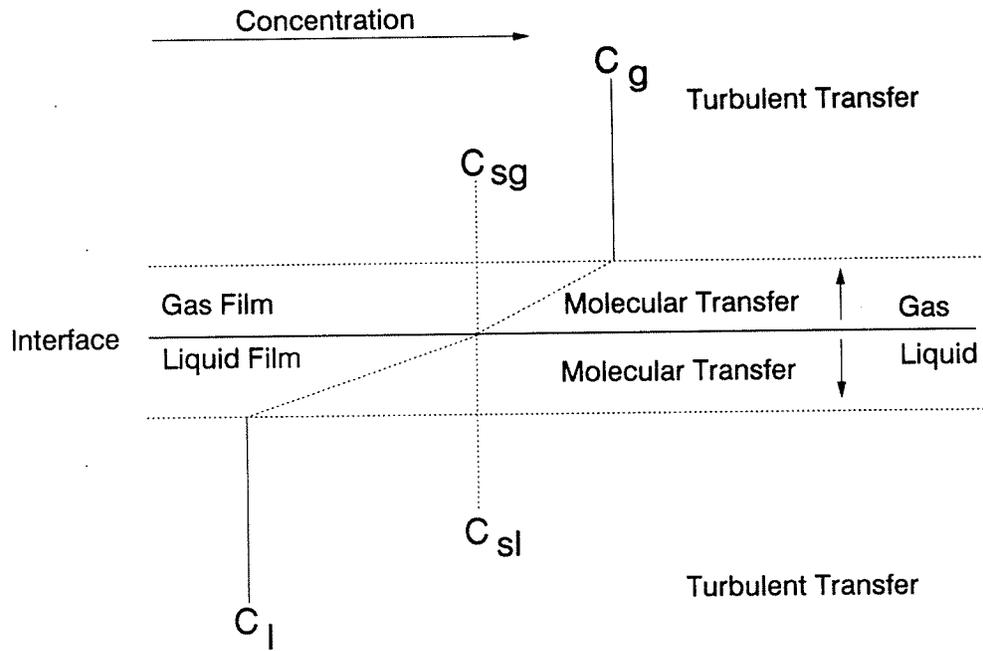


Figure 2. The Stagnant Boundary Layer Model (Liss and Slater 1974).

Model (Figure 2) assumes that the gas in the atmosphere is well mixed by turbulent mixing and that the concentration is C_g . As the air-water interface is approached a concentration gradient forms in the gas film and the concentration near the interface is C_{sg} . The liquid phase is similar to the air phase in that the bulk of the liquid is assumed to be uniformly mixed by turbulent mixing with a concentration of C_l . As the air-water interface is approached, however, the gas concentration becomes affected by the concentration in the air. The concentration at the interface, in the water, is C_{sl} .

The main resistance to gas transfer between the atmosphere and water masses occurs at the air/water interface and is controlled by molecular diffusion in the gas and liquid films. Hence Fick's First Law of Diffusion can be applied:

$$F = \frac{D}{z} \Delta C \quad (2)$$

where:

F= the flux of gas.

D=the diffusion coefficient of the gas.

z=the boundary layer thickness.

ΔC = the change in gas concentration.

The term z is not directly measurable but F and ΔC are, and D/z are combined in a single term called the gas exchange

coefficient (k).

Assuming that the gas transport across the air-water interface is in steady state then equation (2) can be applied:

$$F = k_g(C_g - C_{sg}) = k_l(C_{sl} - C_l) \quad (3)$$

In practice it is the phase with the slowest diffusion rate that will control the flux (Liss 1973). For example the diffusion coefficient for oxygen is about 10^4 times slower in water than in air. Therefore diffusion through the liquid film will control the flux. Equation (2) can then be simplified to:

$$F = k_l(C_{sl} - C_l) \quad (4)$$

Equation (4) can be used for gas such as N_2 , CO_2 and CH_4 , etc. which are not very soluble in water and therefore will have the greatest concentration gradients in the water film (not in the air film) where the diffusion coefficient (and therefore k) is much slower. This causes the flux term in the water to be the limiting rate.

The Stagnant Boundary Layer Model has undergone extensive testing in the past 18 years using biologically inert tracers such as Radon (Emerson *et al.* 1973, Peng *et al.* 1979 and Torgerson *et al.* 1982), Helium isotope (3He) (Torgerson *et al.* 1982) and sulfur hexafluoride SF_6 (Wanninkhof *et al.* 1985 and Crusius and Wanninkhof 1991) both *in situ* and in wind tunnels. In these tests, the concentration gradient and the loss

Lake 302N

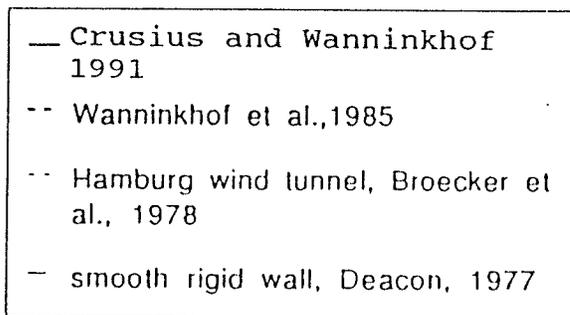
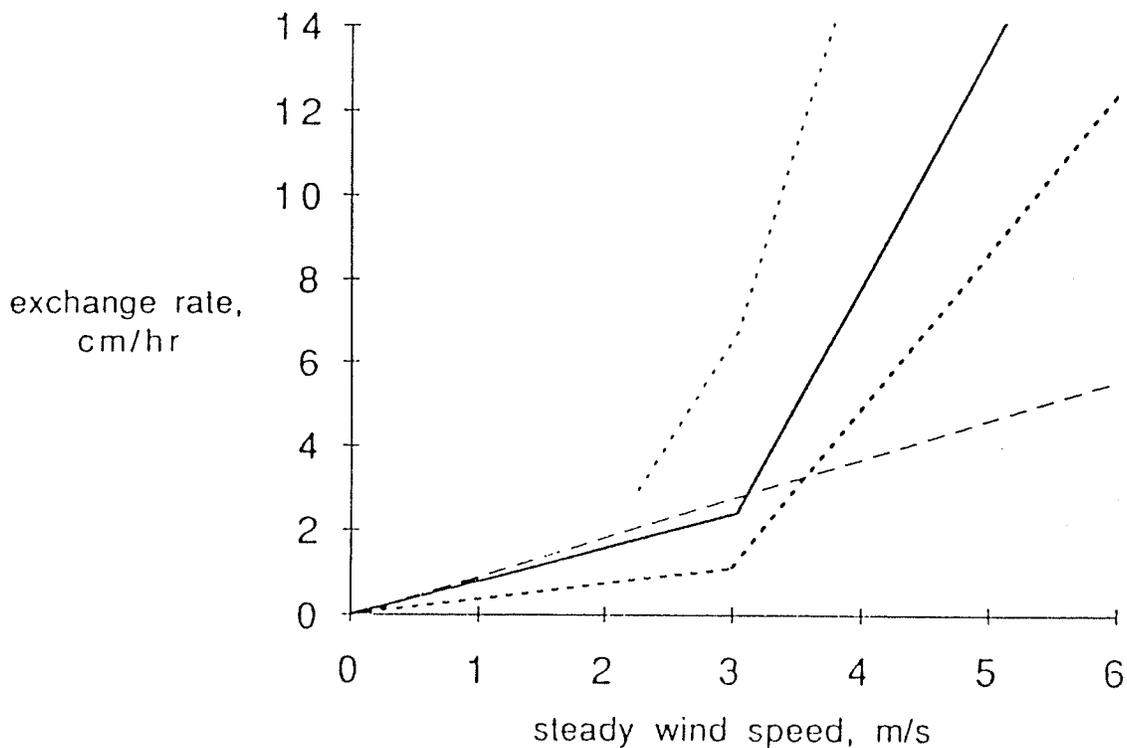


Figure 3. The Relationship Between Wind Speed (m/sec) and Piston Velocity (k). (Crusius and Wanninkhof 1991).

(disappearance) of gas from a water body are measured and k is calculated. Also wind speed (μ) is measured in order to develop a relationship between μ and k that can be used under situations where loss cannot be determined directly. All of these studies have shown that Stagnant Boundary Layer Model is a good predictor of gas exchange across the air/water interface (Figure 3).

The Stagnant Boundary Layer Model does not take into account the ebullitive flux or transport through plants because it only determines the diffusive gas flux. Therefore ebullition must also be measured in order get a total gas flux for the systems where ebullition occurs, such as in the Amazon (Bartlett et al. 1988; Crill et al. 1988).

It is essential to obtain an accurate wind speed measurement at time of sampling in order to predict k . The altitude at which to measure the wind speed can affect the results. As the wind approaches the ground it will slow down due to increased friction with the ground and physical obstructions (i.e. trees, shrubs, buildings, etc.) (Panofsky and Dutton 1984 give a good review of this). Wind speed has often been measured at 10 m as this is the usual height of anemometers at meterological sites. Not all studies have measured wind at this height and in order to compare results researchers have used various to height relationships such as that used by Panofsky and Dutton (1984).

$$V_2 = V_1 * \left(\frac{z_2}{z_1} \right)^p \quad (5)$$

where:

V_2 =Wind velocity at the new height.

V_1 =Measured wind velocity.

z_2 =New height.

z_1 =Height at which the wind was measured.

p =The coefficient of roughness for the terrain over which the wind is being measured.

Errors introduced by this are probably best minimized by using μ -k relationships measured with wind speed measured at the same height.

There are also potential problems with spatial differences in wind speeds over one water body. For example, the lee area produced by obstructions at the edge of a small pond must be considered in using a single wind speed for the whole pond (Talor and Kwan in prep).

VI Ebullition

Ebullition of methane can be a major transport route of CH_4 , and to a lesser extent CO_2 , to the atmosphere. Ebullition tends to be episodic. Chanton *et al.* (1989) found that bubble release was controlled by the hydrostatic pressure of the overlying water. Using inverted funnel methodology, Holzapfel-

Pschorn *et al.* (1985) found that in rice paddies 35% of the total methane flux was in the form of bubble transport, while Crill *et al.* (1988a) found that at times of high ebullition, bubbles could account for essentially 100% of the daily CH₄ flux (10-100 mg CH₄/m²/day in the Amazon). Strayer and Teidje (1978) found that approximately half of the CH₄ released from anoxic sediments was transported by bubbles in Wintergreen Lake, Michigan, up to 336 mg CH₄/m²/day.

Released bubbles are composed of CH₄, CO₂, and N₂. The ratios of these gases varies seasonally (Chanton and Martens 1988), with location (Williams and Crawford 1984, Strayer and Teidje 1978 and Holzapfel-Pschorn *et al.* 1985), and whether or not plants are associated with the sediments where the bubbles originated (Chanton and Martens 1988).

VII Gas Transport by Aquatic Macrophytes

It has been observed that gas bubbles are trapped in the rhizosphere of aquatic plants. These trapped gas bubbles as well as gas dissolved in interstitial water, can readily diffuse into gas spaces within the plant (Dacey and Klug 1979). The major species of gas transported through plants are CH₄ (40-50%), N₂ (40-50%), CO₂ (6%) and O₂ (2%) (Dacey and Klug 1979 and Sebacher *et al.* 1985).

The amount of gas that escapes by this pathway can vary from below detection limits to 14.8 mg CH₄/m²/day depending on

Table 1a. Summary of Literature Values for CH₄ Flux from the Vegetated Surfaces of Wetland Environments.

Site	CH ₄ Flux mgCH ₄ /m ² /d	Method	Author
Alaskan Bog	4.0	Dynamic Chamber	Sebacher et al. (1986)
Swedish Bog	4.7	Static Chamber	Svennson and Rosswall (1984)
Minnesota Bog	106	Dynamic Chamber	Crill et al. (1988b)
Alaskan Fen	59	Dynamic Chamber	Sebacher et al. (1986)
Swedish Fen	95	Static Chamber	Svennson and Rosswall (1984)
Schefferville, Quebec Fen	29-125	Static Chamber	Moore et al. (1990)

Table 1b. Summary of Literature Values for CH₄ Flux from Pools or Lakes within Wetland Environments.

Site	CH ₄ Flux mgCH ₄ /m ² /d	Method	Author
Alaskan Tundra Pool	21	Dynamic Chamber	Whalen and Reeburgh (1989)
Schefferville Quebec Fen Pool	65.9	Static Chamber	Moore et al. (1990)
Amazon Lake	27	Dynamic Chamber	Bartlett et al. (1988)
Florida Impoundment	74	Dynamic Chamber	Harriss et al.

the type of plant (Sebacher et al. 1985). Dacey and Klug (1979) estimated that as much as 75% of the CH_4 leaving the littoral zone of a lake can escape via transport through plants.

VIII Methane Flux from Wetlands

There have been numerous estimates of CH_4 flux from wetland environments (Table 1). Most measurements have been done on the vegetated or terrestrial parts of wetlands, with a few done on wetland lakes or ponds. I will discuss terrestrial measurements first.

Sebacher et al. (1986) showed that for Alaskan bogs CH_4 flux was 4 mg $\text{CH}_4/\text{m}^2/\text{day}$. Svensson and Rosswall (1984) found that bogs in northern Sweden had a similar flux rate of 4.7 mg $\text{CH}_4/\text{m}^2/\text{day}$. More southerly located bogs have a much higher flux rate. For example Crill et al. (1988b) showed that bogs in the Minnesota peatlands had a rate of flux of 106 mg $\text{CH}_4/\text{m}^2/\text{day}$.

Fens tend to produce more CH_4 than bogs. Sebacher et al. (1986) showed that fens in Alaska produced 59 mg $\text{CH}_4/\text{m}^2/\text{day}$. Svensson and Rosswall (1984) showed that fens in Sweden produced 95 mg $\text{CH}_4/\text{m}^2/\text{day}$. Fens near Schefferville, Quebec produce CH_4 at a rate 29-125 mg $\text{CH}_4/\text{m}^2/\text{day}$ (Moore et al. 1990).

As mentioned above, lakes and ponds within the different

wetland classifications have been much less studied. Whalen and Reeburgh (1989) found ponds and lakes in the Alaskan tundra had an average CH_4 flux rate of $21 \text{ mg CH}_4/\text{m}^2/\text{day}$. Moore *et al.* (1990) showed that the CH_4 flux from a pool in some of the fens located near Schefferville, Quebec was $65.9 \text{ mg CH}_4/\text{m}^2/\text{day}$. Methane fluxes from lakes in other wetland regions ranges from $27 \text{ mg CH}_4/\text{m}^2/\text{day}$ in the Amazon (Bartlett *et al.* 1988), $74 \text{ mg CH}_4/\text{m}^2/\text{day}$ from impoundments in the Florida everglades (Hariss *et al.* 1988).

The above estimates of CH_4 flux from ponds were measured using different types of floating chambers. As discussed in Section V above, wind is an important factor in the flux of gas across the air/water interface. The static chamber method such as that used by Moore *et al.* might underestimate the flux as it eliminates the wind influence. Another problem that can lead to an underestimate of flux is that as the partial pressure of CH_4 builds up within the chamber this will decrease the slope of the concentration gradient between the air and water which will decrease the diffusion of CH_4 across the air/water interface.

To minimize the problem of the static chamber Sebacher and Harris (1982) designed a dynamic chamber for estimating gas flux. This style of chamber circulates the air with a variable speed pump that simulates wind action. This gives a more realistic estimate of the gas flux from water bodies than the static chamber. However, if left long enough the gas

Table 2a. Summary of Literature Values for CO₂ Flux from the Vegetated Surfaces of Wetland Environments.

Site	CO ₂ Flux mgCO ₂ /m ² /d	Method	Author
Schefferville, Quebec Fen	300-500	Static Chamber	Moore and Knowles (1987)
Swedish Bog	100-700	Static Chamber	Svensson (1980)

Table 2b. Summary of Literature Values for CO₂ Flux from Pools and Lakes within Wetland Environments.

Site	CO ₂ Flux mgCO ₄ /m ² /d	Method	Author
Alaskan Tundra Lake	-242-2630	Static Chamber or SBLM	Kling et al. (1991)

concentrations can still build up in the headspace of the chamber.

IX Carbon Dioxide Flux from Wetlands

There has been less work done on CO₂ flux from wetlands than on CH₄ flux. There have been no studies that have intensively studied the production of CO₂ from wetland pond or lake sediments during the course of an open water season. However it is clear that at night when photosynthetic CO₂ fixation is shut down, the CO₂ flux to the atmosphere is much larger than CH₄ flux. Moore (1986) found that the ratio of CO₂:CH₄ flux for fens in the Schefferville area ranged from as low as 4:1 in a poor fen to as high as >700:1 in a very rich fen.

By placing static chambers on the vegetated surfaces for 24 hours, Moore and Knowles (1987) found the CO₂ evasion rate ranged from 300-500 mg CO₂/m²/day and CH₄ evasion rates of 19.2-46.4 mg CH₄/m²/day for fens near Schefferville, Quebec. Svensson (1980) found similar values of 100-700 mg CO₂/m²/day for a subarctic mire in Sweden (Table 2).

In a laboratory study Moore and Knowles (1989) have demonstrated that the magnitude of CO₂ flux is correlated with the water table depth. When the water table was 10 cm above the surface of cores taken from fens the CO₂ flux was 300-500 mg CO₂/m²/day. As the water table drops the CO₂ flux increases.

When the water table dropped to 70 cm below the fen surface CO₂ flux increased to 6600-9400 mg CO₂/m²/day.

There has been even less work done on CO₂ flux from isolated ponds and small lakes within the fens and bogs. Coyne and Kelley (1974) showed that ponds in the Point Barrow region of Alaska were supersaturated with CO₂ except during periods of intense algal activity. These authors also found that while the ponds are supersaturated, the flux per unit area from ponds is approximately 15% of the per unit flux area from the adjacent land area. Kling et al. (1991) observed CO₂ flux from lakes in the Alaskan tundra ranging from -242 mg CO₂/m²/day to a high of 2630 mg CO₂/m²/day with a mean flux of 20 mg CO₂/m²/day. Kling et al. (1991) attribute the high fluxes that they observed to ground water transport of terrestrially formed CO₂ into the ponds which then escapes to the atmosphere.

X The Northern Wetland Study

The Northern Wetland Study was designed to study the CH₄ and CO₂ production from the Hudson's Bay Lowland of Northern Canada. This area was chosen for study as it comprises the largest continuous wetland in North America and the second largest peatland in the world (the Siberian peatlands are larger) (Aselmann and Crutzen 1989). Aqueous surfaces cover approximately one third of the surface area of the Hudson Bay

Lowland, with water bodies ranging from small ponds of <1 m across to lakes >1 km long and located in all of the open bog and fen areas of the Hudson Bay Lowland. This is an area that, despite its size, has never been studied intensively. The objective of the study was to obtain an accurate estimate of the release of CH₄ from these environments, because northern peatlands have been implicated as major global sources of CH₄ (Aselmann and Crutzen 1989). A secondary objective was to study the net carbon flux in the wetlands by measuring the day and night CO₂ fluxes.

The study was a collaborative effort by a large number of universities and government agencies from both Canada and the United States. The Atmospheric Environment Service (AES Canada) and NASA furnished aircraft, equipment and personnel to measure the movement of CH₄, CO₂ and other greenhouse gases through the troposphere. AES also established a ground based station at Kinosheo Lake to measure gas movement from ground level to 18 m above ground. The Universities of York and McGill as well as the National Center for Atmospheric Research (Boulder, Colorado) had teams present to measure the flux of CH₄ from the terrestrial surface to the atmosphere. NASA/BREW supplied a team to measure the primary productivity of the terrestrial surface. To meet the objectives of the study, all participants were in the field at the same time to determine the flux of CH₄ and CO₂ from the ground and water surfaces to approximately 20 km into the atmosphere. The full study

operated from July 1 to August 2, 1991. The teams studying the flux of CH_4 from the terrestrial surfaces and the ponds operated from June to the middle of October. In addition to the work done in the Moosonee area there were ongoing spatial surveys of gas flux being carried out at Schefferville, Quebec and Churchill, Manitoba.

The major objective of the study reported in this thesis was to quantify the diffusive and ebullitive flux of CH_4 and CO_2 from the ponds and small lakes within the different ecosystems (fens and bogs) of the Hudson's Bay Lowlands. Secondly, a modelling approach was used to gain an understanding of the possible mechanism controlling the diel cycle of both CH_4 and CO_2 fluxes.

Methods

I Study Area

(1) Physical Description:

The study area is located in the Subarctic Region of Canada (50-55°N) on the Hudson Bay Lowlands. The base of operations and lab facilities were located in the town of Moosonee, Ontario (51° 29'N; 80° 27'W).

The Hudson Bay Lowland area is undergoing isostatic rebound as a result of compression of the North American continental plate during the last glacial period. This is causing the Lowlands to uplift at a rate of 0.75-1.25m/100 years (Clarke et al. 1982). Elevation ranges from 0 m to a maximum of 150 m above Sea Level (Jeglum and Cowell 1982). The main study area at Kinosheo Lake is only 60 m above Sea Level. The entire Lowland is underlain with impermeable glacial moraine clays and silts. This combination of very flat land and poor sub-surface drainage are an ideal combination for the development of wetlands.

The Hudson Bay Lowland is comprised of approximately 85-90% wetland areas. Pala and Boissonneau (1982) have categorized the Hudson Bay Lowlands into 27 different ecological zones but the study area can be separated into three broad categories; supertidal marsh along the coast of James Bay, minerotrophic fens approximately 2 km inland from the marsh and ombrotrophic bogs approximately 40 km inland

from the marsh.

Water outflow from the Lowlands consists of non-channelized seepage which feeds into a number of rivers that flow parallel to the coast. These rivers flow into larger rivers that discharge into James Bay (Jeglum and Cowell 1982).

Soil types range from Chernozemic at the coast to Fibrisols and Mesisols at the inland sites. Peat accumulations vary. The study area was situated in a zone of discontinuous to no permafrost. At the younger Coastal Fen site (15 km inland), the peat is approximately 1000 years old with a depth of about 1m. At the older Kinosheo Lake site (114 km inland), the peat is approximately 5000-7000 years old and has a depth of approximately 10 m (Roulet pers.com.).

(2) Climate

The study was carried out during the ice free season of 1990. The area is ice-free from the beginning of June to the middle of November, with a mean annual growing season of 123 days (Mortsch 1990).

The mean 24 hour daily temperature for July is 15°C. However during the study period temperatures frequently reached 30°C. The average temperature for Moosonee during the study period was only 1°C above normal (Mortsch pers. com.).

The mean annual precipitation is 600-700 mm, with 100 mm falling in July and 60-80 mm/month from August to November

(Mortsch 1990). Again 1990 differed from the average. A large rain event in June supplied most of the summers moisture input. During June Moosonee recieved twice the normal precipitation for that month. July and August were very dry. The precipitation recorded at the Moosonee weather station in July was 69% of the normal values and August was 10% of the normal values (Mortsch pers.com). Because of the dry months 50% of the ponds in the study dried up during the course of the study but refilled for the fall sampling period.

Climatic conditions in September and October followed normal patterns for temperature and precipitation. Air temperatures ranged between 0 and 9°C and precipitation was approximately 60 mm per month.

II Sample Location

Sampling was carried out along a transect starting at the North Point (51°29.8'N; 80°28.1'W, 17 km NE of Moosonee) on the James Bay Coast, then directly inland 114 km to Kinosheo Lake(51°33.0'N; 81°49.5'W). Along this transect line four sites were picked for study as representative areas of the different ecological zones in the Lowlands.

These sites were designated the Coastal Marsh, Coastal Fen, Interior Fen, and Kinosheo Lake Area. For my work only three of the sites were regularly sampled and these three are described in detail below. The Coastal Marsh was only sampled

once due to sulfide production at this site which would have damaged the methanizer catalyst material in the gas chromatograph.

At each site a number of representative ponds were chosen. Ponds were specifically selected to cover the range of depth, size and bottom composition at that site.

(1) Coastal Fen

The Coastal Fen (51°28.2'N; 80°37.0'W) is a minerotrophic fen 15 km inland from North Point. It is a graminoid fen with some carex, low shrubs and *Sphagnum* mosses. Tamaracks bordered the north side of the site near a small river. The peat is approximately 1m in depth and approximately 1000 years old.

Water levels were usually at or just above the surface of the fen. Ponds were distinguished from the surrounding fen surface by the slightly raised edges and deeper water.

Eight ponds (Ponds 11-18) were chosen for study. Pond depths ranged from 0.05 m to 0.5 m; with the average depth being 0.1-0.2 m. Pond surface area ranged from 200-530 m².

As the summer progressed all the ponds with the exception of Pond 14 either dried up (no standing water) or the water levels dropped to the point that it was no longer possible to sample. By the end of July it was only possible to sample Pond 14. By September, all the ponds could again be sampled with

exceptions of Ponds 17 and 18. All eight ponds were sampled in October.

(2) Interior Fen

The Interior Fen (51°30.7'N; 80°52.8'W) was approximately 26.8 km inland from North Point. It is a treed and gramminoid fen. Trees were located on elevated peat islands. This site is chronologically older than the Coastal Fen (i.e. it has been above sea level longer than the Coastal Fen) with 1-2 m of peat. The Interior Fen was much drier than the Coastal Fen with the water at or below the fen surface.

Six ponds (Ponds 19-24) were chosen to represent this location. The ponds were part of semi-continuous strings of ponds that ran through this area. During the peak water levels of spring, the ponds are contiguous, forming long strings of connected ponds. During the low water levels ponds were isolated from each other by raised peat ridges. Pond depths varied from 0.05 m to 0.5 m. The average depth was about 0.2 m. The surface area ranged from 200-400 m².

By the middle of July at this location only Pond 19 dried up such that it became impossible to sample, but it had enough water in it again by the middle of September.

(3) Kinosheo Lake Area

The Kinosheo Lake Area (51°33.0'N; 81°49.5'W) was the furthest point inland in the study site. Kinosheo Lake is approximately 85 km WNW of Moosonee and 114 km inland from North Point. This area is an ombrotrophic bog situated on top of 10 m of peat which 5000-7000 years old. Small shrubs and stunted tamaracks or black spruce grew on raised hummocks. Lichens grew on the highest, driest parts of these hummocks. *Sphagnum* mosses grew where moisture conditions were adequate. Stands of Black Spruce and Tamarack grew on the edges of the very large ponds and lakes.

Ten ponds (Ponds 1-10) were chosen at this site. Ponds ranged in depth from .1 m to 2 m. Surface area ranged from 10-42000 m². Some of the ponds or lakes in the bog areas were much larger than the largest pond sampled in the Kinosheo area. Satellite images (available from the Canadian Centre for Remote Sensing) showed that large lakes are found only in the older bog areas of the Hudson Bay Lowland.

During the dry months of July and August only Ponds 1,6,7, and 10 had sufficient water to sample. By the middle of October all the ponds could be sampled again.

III Sampling Procedure

(1) Water Samples

(a) Sample Bottle Preparation

Water samples for CH₄ and CO₂ analyses were taken in evacuated 125 ml serum bottles (Wheaton Glass Co.). The preparation of the sample bottles was as follows:

i) The bottles were preweighed empty with the serum stoppers in place. Serum stoppers came from Vacutainer Tubes (Fischer Scientific). Prior to use Each bottle was measured for internal volume, which was recorded on the side of the bottle.

ii) Approximately 8.9 g of Potassium Chloride Salt (KCl) (Fisher Scientific) was added to each bottle. The KCl acts as a preservative in that it inhibits microbial activity in the water by raising the salinity. The reason that KCl was chosen rather than NaCl is that KCl had no detectable alkalinity contamination and therefore it's addition does not affect the pCO₂ concentration of the water sample. The shelf life of these samples is two to three weeks (Furutani pers. com.). In practice they were never kept longer than 7 days.

iii) The bottles were then flushed with Ultra High Purity Nitrogen (UHP N₂) (Linde Gas) for two minutes (flow rate of 200-300 ml/min) to displace any room air from the bottles. After flushing the serum stoppers were put firmly into place.

iv) The flushed bottles were then evacuated for two minutes using a Sargent Welch Duo-Seal Vacuum Pump (Model No. 1405) with a 20G needle (Becton Dickinson) attached

to pierce the stopper.

v) After evacuation, 10 ml of UHP N₂ was added to the bottle to prevent over-filling during sampling. A 10 cc glass syringe fitted with a two way valve and 20G needle, was used to add the UHP N₂.

Sample bottles were usually prepared the day before sampling, but can be stored for periods of one to two months without any appreciable leakage.

(b) Water Samples

Upon arrival at the site an initial sample for pCO₂ and pCH₄ analysis was taken from each of the ponds. When diel measurements were done further samples were taken at three to four hours intervals.

Since all three of the sampling locations sit upon peat, care had be taken when sampling these ponds as it was quite easy to disturb the pond sediments by walking close to the edge. Small board walks were used when possible to minimize such disturbances. When board walks were not available ponds were approached with care from the firmest ground or plastic snow shoes were used. Once at the edge of the pond it was then necessary to reach out as far as possible from the edge to avoid any interstitial water that may have been forced out the sediments by walking near the edge.

The procedure for the taking of a water sample is as follows or see Hesslein et al. 1991 for further details:

i) The neck of a serum bottle was held just under surface of the water and an 18G needle (Beckon Dickinson) was used to pierce the serum stopper. An 18G needle was used instead of the 20G needle, as it will allow the bottle to fill faster.

ii) Water was allowed to enter the bottle until pressure equilibrium was attained. This was determined by watching the salt crystals moving inside the bottle as well as periodically placing a finger over the needle to feel for vacuum.

iii) Once water stopped entering the bottle the needle was removed while the bottle was still submerged. When the water was less than 10°C it was necessary to leave the bottle submerged for approximately 5 to 10 seconds to allow the rubber to seal the hole made by the needle.

iv) The bottle was then removed from the water and shaken to dissolve all of the salt.

v) The bottle was then stored in the dark, until analyzed.

vi) Water temperature was measured with a telethermometer ($\pm 0.05^\circ\text{C}$) (Flett Research Ltd., Winnipeg, Manitoba).

(2) Gas Bubble Samples

(a) Sample Bottle Preparation

Five and 10 ml serum bottles were prepared as described

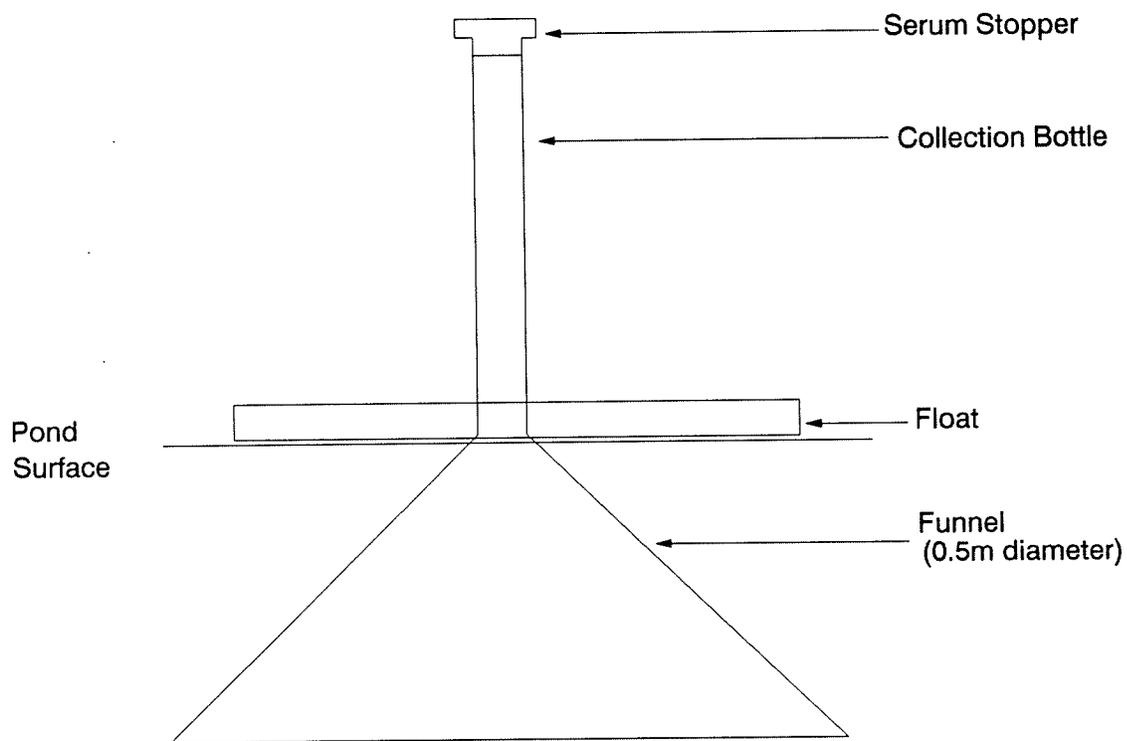


Figure 4. Floating Gas Bubble Trap.

above, with the exception of adding KCl.

(b) Bubble Trap Construction

Two types of bubble traps were used:

i) An inverted plastic was funnel made of Cellulose Acetate Butyrate (Johnston Industrial Plastics, Winnipeg, Manitoba). The funnel was 0.5 Hxin diameter. There were three types of collection bottles that could be attached; a 100 ml Graduated Cylinder and a 500 or 1000 ml Erylenmyer Flask. All three collection bottles had serum bottle necks blown into their bottoms.

The inverted funnel was floated on a styrofoam collar (Figure 4). A hand vacuum pump (Nalgene) fitted with a 20G needle was used to draw water up into the collection bottle until the bottle was full.

The floating traps were anchored in place by three lines attached to 1 Kg SCUBA weights. Each line was 3 to 4 m in length so that the SCUBA weights rested in areas well away from were the trap was be collecting.

ii) The second type of Bubble Trap was a modified 2.8 L liquid culture flask (Fisher Scientific). The bottom of the culture flask was removed and the neck blown into a serum bottle neck. A hand vacuum pump was used to displace any air in the trap with water. This type of trap could either be rested gently on the bottom or

floated in a styrofoam ring.

(c) Taking A Gas Bubble Sample

Upon arrival at the site two to three bubble traps of either or both kinds were deployed on to the ponds. The traps were left in place for 10 hours. However, on some occasions it was possible to leave them for 24 to 48 hours. All traps were checked every three to four hours.

When an appreciable amount of gas was collected, a 5 to 10 ml sub-sample was removed from the trap using a 10 cc glass syringe fitted with a two way valve and a 20G needle, then placed in the appropriate size of sample bottle. The total amount of gas as indicated by the graduations on the collection bottle was recorded.

IV Water Chemistry Collection and Analysis

Water samples for chemical analysis were taken in 500 ml Nalgene bottles. These water samples were taken during the last sampling circuit of the day. Samples were kept on ice and transported to the chemistry lab at the Freshwater Institute (Department of Fisheries and Oceans) in Winnipeg for analysis. Due to the distant and difficult travel arrangements, the water samples were sometimes three or four days old by the time they were analysed, and nutrient analyses were not done.

The water samples were analysed for suspended carbon, nitrogen and phosphorous, total dissolved phosphorous, dissolved inorganic carbon, dissolved organic carbon, chlorophyll, soluble silica, chloride and sulfate, conductivity, sodium, potassium, calcium, magnesium, alkalinity and organic acids.

V Sample Analysis

(1) Water Samples

Samples were stored in the dark until analysis, which was usually within 24 hours. Samples were always analysed within one week.

a) Analysis of pCO₂ and pCH₄

The following procedure was used for pCO₂ and pCH₄ determination:

i) 200 ul subsamples of known gas standards were injected into a Shimadzu Mini-2 Flame Ionizing Gas Chromatograph equipped with a modified Shimadzu MTN-1 Methanizer and a Spectra Physics Integrator. The gas standards for CO₂ were 350, 1010, 3390, 9940, 19900, and 40000 parts per million (ppm). Standards for CH₄ were 353, 1000, 3380,

9900, 20100, and 39800 ppm (Linde Gas).

Gas Chromatograph:

- (1) A 2 m teflon column of Por Pak Q (mesh size 50-80).
- (2) Carrier Gas UHP N₂ (Linde Gas). Flow Rate 15 ml/min.
- (3) UHP H₂ (Linde Gas). Flow rate 20 ml/min.
- (4) Ultra Zero Air (Linde Gas). Flow rate 600 ml/min.
- (5) Oven temperature 60°C.
- (6) Detector temperature 100°C.

Methanizer:

- (1) Methanizer tube was packed with 5 cm of Ruthenium Oxide Catalyst (see Colket et. al. 1974, for catalyst preparation). Conversion of CO₂ to CH₄ was 88 to 95%.
- (2) Hydrogen flow was taken from the second detector and piped into the methanizer. Flow rate was 10 ml/min.
- (3) Methanizer oven temperature was 325°C.

ii) After each of the gas standards were injected separately. A calibration curve of Peak Area vs. ppm of CO₂ or ppm of CH₄ was made on a Sharp Scientific Calculator (Model No. EL-5103S). Standard curves were

generated at the start of each day and often in the middle of each day if there was a large fluctuation in atmospheric pressure.

iii) Sample bottles were re-weighed to determine the size of the sample.

iv) Samples were shaken for 10 minutes using a Burnell Wrist Action Shaker (capacity of 8 bottles) to to promote equilibrium between the gas phase and the liquid phases.

v) a 200 ul subsample of the gas phase was removed from the bottle using a 0.5 ml Pressure Lock Syringe (Mandel Scientific).

vi) Samples were measured in duplicates. If the variability between injections was great than 5%, another replicate injection was made.

vii) The peak areas for the samples were compared to the standard curve for the gas standards to determine the concentration of CO₂ and CH₄ in the headspace of the bottle.

viii) the water temperature in the bottles was taken with an Omega 450 APT Platinum Thermometer. The Platinum probe was pushed through the serum stopper and the bottle was laid on it's side so that the entire probe was immersed.

ix) After every three or four samples were injected a set of three standards (350, 9940, and 19900 ppm CO₂ and 353, 9900 and 20100 ppm CH₄) were injected to test the catalyst efficiency.

x) Atmospheric pressure was measured using an Airguide Barometer (Fisher Scientific).

(b) Analysis of Dissolved Inorganic Carbon

i) After the water samples were analyzed for $p\text{CO}_2$ and $p\text{CH}_4$ they were acidified by the addition of 200 ul of Phosphoric Acid (85%).

ii) Steps i through x as outlined above are then carried out.

(2) Analysis of Gas Bubble Trap Samples

The analysis of gas samples for $p\text{CO}_2$ and $p\text{CH}_4$ was as outlined for the water samples with the exception of step iv.

VI Calculations

Once the concentration of CO_2 , CH_4 and DIC in the head space was known it was possible to calculate the gas concentration in the water. This was done using the following calculations on a IBM Compatible computer using a Lotus 2.2 spreadsheet:

(1) Miscellaneous Calculations:

Water in Sample:

$$V_{ws} = (Btl. + Sample) - (Btl. + KCl) \quad (1)$$

where:

V_{ws} = Volume of water in the bottle, in millilitres
(assumes 1 ml = 1 g of water).

Btl + sample = The total weight of the bottle, the KCl
and the sample water, in grams.

Btl. + KCl = the total weight of the empty bottle and
the KCl, in grams.

Head Space Volume:

$$V_{hs} = V_{btl} - V_{ws} \quad (2)$$

where:

V_{hs} = Volume of the headspace in the bottle, in
millilitres (ml).

V_{btl} = Bottle Volume, in ml.

Grams of KCl:

$$KCl = (Btl + KCl) - EmptyBtl \quad (3)$$

where:

KCl = KCl added to the bottle, in grams.

Btl + KCl = The total weight of the empty bottle and
the KCl, in grams.

Empty Btl = Weight of the empty bottle, in grams.

Molarity of KCl:

$$M_{KCl} = \frac{\left(\frac{KCl}{Mol. wt.} \right)}{\left(V_{ws} * \left(\frac{1L}{1000ml} \right) \right)} \quad (4)$$

where:

M_{KCl} = Molarity of KCl.

KCl = grams of KCl added.

Mol. wt. = Molecular weight of KCl.

Salinity:

Salinity is required in the calculation of the new CH_4 solubility coefficient (see equation 14).

$$S = \left(\frac{KCl}{KCl + WaterSample} \right) * 1000 \quad (5)$$

where:

S = Salinity in parts per thousand (ppt).

KCl = Amount of KCl added, in grams.

Water sample = Amount of water in the bottle, in grams.

(2) Calculation of CO_2 Concentration

Since the KCl added to the bottle increases the salinity, it is necessary to calculate a salt corrected Henry's Solubility Constant.

Ionic Strength (i):

$$i = 0.001 + M_{KCl} \quad (6)$$

where:

0.001 = The ionic strength of dilute waters.

pK:

$$pK = - \left[\left(\frac{a}{T} \right) - b + c * T \right] \quad (7)$$

where:

T = The water temperature in the bottle, in degrees Kelvin.

$$a = 2389.13 - (187.17 * i)$$

$$b = 14.042 - (1.0126 * i)$$

$$c = 0.015303 - (0.0016283 * i)$$

Henry's Solubility Constant:

$$k = 10^{(-pK * 2.302585)} \quad (8)$$

where:

k = Henry's Solubility Constant, in mol/L * atm.

Equations 6-8, Harned and Davies (1943)

With the corrected Henry's Law Constant it is becomes possible to calculate the concentration of gas in the bottle.

The Mass of CO₂ in the Headspace:

$$CO_{2g} = V_{hs} * \frac{CO_2}{10^6} * 1000 \mu l / ml * \frac{P}{760} * \frac{273}{T} * \frac{1 \mu mol}{22.4 \mu l} \quad (9)$$

where:

CO_{2g} = Mass of CO_2 in the headspace in micromoles (μmol).

V_{hs} = volume of headspace, in ml.

CO_2 = concentration of CO_2 in the headspace in parts per million (ppm). as measured by gas chromatography using standards of known ppm (Linde Gas)

P = Atmospheric pressure (mm Hg)

Concentration of CO_2 in the water in the sample bottle:

$$[CO_2]_{aq} = \left[k * \frac{CO_2}{10^6} * \frac{P}{760} * \frac{273}{T} * \frac{V_{ws}}{1000 \text{ ml/L}} * (1 * 10^6 \mu\text{mol/mol}) \right] \quad (10)$$

where:

$[CO_2]_{aq}$ = Concentration of CO_2 dissolved in the water, $\mu\text{mol/L}$.

Total CO_2 :

$$[CO_2]_{Total} = \frac{CO_{2g} + \left([CO_2]_{aq} * V_{ws} * \frac{1L}{1000 \text{ ml}} \right)}{\left(\frac{V_{ws}}{1000 \text{ ml/L}} \right)} \quad (11)$$

where:

$[CO_2]_{total}$ = The total concentration of CO_2 , in $\mu\text{mol/L}$, in the original water sample.

(2) Calculation of DIC Concentration

The procedure for calculating the DIC concentration is the same as for CO₂ (equations 6-11), except that the salt correction calculation for ionic strength (i) (equation 6) is different due to the acid added to the bottle for DIC analysis.

Ionic Strength (i) for DIC calculation:

$$i = 0.001 + M_{KCl} + 0.01 \quad (12)$$

where:

0.01 = ionic strength of Phosphoric Acid.

(3) Calculation of Aqueous CO₂ Concentration in equilibrium with air at *in situ* water conditions

In order to know whether the aqueous CO₂ concentration measured in each sample is above or below that which would occur if the water were in equilibrium with the air, the equilibrium CO₂ concentration must be calculated for the *in situ* conditions. The Henry's Law Constant is derived for the *in situ* temperature as outlined above for aqueous CO₂ except that $i = 0.001$, which is the approximate *in situ* ionic strength of the Hudson Bay Lowland pond water.

Equilibrium CO₂ Concentration:

$$CO_{2_{Equil}} = k * \frac{350}{10^6} * (1 * 10^6 \mu mol/mol) * (\frac{P}{760}) \quad (13)$$

where:

$[CO_2]_{equil}$ = The concentration of CO_2 for water at *in situ* temperature and pressure and in equilibrium with the atmospheric CO_2 , in $\mu mol/L$.

k = Henry's Law Constant for CO_2 at *in situ* temperature and pond water ionic strength.

350 = Atmospheric CO_2 concentration (ppm) (assumed).

(4) Calculation of CH_4 Concentration

For CH_4 it is also necessary to calculate a new solubility constant as a result of the increased salinity in the bottle.

Bunsen Coefficient for Solubility of CH_4 :

$$\beta = 10 \exp(A_1 + (A_2 * (\frac{100}{T})) + (A_3 * (\ln * (\frac{T}{100}))) + (S * (B_1 + (B_2 * (\frac{T}{100})) + (B_3 * (\frac{T}{100})^2))) \quad (14)$$

where:

B = Bunsen Coefficient (ml CH_4 /ml H_2O)

$A_1 = -67.1962$

$A_2 = 99.1624$

$A_3 = 27.9015$

$B_1 = -0.072909$

$B_2 = 0.041674$

$B_3 = -0.0064603$

S=Salinity(ppt)

(Yamamoto et al. 1976)

Mass of CH₄ in the Headspace:

Same as for CO₂ (see equation 12).

Concentration of CH₄ in the Water in the Sample Bottle:

$$[CH_4]_{aq} = \left(\beta \cdot \frac{CH_4}{1 \cdot 10^6} \cdot \frac{P}{760} \cdot 1000 \mu\text{mol}/\text{mmol} \cdot \frac{1 \text{ mmol}}{22.4 \text{ ml CH}_4} \cdot \frac{1000 \text{ ml}}{1 \text{ L}} \right) \quad (15)$$

where:

[CH₄]_{aq} = The concentration of CH₄ dissolved in the water, in μmol/L.

CH₄ = Concentration of CH₄ in the headspace of the bottle, in ppm.

β = ml CH₄/ml H₂O.

Total CH₄ Concentration in the Original Water Sample:

Same as for CO₂ (see equation 14).

(5) Calculation of Flux

To calculate flux using the Thin Boundary Layer Model (Liss and Slater 1974) requires the following measured values: *in situ* aqueous gas concentration, wind speed and water temperature. The model also requires the calculated values for water viscosity, water density, the equilibrium gas

concentration, gas diffusion coefficients, *in situ* Schmidt number, and gas piston velocity (as determined from wind speed).

To facilitate the utilization of the Sulfur Hexafluoride (SF_6) results, gas transfer velocities have been adjusted to their expected values at a common Schmidt number of 600 (k_{600}), this takes into account the affects of temperature and water viscosity. The Schmidt number is equal to the kinematic viscosity of water divided by the molecular diffusion coefficient of the gas in question (Crusius and Wanninkhof 1991). The standard Schmidt number of 600 (Sc_{600}) is the value for SF_6 at 20° C (Crusius and Wanninkhof 1991).

The relationship between wind speed and the gas piston velocity has been developed through additions of SF_6 to a variety of water bodies (Crusius and Wanninkhof 1991) and measurement of it's loss to the atmosphere at different wind speeds. In order to use these data, one must take into account the water temperature during these measurements because temperature affects the diffusion rate of the gas diffusing across the boundary layer and the viscosity of water. Converting to a standard Schmidt number takes into account the affects of temperature and viscosity.

Kinematic Viscosity:

$$kv = \frac{\eta}{d + 0.033} \quad (16)$$

where:

ν = The kinematic viscosity

η = The viscosity of water, in poise.

d = The density of water at the *in situ* temperature (gm/ml).

0.033 is the correction for the density for dissolved salts etc in the water.

(Chemical Rubber Company Handbook 63 ed.)

Viscosity of Water:

$$\nu = 10 \exp \left[\left(\frac{1301}{998.33 + (8.8155 * (T - 20)) + (0.00585 * (T - 20)^2)} \right) - 1.30233 \right] \quad (17)$$

where:

ν = The viscosity of water, in centipoise.

T = The *in situ* temperature, in degrees Celcius ($^{\circ}\text{C}$)

(Chemical Rubber Company Handbook 63 ed.)

Density of Water:

$$\text{Density} = 1.00008263 + (0.000010958 * T) - (0.000005207 * T^2) \quad (18)$$

where:

T= The *in situ* temperature, in (°C).

(Chemical Rubber Company Handbook 63 ed., equation derived on SAS System)

CO₂ Diffusion Coefficient:

$$CO_2DiffCo = (3.39 \cdot 10^{-7} \cdot T) + 9.1 \cdot 10^{-6} \quad (19)$$

where:

CO₂DiffCo= The CO₂ diffusion coefficient, cm²/sec.

T= the *in situ* temperature, in (°C).

(Himmelblau 1964)

CH₄ Diffusion Coefficient:

$$CH_4DiffCo (cm^2/sec) = (3.61 \cdot 10^{-7} \cdot T) + 9.59 \cdot 10^{-6} \quad (20)$$

where:

CH₄DiffCo= The CH₄ diffusion coefficient, cm²/sec.

T= The *in situ* temperature, in (°C).

(Witherspoon and Bonoli 1969)

In situ Schmidt Number for CO₂:

$$Sc_{CO_2} = \frac{kv}{CO_2DiffCo} \quad (21)$$

(Crusius and Wanninkhof 1991)

In situ Schmidt Number for CH₄:

$$SC_{CH_4} = \frac{kv}{CH_4 DiffCo} \quad (22)$$

(Crusius and Wanninkhof 1991)

Crusius and Wanninkhof (1991) have shown that the SF₆ gas transfer can be estimated by two linear functions of wind speed, one for wind speed below 3 m/sec and one for wind speeds greater than or equal to 3 m/sec (see Figure 3 in the Historical). It was therefore necessary to use two different equations to calculate k_{600} from wind speed.

k_{600} (cm/hr):

for wind speed < 3 m/sec:

$$k_{600} (cm/hr) = 0.76 * \mu \quad (23)$$

for wind speed >= 3 m/sec:

$$k_{600} (cm/hr) = (5.6 * \mu) - 14.4 \quad (24)$$

where:

$$\mu = \text{insitu wind speed (m/sec)}$$

Gas exchange rates (k) vary as a function of $Sc^{-0.5}$ for wind speed ≥ 3.0 m/sec and as a function of $Sc^{-2/3}$ when the wind speed is less than 3.0 m/sec (Crusius and Wanninkhof 1991). It is these functions that were used to normalize the measured k 's to k_{600} values in Figure 3 (Crusius and Wanninkhof 1991). The k values for a specific gas (e.g. CO_2 or CH_4) are then calculated by using the Schmidt number for that gas at *in situ* temperature.

CO_2 Piston Velocity:

For wind speed < 3.0 m/sec:

$$k_{CO_2} (cm/hr) = k_{600} * \left[\frac{(600^{0.67})}{(Sc_{CO_2})^{0.67}} \right] \quad (25)$$

For wind speed ≥ 3.0 m/sec:

$$k_{CO_2} (cm/hr) = k_{600} * \left[\frac{(600^{0.5})}{(Sc_{CO_2})^{0.5}} \right] \quad (26)$$

CH_4 Piston Velocity:

For wind speed < 3.0 m/sec:

$$k_{CH_4} (cm/hr) = k_{600} * \left[\frac{(600^{0.67})}{(SC_{CH_4})^{0.67}} \right] \quad (27)$$

For wind speed >= 3.0 m/sec:

$$k_{CH_4} (cm/hr) = k_{600} * \left[\frac{(600^{0.5})}{(SC_{CH_4})^{0.5}} \right] \quad (28)$$

With the piston velocities for both CO₂ and CH₄ calculated the flux of gas from the water to the atmosphere can be calculated. Flux (F) is equal to the piston velocity multiplied by the concentration gradient across the gas-water interface (Liss and Merlivat 1986).

CO₂ Flux:

$$F_{CO_2} = \frac{k_{CO_2} * ([CO_2]_{total} - [CO_2]_{Equil}) * 10000 cm^2/m^2}{1000 cm^3/L} \quad (29)$$

where:

F_{CO₂} = The flux of CO₂, in μmol/m²/hour.

CH₄ Flux:

$$F_{CH_4} = \frac{k_{CH_4} * ([CH_4]_{total} - [CH_4]_{Equil}) * 10000 cm^2/m^2}{1000 cm^3/L} \quad (30)$$

where:

F_{CH_4} = The flux of CH_4 , in $\mu\text{mol}/\text{m}^2/\text{hr}$.

Since the wind speed is so crucial to the calculation of gas flux, a concern that arose from the work on the small ponds in the Hudson Bay Lowland is how accurate is the Thin Boundary Layer Method on small ponds with very small fetch and obstructions along the edges. Panofsky and Dutton (1984) have shown that obstructions or surface roughness has a significant effect on wind speed. It is probable that portions of these ponds are in the lee of the raised edges and hummocks that border the ponds which makes it difficult to obtain an accurate measure of wind speed over the ponds. Dr. Peter Taylor (York University) is presently examining this problem in conjunction with our study. Taylor and Kwan (1991) estimate that for very small ponds (5-6m diameter or less) the Thin Boundary Layer Model as used in this work may have over estimated gas flux by approximately 20%. Since this size of pond makes up only a small number of the total ponds studied (see Table A34) the effect on the results presented here is small especially when one realizes that such small ponds were dry for most of July, August and September.

VII Computer Simulations

The diel changes in the aqueous concentrations of both

CO₂ and CH₄ were modeled using a computer program in an attempt to differentiate the influence that some of the controlling processes may play within these ponds. The model used is outlined in detail by Hesslein et al. (1991).

The model predicts the expected aqueous CO₂ or CH₄ concentration over a daily cycle with measured inputs of pond depth, wind speed and initial gas concentrations and estimated inputs of primary production, algal respiration, CH₄ oxidation, and sediment decomposition. Gas exchange parameters are also included. A complete listing of inputs follows:

k= Piston Velocity calculated as above.

μ = Wind speed which was measured on site (m/sec).

S_{CO₂} or S_{CH₄}= Sediment release of either CO₂ or CH₄ (mmol/m²/day), which can be calculated from the measured water column concentrations.

z= Water column depth (m) which was measured on site.

[CO₂]_{equil} or [CH₄]_{equil}= The concentration of CO₂ or CH₄ in the water that is in equilibrium with the atmosphere (μ mol/L) under *in situ* conditions, see equation 13 above.

[CO₂]_{aq} or [CH₄]_{aq}= The aqueous concentration of CO₂ or CH₄ in the water, see equations 6-11 above. At time zero the measured concentrations were used.

DT= The time step, which can be adjusted from 1 sec

to one day in length. For this work a time step of 30 minutes was used as the *in situ* wind speed was recorded ever 30 minutes.

PP= Rate of Primary Productivity. This was estimated from work by Robinson (pers.com.)³ for ponds in the Delta Marsh region of Manitoba.

R= Algal respiration rates. This was also estimated from the information supplied on the Delta Marsh Ponds.

R_{CH₄}= Methane oxidation rate. This was estimated from the ranges reported by Rudd and Hamilton (1978).

Calculation of Piston Velocity:

This calculation is the same as outlined in equations 25 and 26 above. Note that here the piston velocity is in units of m/d.

Calculation of Gas Exchange:

$$G.E. = ([CO_2]_{equil} - [CO_2]_{aq}) * k_{CO_2} / z * DT \quad (31)$$

where:

G.E.= Gas exchange, where a negative value

³ Dr. G. Robinson, Dept. of Botany, University of Manitoba, Winnipeg, Manitoba.

signifies flux to the atmosphere and a positive value is flux into the water.

k_{CO_2} = The Piston Velocity for CO_2 (m/d).

Calculation of the new aqueous CO_2 concentration:

$$[CO_2]_{aq} = [CO_2]_{aq} + G.E. - PP + R + Sed.Flux \quad (32)$$

where:

$[CO_2]_{aq}$ = The starting aqueous CO_2 concentration ($\mu\text{mol/L}$). After the first time step the computer uses the calculated aqueous CO_2 from the previous time step.

The measured CO_2 or CH_4 values are then compared graphically to the graph that is generated by the models successive iterations are performed by changing the unmeasured inputs. This approach is especially useful in asking such questions as (1) could a constant CH_4 flux from the sediments plus measured changes in wind speed account for the changes in concentration observed over 24 hours *in situ*? (2) do the day/night changes in the concentration of CH_4 and CO_2 fit with reasonable assumptions about day/night changes in algal activity?

Results

Table 3. Summary of Water Chemistry.

Location	Date	Pond No.	SUSPN	SUSPP	SUSPC	SUSP C:N	SUSP C:P	Chl.A	Cond.	pH*	Alk.*
Kinosheo	June 06	1	75	5	970	15.1	500	1.25	36	6.70	87.20
		2	125	9	1670	15.6	480	1.15	35	5.06	-4.40
		3	117	8	1500	15.0	480	0.69	35	5.41	1.50
		4	707	40	13160	21.7	850	8.70	37	7.92	490
		6	360	30	4530	14.6	380	5.70	30	5.19	3.30
		7	65	3	820	14.7	700	1.92	25	5.40	-2.10
		8	87	6	1010	13.5	430	0.83	38	5.23	0.10
		9	150	11	2500	16.2	480	2.30	36	5.34	1.00
		10	105	6	930	10.3	400	3.10	13	4.95	-9.20
		Kinosheo	June 28	1	127	8	1220	11.2	390	3.20	23
2	144			10	2100	17.0	540	3.10	41	5.05	-7.40
6	144			7	1650	13.4	610	3.80	36	5.13	-5.90
7	60			3	710	13.8	610	0.90	23	5.23	-3.60
8	85			4	1190	12.3	770	1.42	44	5.24	-3.90
10	106			7	940	10.3	350	4.60	13	4.87	-13
Kinosheo	Aug. 16	1	115	12	1800	18.2	390	6.70	26	6.83	100
		6	250	19	6240	29.0	850	10.0	50	4.98	-5.70

Units $\mu\text{g/L}$, except for C:N and C:P are in units of $\mu\text{mol}:\mu\text{mol}$, Conductivity is $\mu\text{mho}/\text{cm}^2$ and Alkalinity is in $\mu\text{eq/L}$.

* The pH and alkalinity are calculated from measured CO_2 and DIC concentrations.

Table 3 continued. Summary of Water Chemistry.

Location	Date	Pond No.	SUSPN	SUSSP	SUSPC	SUSP C:N	SUSP C:P	Chl.A	Cond.	pH*	Alk.*
Kinosheo	Aug. 16	7	75	6	1370	21.3	590	3.90	34	5.15	-5.00
		10	69	7	1030	17.4	380	6.50	14	5.24	-2.00
	Sept 12	1	134	13	1940	16.9	380	5.2	26	7.00	114
		7	87	6	1680	22.5	722	3.30	36	5.05	-6.10
		10	121	9	1550	15.0	440	7.10	15	5.81	70
Coastal Fen	June 7	11	75	3	610	9.49	520	1.13	38	6.75	220
		12	58	2	570	11.5	730	1.33	42	6.90	250
	June 27	12	170	9	2010	13.7	580	2.60	53	7.32	450
		13	25	1	310	14.5	800	0.54	56	6.38	470
		14	112	5	1210	12.6	620	2.80	68	7.05	545
	Aug. 14	15	184	9	2640	16.7	760	5.80	62	6.91	440
		16	192	12	2320	14.1	500	9.00	44	6.83	330
		17	593	26	9030	17.8	900	22.0	45	6.80	330
		18	503	28	6110	14.2	560	11.0	41	6.64	290
		14	42	3	680	18.9	585	0.87	120	6.85	1080
Sept 11	14	57	3	860	17.6	740	1.37	110	7.47	940	

Units $\mu\text{g/L}$, except for C:N and C:P are in units of $\mu\text{mol}:\mu\text{mol}$, Conductivity is $\mu\text{mho/cm}^2$ and Alkalinity is in $\mu\text{eq/L}$.

* The pH and alkalinity are calculated from measured CO_2 and DIC concentrations.

Table 3 continued. Summary of Water Chemistry.

Location	Date	Pond No.	SUSPN	SUSPP	SUSPC	SUSP C:N	SUSP C:P	Chl.A	Cond.	pH*	Alk.*	
Coastal Fen	Oct. 11	11	130	6	2190	20.0	940	2.30	61	7.05	300	
		12	69	3	1200	20.3	1030	1.34	57	7.25	260	
		14	29	2	1010	40.6	1300	0.72	72	7.10	440	
Interior Fen	June 7	19	57	3	550	11.3	470	1.49	70	7.36	570	
		22	58	3	590	11.9	507	1.45	71	7.54	570	
		23	79	3	760	11.2	650	3.70	70	7.43	560	
	June 27	19	112	5	1170	12.2	600	3.90	123	7.59	1015	
		20	64	4	900	16.4	580	1.49	103	7.27	890	
		21	26	1	300	13.5	770	0.38	102	6.96	1010	
		22	39	2	440	13.2	570	0.64	99	7.76	900	
	Aug. 16		23	27	1	350	15.1	900	0.39	105	7.23	910
			24	110	6	1230	13.0	530	3.60	100	7.32	910
			20	21	2	450	25.0	580	0.59	186	7.10	1790
21			47	4	790	19.6	510	1.67	228	6.98	1980	
22			62	4	920	17.3	590	2.20	155	8.28	1340	

Units $\mu\text{g/L}$, except for C:N and C:P are in units of $\mu\text{mol}:\mu\text{mol}$, Conductivity is $\mu\text{mho}/\text{cm}^2$ and Alkalinity is in $\mu\text{eq/L}$.
 * The pH and alkalinity are calculated from measured CO_2 and DIC concentrations.

Table 3 continued. Summary of Water Chemistry.

Location	Date	Pond No.	SUSPN	SUSPP	SUSPC	SUSP C:N	SUSP C:P	Chl.A	Cond.	pH*	Alk.*
Interior Fen	Aug 16	23	36	3	650	21.1	560	0.70	186	7.37	1715
		24	19	2	410	25.2	530	0.62	210	7.22	2100
	Sept 11	20	25	2	460	21.5	590	0.50	172	7.87	3030
		21	31	2	500	18.8	645	0.52	171	6.98	1480
		22	39	4	630	18.8	410	0.69	141	7.70	1230
	Oct. 11	19	39	2	660	19.7	850	0.48	122	7.88	975
		20	42	2	760	21.1	980	0.69	100	7.65	840
		22	21	2	480	26.7	620	0.33	105	7.27	820

Units $\mu\text{g/L}$, except for C:N and C:P are in units of $\mu\text{mol}:\mu\text{mol}$, Conductivity is $\mu\text{mho/cm}^2$ and Alkalinity is in $\mu\text{eq/L}$.

* The pH and alkalinity are calculated from measured CO_2 and DIC concentrations.

I Water Chemistry and Microscopic Examination

Water chemistry sampling was conducted throughout the open water season. Suspended N, P, and C, Chl.A., conductivity, pH and alkalinity results are shown in Table 3. Complete results including cations (Na, Ca, Mg), total dissolved P, DIC, DOC, soluble silica, chloride, sulfate, and organic acids are shown in Table A1 in the appendix. Dissolved nutrients such as total dissolved P, NO_3^- and NH_4^+ were usually not done because the transit time from the Hudson Bay Lowland was often greater than 24 hours.

The ponds of the Hudson's Bay Lowlands are very dilute with conductivities ranging from 13-228 $\mu\text{mho}/\text{cm}^2$ (Table 3) and are poor in nutrients for the algal communities. The conductivity measurements which were lower at the Kinosheo Bog site (20-50 $\mu\text{mho}/\text{cm}^2$). At the fen sites the conductivities were generally higher (38-228 $\mu\text{mho}/\text{cm}^2$).

The most striking result is the difference in pH between the three sites. The ponds within the Kinosheo bog site are acidic throughout the openwater season (pH 4.8-7.0). The pH of the ponds at the fen sites are more neutral with pH ranging from 6.4-7.5 at the Coastal Fen. The Interior Fen exhibits pH from 7.0-7.9. The more alkaline pH in the fens maybe a result of solubilization of the old marine clay that underlies the area. The marine clay might contain CaCO_3 deposits which when dissolved in water would release hydroxyl ions (Broecker and

Peng 1987) and this could explain the higher alkalinity at the fens (Table 3).

Carbon to Nitrogen ratios (9.49-40) and Carbon to Phosphorous ratios (350-1300) in suspended material (which microscopic examination showed to contain mostly algal cells and very little debris (Kling pers.comm)⁴) indicate that all of the algae in the ponds that were studied were moderately to severely nitrogen limited and severely phosphorous limited (Healey and Hendzel 1980). Water column chlorophyll A concentrations remained fairly constant throughout the open water season at the ponds within the Kinosheo Lake bog (1.25-10 $\mu\text{g/L}$). There was a slight decline from 2.8 $\mu\text{g/L}$ in June in pond 14 at the Coastal Fen, down to 0.87 $\mu\text{g/L}$ in August, which might be a result of heat stress and decreasing water levels. Chlorophyll concentrations of the Interior Fen ponds were constant throughout the summer and declined during the fall. Examination of the algal samples⁵ has shown that most of the algae can be found in dense algal mats on the bottom of the ponds, with relatively few algae in the water column (data not shown). When samples of the benthic mats are viewed under 400x, 10-30% of the cells in the field of view were heterocysts (Kling pers.com.).

⁴Ms. Hedi Kling. Dept. of Fisheries and Oceans, Freshwater Institute, Winnipeg, Manitoba.

⁵Analysis of the algal samples were conducted by Ms. Hedi Kling of the Dept. of Fisheries and Oceans, Freshwater Institute, Winnipeg, Manitoba.

Table 4. Comparison of Duplicate Samples

Location	Date	Pond No.	CH ₄ Conc. (μmol/L)		Difference of Means ¹	CO ₂ Conc. (μmol/L)		Difference of Means	
Coastal Fen	June 30	14	3.89	3.66	0.061	113.07	115.35	0.020	
		15	1.85	1.64	0.120	126.16	127.85	0.013	
		16	1.64	2.88	0.549	127.85	125.53	0.018	
		18	1.77	1.81	0.022	136.42	154.05	0.121	
Interior Fen	June 30	19	1.18	1.13	0.043	73.63	67.39	0.089	
		20	1.17	1.05	0.108	116.72	119.36	0.022	
		21	9.82	7.95	0.211	331.83	274.50	0.189	
		22	2.56	2.45	0.044	47.46	46.05	0.030	
		24	0.84	0.94	0.112	103.11	109.24	0.058	
	Aug. 14	22	4.07	3.71	0.093	114.55	113.92	0.006	
	Kinosheo Lake Bog	June 05	3	1.89	2.42	0.246	64.44	72.69	0.120
			5	5.58	5.66	0.014	61.36	59.90	0.024
7			1.06	1.20	0.123	39.35	40.72	0.034	
June 28		10	0.58	0.53	0.040	20.91	20.17	0.036	
July 05		1	0.26	0.39	0.400	28.37	39.55	0.329	
		6	0.94	0.94	0.000	21.87	26.55	0.193	
		7	0.68	0.69	0.015	29.47	33.10	0.116	
July 17		1	0.35	0.34	0.029	31.93	35.11	0.094	
		10	3.48	3.37	0.032	43.47	42.66	0.027	
July 25		1	0.86	0.98	0.130	40.83	41.99	0.028	
		6	2.26	2.15	0.050	48.18	51.39	0.065	
		7	2.28	2.21	0.031	46.63	47.11	0.010	
Aug 15		7	10	5.78	5.76	0.004	67.33	66.89	0.007
	7		3.08	3.21	0.041	70.37	73.23	0.040	
	10		0.99	1.00	0.010	23.90	22.24	0.072	
					Mean St. Dev.	0.1032 (or 10.3%) ± 0.13	Mean St. Dev.	0.0704 (or 7.0%) ± 0.087	

¹ Calculated by the following formula:
 $(A-B) / [(A+B) / 2]$

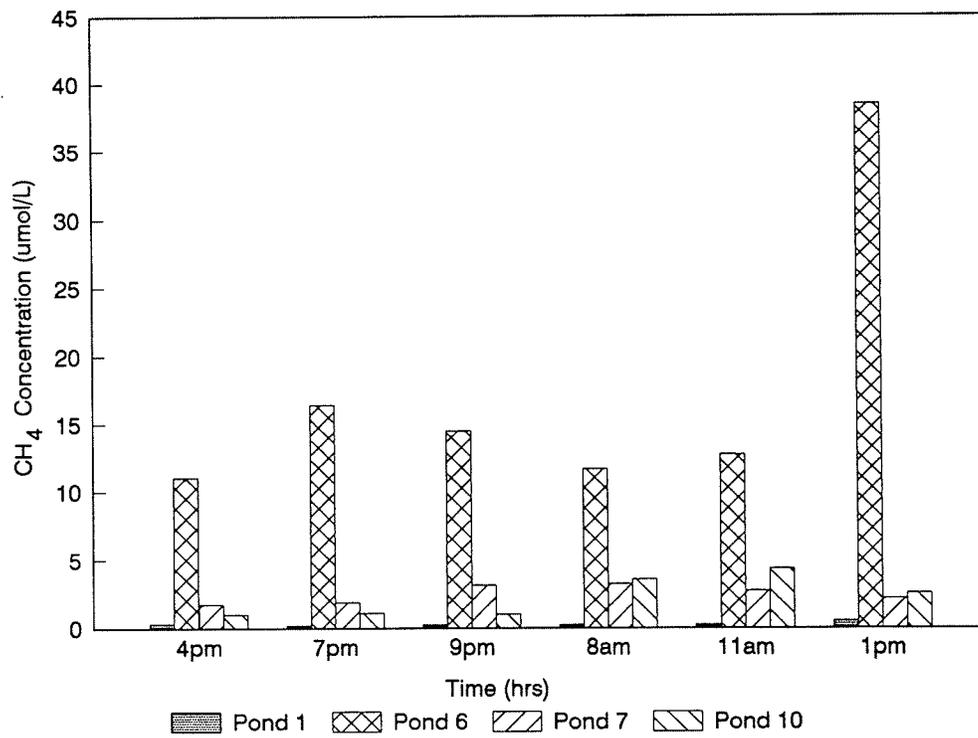


Figure 5. Diel CH₄ Concentration at Kinosheo Lake Bog (August 15-16, 1990).

II Concentration of Dissolved Gases

Precision of Dissolved CH₄ and CO₂ Measurements

The precision of the measurement of dissolved CO₂ and CH₄ was determined by frequent duplication of samples (Table 4). By examining the differences between the duplicate samples as a percentage of the mean of the two samples it was possible to determine the precision of the analytical method. For the CH₄ measurements the mean error of replication between duplicate samples was 10.3% and 7.0% for CO₂ (Table 4).

Periodically (approximately 15% of the time in the duplicate sample data set) there were replicates for which the difference between the replicates was more than two standard deviations (Table 4). I do not believe that this is an error in the analytical procedure (i.e. GC performance and sample volume), but that there were real differences in sample concentration. For example one of the replicate samples could be high because of pore water contamination as I had to shift my weight on the shore between samples in order to pick up the second sample bottle.

Surface Water Methane Concentration

The concentration of CH₄ changed through out the day (Figure 5). The concentration was usually, but not always,

Table 5. Mean and Median CH₄ Concentration
Sum of Differences

Location	Average Sum of Differences
Coastal Fen	1.34
Interior Fen	2.46
Kinosheo Lake Bog	1.82

highest in the mid-morning and fell rapidly throughout the afternoon. On some occasions a peak was not seen, or the peak in concentration occurred in the afternoon (See figures in the Appendix). Even with the diel changes the concentration of CH₄ was always above the atmospheric equilibrium concentration of approximately 0.01 μmol/L.

Initially sampling was done once a day, but was changed to sampling 3-5 times during a diel period once the changes in concentration were observed.

The mean and median CH₄ concentrations for each sampling day at each site (i.e. all the CH₄ concentration data collected at the Coastal Fen, Interior Fen and Kinosheo Lake Bog) were examined by looking at the Average Sum of Differences to see if the means and medians were different. Table 5 shows that the average difference between the mean and median CH₄ concentrations at the Coastal fen was 1.34 μmol/L, 2.46 μmol/L at the Interior Fen and 1.82 μmol/L at the Kinosheo Lake Bog. The differences between the means and medians are a result of the statistical mean being strongly influenced by the very high concentrations in some of the ponds. The few high concentrations skew the data, so that the data is not normally distributed.

Because the data is not distributed normally; normal statistical treatments of these data sets result in misleading or impossible information. For example, if the standard deviation around the mean is determined, the result is often

Table 6a. Kinosheo Lake Bog Mean Pond CH₄ Concentration (μmol/L) on Diel Sampling Days.

Date	1	2	3	4	5	6	7	8	9	10
July 5	0.30	15	Dry	Dry	Dry	1.2	0.72	3.4	Dry	2.6
July 13	0.22	Dry	Dry	Dry	Dry	1.7	0.98	5.9	Dry	2.1
July 17	0.33	Dry	Dry	Dry	Dry	4.1	1.1	Dry	Dry	3.6
July 25	0.64	Dry	Dry	Dry	Dry	14	2.1	Dry	Dry	5.0
Aug 15	0.17	Dry	Dry	Dry	Dry	18	2.5	Dry	Dry	2.1
Sept 12	0.54	5.8	Dry	Dry	Dry	6.8	6.9	28	Dry	5.2
Oct. 12	0.95	1.2	1.7	1.2	1.0	4.5	1.5	7.3	2.8	22

*Note: The data was treated equally, the means presented are statistical means, not time weighted means.

Table 6b. Order of Ponds (highest to lowest CH₄ Concentration)

Date	Order of Ponds (highest → lowest)
July 5	2 > 8 > 10 > 6 > 7 > 1
July 13	8 > 10 > 6 > 7 > 1
July 17	6 > 10 > 7 > 1
July 25	6 > 10 > 7 > 1
Aug 15	6 > 7 > 10 > 1
Sept 12	8 > 7 > 6 > 2 > 10 > 1
Oct 12	10 > 8 > 9 > 6 > 3 > 7 > 2,4 > 5 > 1

Table 7a. Coastal Fen Mean* Pond CH₄ Concentration (μmol/l) on Diel Sampling Days.

Date	11	12	13	14	15	16	17	18
July 9	1.3	1.4	16	2.7	1.2	1.5	0.60	3.7
July 24	25	3.7	8.9	4.5	2.2	6.1	26	Dry
Aug 14	Dry	Dry	Dry	34	Dry	Dry	Dry	Dry
Sept 10	8.1	2.5	21	4.5	3.7	6.4	Dry	Dry
Oct 10	2.6	3.3	23	4.4	1.4	3.6	1.6	4.1

*Note: The data was treated equally, the means presented are statistical means, not time weighted means.

Table 7b. Order of Ponds (highest to lowest CH₄ concentration)

Date	Order of Ponds (highest → lowest)
July 9	13 > 18 > 14 > 16 > 12 > 11 > 15 > 17
July 24	17 > 11 > 13 > 16 > 14 > 12 > 15
Aug 14	14
Sept 10	13 > 11 > 16 > 14 > 15 > 12
Oct 10	13 > 14 > 18 > 16 > 12 > 11 > 16 > 15

Table 8a. Interior Fen Mean* Pond CH₄ Concentration (μmol/L) on Diel Sampling Days.

Date	19	20	21	22	23	24
July 3			7.8	24		
July 9	1.9	2.6	4.0	2.1	4.8	4.3
July 24	8.4	4.1	17	10	5.7	7.3
Aug 14	Dry	11	9.6	4.3	11	6.6
Sept 10	3.4	3.4	11	13	13	3.4
Oct 10	8.2	1.8	2.8	2.6	1.9	2.5

*Note: The data was treated equally, the means presented are statistical means, not time weighted means.

Table 8b. Order of Ponds (highest to lowest CH₄ Concentration)

Date	Order of Ponds (highest → lowest)
July 3	22 > 21
July 9	23 > 24 > 21 > 20 > 22 > 19
July 24	21 > 22 > 19 > 24 > 23 > 20
Aug 14	23,20 > 21 > 24 > 22
Sept 10	23,22 > 21 > 24,20,19
Oct 10	19 > 21 > 22 > 24 > 23 > 20

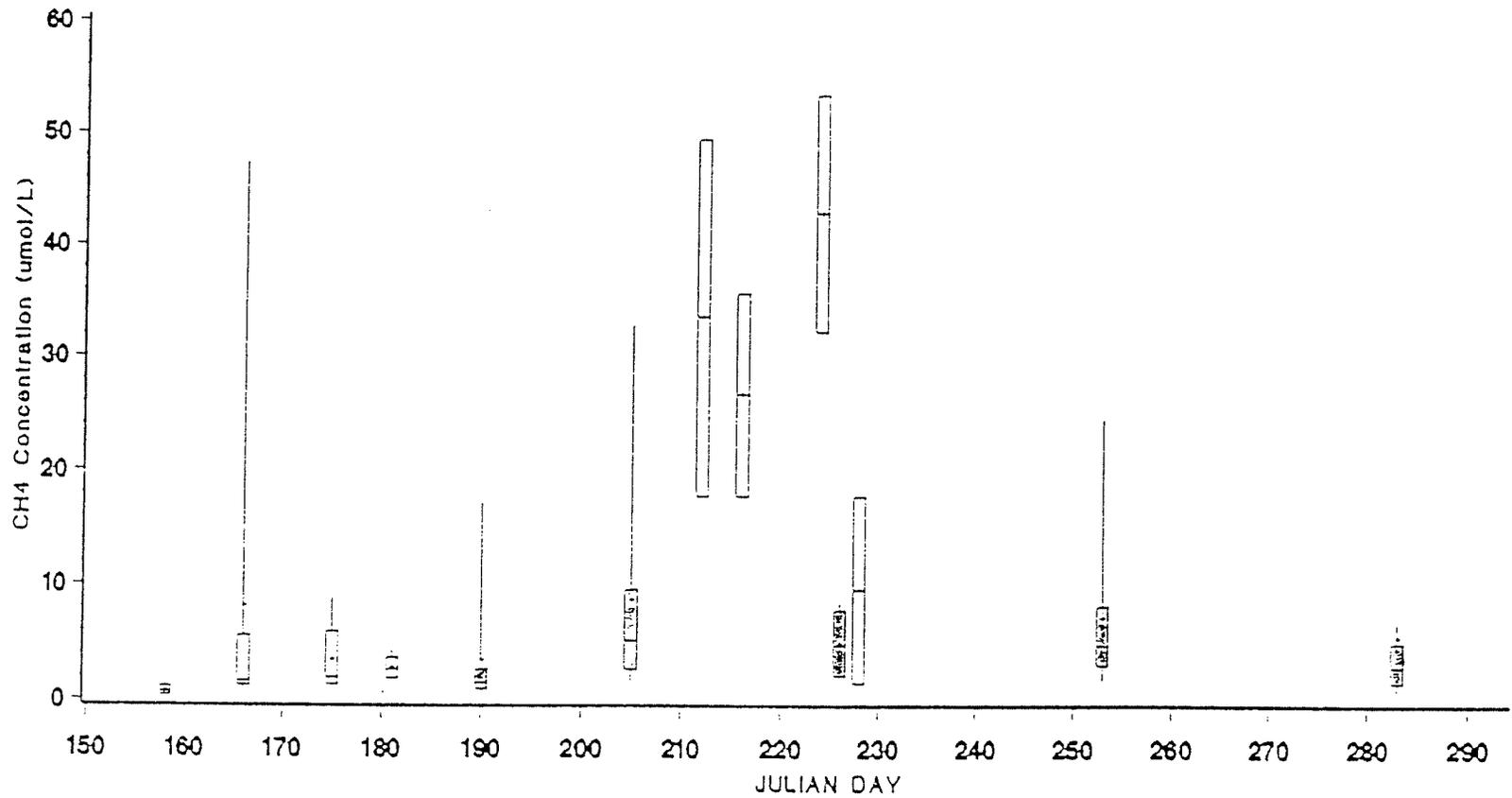


Figure 6a. Coastal Fen Seasonal CH₄ Concentration Pattern. (includes all instantaneous concentration data, June-October, 1990. All samples are treated equally, i.e not time weighted). The upper and lower ends of the box represent the 75% and 25% quartiles. The horizontal line in the box represents the sample median, the + indicates the mean and the vertical lines represent the 5% and 95% confidence limits. Shaded boxes are diel sampling days

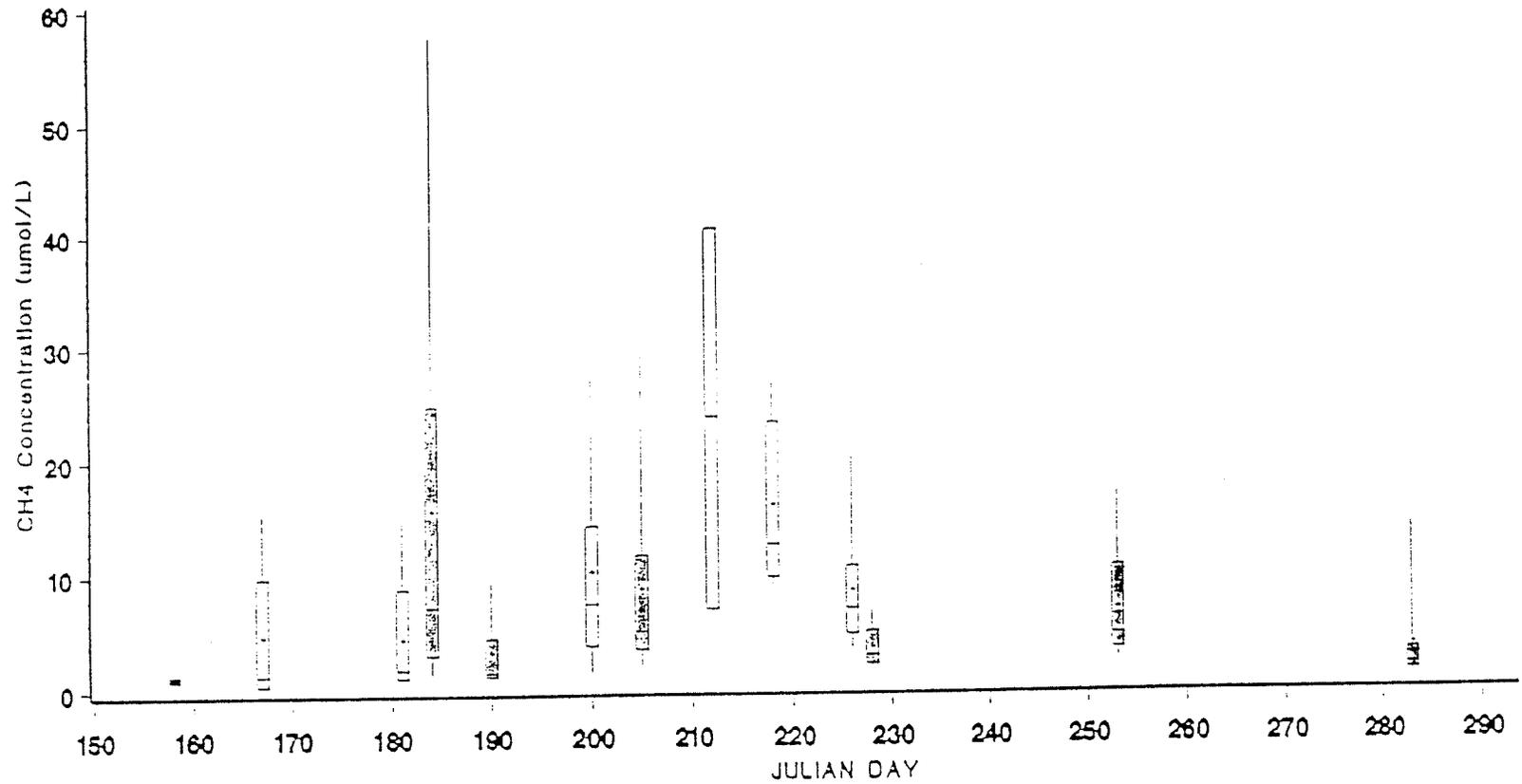


Figure 6b. Interior Fen Seasonal CH₄ Concentration Pattern.
(includes all concentration measurements done on each date, not time-weighted June-October, 1990). See Figure 6a for details.

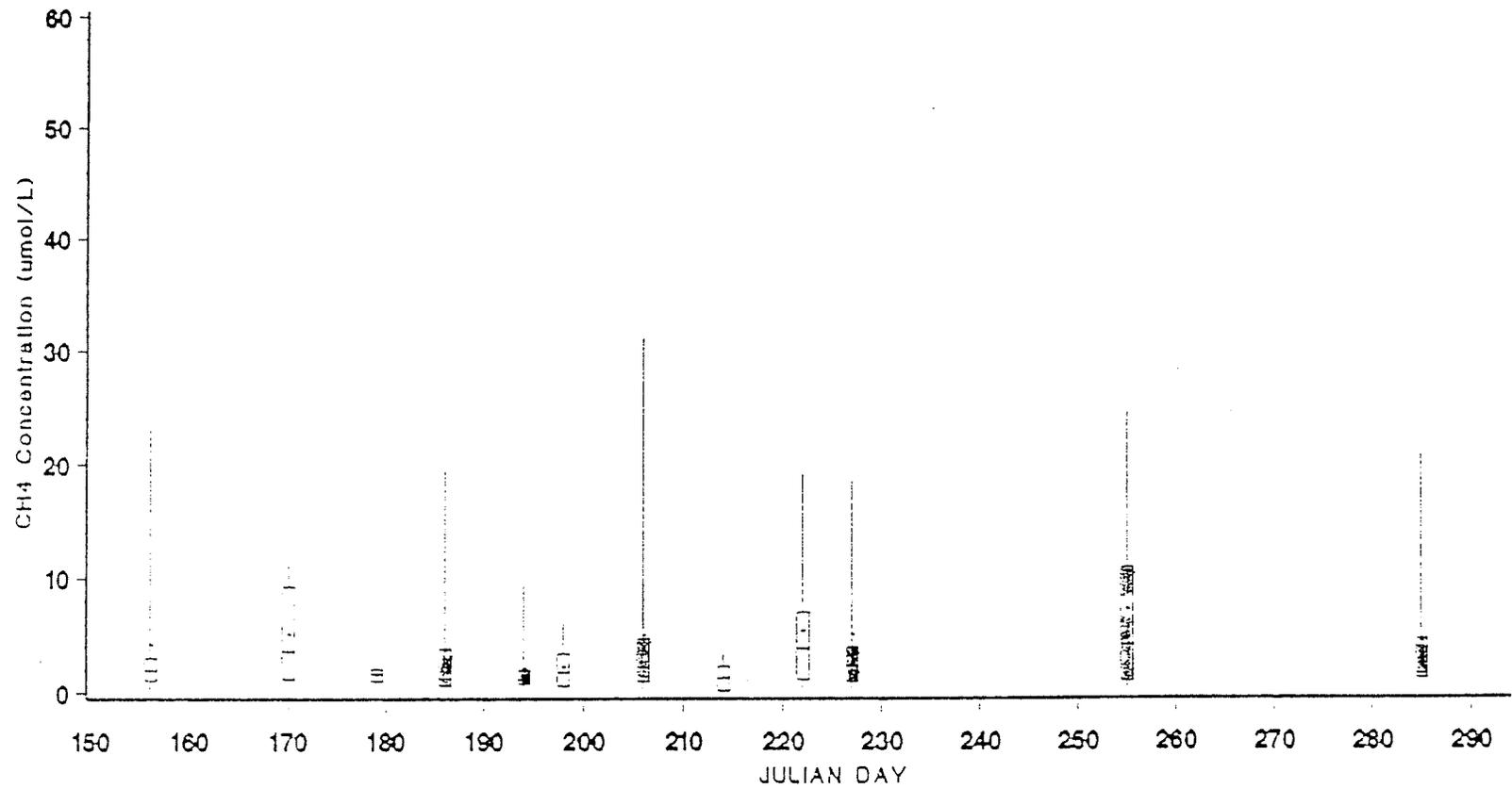


Figure 6c. Kinosheo Lake Bog Seasonal CH₄ Concentration Pattern. (includes all concentration measurements done on each date, not time-weighted June-October, 1990). See Figure 6a for details.

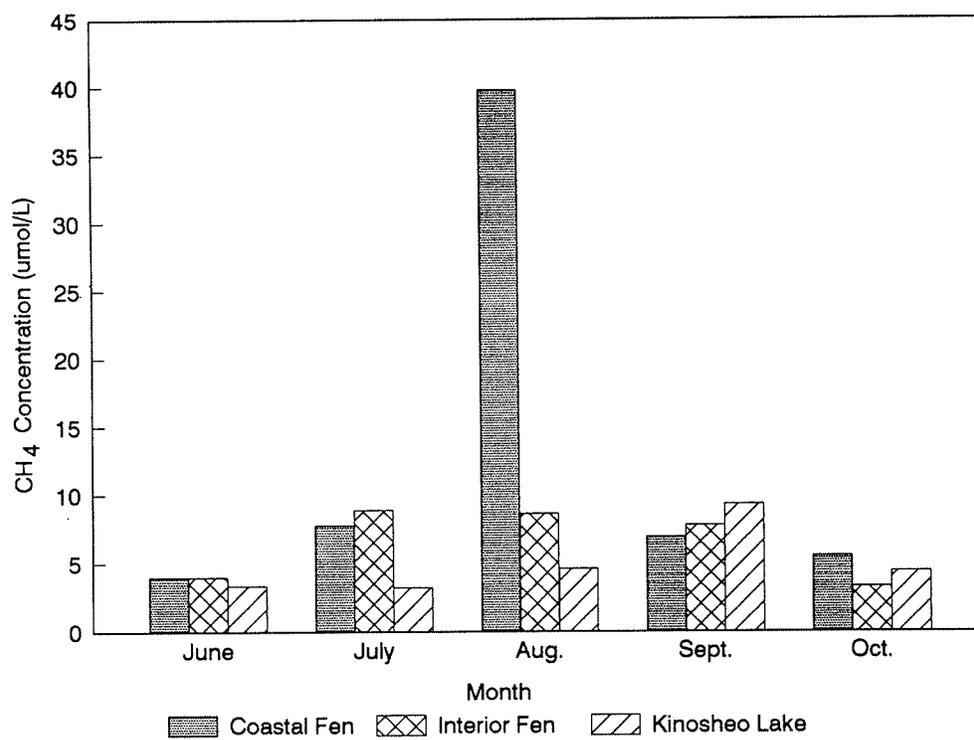


Figure 7. Average Monthly CH₄ Concentrations.
 (All data treated equally, i.e. not time weighted)

Table 9. Monthly Methane Concentrations in the Hudson's Bay Lowlands (June-October, 1990).

Location	Month	Mean CH ₄ Concentration ($\mu\text{mol/L}$)	Median CH ₄ Concentration ($\mu\text{mol/L}$)	Minimum CH ₄ Concentration ($\mu\text{mol/L}$)	Maximum CH ₄ Concentration ($\mu\text{mol/L}$)
Coastal Fen	June	4.1	2.3	0.3	47
	July	6.8	3.0	0.3	50
	August	40	13	1.5	290
	September	7.0	4.8	1.5	30
	October	6.0	3.5	0.4	66
Interior Fen	June	4.0	1.4	0.4	15
	July	24	5.0	0.73	60
	August	8.5	8.0	3.4	23
	September	6.7	5.0	2.1	40
	October	3.0	1.7	0.5	19
Kinosheo Lake	June	4.0	1.3	0.3	38
	July	3.3	1.5	0.2	38
	August	5.1	2.2	0.2	40
	September	7.0	5.0	0.3	73
	October	4.0	1.6	0.4	29

Note: The data was treated equally, the means and medians presented are statistical means or medians, not time weighted.

a negative concentration which is not possible. As a result of the problem with statistical treatments, the data can not be presented as a mean concentration followed by the standard deviation. Instead, the data will be presented as means followed by median and the minimum-maximum values in parenthesis, i.e. mean (median, minimum-maximum).

It is important to realize that although there are diel CH_4 changes in concentration and the data would appear not to be normally distributed (especially at the Kinosheo Lake Bog site), the changes in CH_4 concentration are not random. For example, if the mean CH_4 concentration are examined, at each site there were ponds that consistently had the highest CH_4 concentration and others that had the lowest concentration (Tables 6, 7, 8).

Methane concentrations varied widely among ponds (Figure 5 and Tables 6, 7, 8) as well as seasonally (Figures 6a, 6b, 6c, 7 and Table 9).

Average monthly CH_4 concentrations for all ponds at the Coastal Fen increased from 4.1 (2.3, 0.3-47) $\mu\text{mol/L}$ in June to 40 (13, 1.5-290) $\mu\text{mol/L}$ in August, then declined through out September and October to 6.0 (3.5, 0.4-66) $\mu\text{mol/L}$ (Figure 6a and Table 9).

The average CH_4 concentrations observed at the Interior Fen in June were 4.0 (1.4, 0.4-15) $\mu\text{mol/L}$ and peaked at the end of July at 24 (5.0, 0.7-60) $\mu\text{mol/L}$. Concentrations had declined to 3.0 (1.7, 0.5-19) $\mu\text{mol/L}$ by October (Figure 6b

Table 10. Methane and Carbon Dioxide Concentrations in the Hudson's Bay Lowlands, September 13, 1989.

Location	Pond Description or Number	CH ₄ Concentration (μmol/l)	CO ₂ Concentration (μmol/L)
Coastal Fen	11	70	670
	12	30	590
Interior Fen	Small Pool	30	190
	Small Pool	7	185
Kinosheo Lake Bog	Pond 10	2	50
	Small Dry Pond	12	40
	Full Pond	4	30
	Very Small Pond	6	50

and Table 9).

Kinosheo Lake Bog exhibited average CH_4 concentrations for all ponds of 4.0 (1.3, 0.3-38) $\mu\text{mol/L}$ in June. The maximum concentration of 7.0 (5.0, 0.3-73) $\mu\text{mol/L}$ was reached in September. By mid October the mean concentration had dropped to 4.0 (1.6, 0.4-29) $\mu\text{mol/L}$ (Figure 6c and Table 9).

The Coastal Fen reached a peak in CH_4 concentration in August (Table 9 and Figures 6 and 7). The Interior Fen reach a concentration peak in late July. The bog site at Kinosheo Lake had lower CH_4 concentrations during the summer than either of the fen sites and reached its peak concentration much later in the season, in September.

The CH_4 concentrations observed in September, 1990 corresponded well with observations carried out in September, 1989 (Table 9 and 10). In 1989, the range of CH_4 concentrations at the Interior Fen (7-30 $\mu\text{mol/L}$) and the Kinosheo Lake bog (2-12 $\mu\text{mol/L}$) fell within the ranges observed in September, 1990. The values at the Coastal Fen in 1989 (32-70 $\mu\text{mol/L}$) were higher than those observed in September 1990 of 1.5-30 $\mu\text{mol/L}$ (Table 9 and 10). In 1989, as in 1990, the fen sites had the highest CH_4 concentration while the Kinosheo Lake Bog had significantly lower concentrations than the fens.

Surface Water Carbon Dioxide Concentration

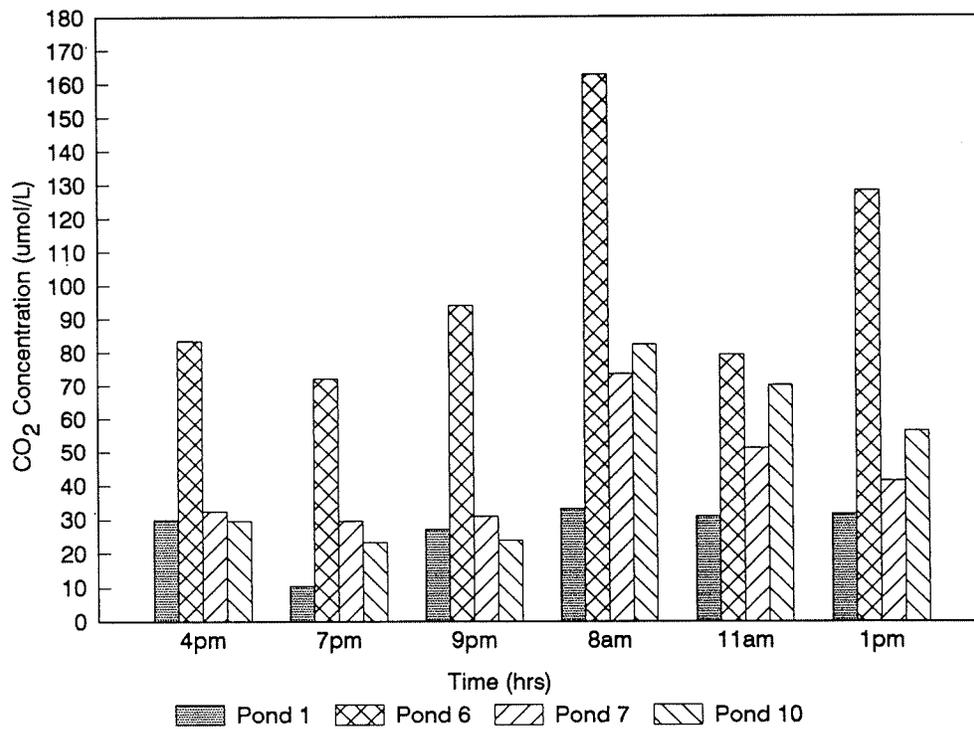


Figure 8. Diel CO₂ Concentration at Kinosheo Lake Bog (August 15-16, 1990).

Table 11. Mean and Median CO₂ Concentration
Sum of Differences.

Location	Average Sum of Differences
Coastal Fen	16.49
Interior Fen	46.51
Kinosheo Lake Bog	18.32

Table 12a. Kinosheo Lake Bog Mean Pond CO₂ Concentration (μmol/L) on Diel Sampling Days.

Date	1	2	3	4	5	6	7	8	9	10
July 5	31	175	Dry	Dry	Dry	40	36	100	Dry	33
July 13	32	Dry	Dry	Dry	Dry	33	34	122	Dry	33
July 17	31	Dry	Dry	Dry	Dry	56	34	Dry	Dry	37
July 25	35	Dry	Dry	Dry	Dry	100	43	Dry	Dry	52
Aug 15	27	Dry	Dry	Dry	Dry	100	46	Dry	Dry	44
Sept 12	36	93	Dry	Dry	Dry	42	60	230	Dry	220
Oct. 12	37	47	39	84	140	43	40	130	50	310

*Note: The data was treated equally, the means presented are statistical means, not time weighted.

Table 12b. Order of Ponds (highest to lowest CO₂ Concentration)

Date	Order of Ponds (highest → lowest)
July 5	2 > 8 > 6 > 7 > 10 > 1
July 13	8 > 7 > 10, 6 > 1
July 17	6 > 10 > 7 > 1
July 25	6 > 10 > 7 > 1
Aug 15	6 > 7 > 10 > 1
Sept 12	8 > 10 > 2 > 7 > 6 > 1
Oct 12	10 > 5 > 8 > 4 > 9 > 2 > 6 > 7 > 3 > 1

Table 13a. Coastal Fen Mean Pond CO₂ Concentration (μmol/l) on Diel Sampling Days.

Date	11	12	13	14	15	16	17	18
July 9	25	69	380	100	110	71	37	220
July 24	200	69	86	130	130	110	600	Dry
Aug 14	Dry	Dry	Dry	400	Dry	Dry	Dry	Dry
Sept 10	110	100	320	140	210	110	Dry	Dry
Oct 10	130	97	270	200	89	140	51	120

*Note: The data was treated equally, the means presented are statistical means, not time weighted.

Table 13b. Order of Ponds (highest to lowest CO₂ Concentration)

Date	Order of Ponds (highest → lowest)
July 9	13 > 18 > 15 > 14 > 16 > 12 > 17 > 11
July 24	17 > 11 > 15,14 > 16 > 13 > 12
Aug 14	14
Sept 10	13 > 15 > 14 > 16,11 > 12
Oct 10	13 > 14 > 16 > 11 > 18 > 12 > 15 > 17

As with CH_4 , the dissolved concentrations of CO_2 in the surface waters varied through out day (Figure 8). The dissolved CO_2 concentration was usually found to be between 2x and 90x greater than the atmospheric equilibrium concentrations of approximately $14 \mu\text{mol/L}$. Indeed only on rare occasions was the concentration of CO_2 below atmospheric equilibrium (Figure 8 or see appendix).

The dissolved CO_2 concentration data set for each sampling day at each of the sampling sites was examined to determine if there was a difference between the mean and median CO_2 concentrations. The results of the Average Sum of Differences (Table 11) show that the average difference between the mean and median CO_2 concentration at the Coast Fen was $16.49 \mu\text{mol/L}$, $46.51 \mu\text{mol/L}$ at the Interior Fen and $18.32 \mu\text{mol/L}$ at the Kinosheo Lake Bog. As seen with the mean and median CH_4 concentrations, a few ponds with very high CO_2 concentrations have skewed the distribution, so that the CO_2 data is not normally distributed. Because of the non-normal distribution at the and the statistical problems outlined above, the CO_2 data will be presented in the same format as the CH_4 concentration data.

As with CH_4 , the CO_2 concentration changes in the ponds were not a random occurrence. For example, when the mean CO_2 concentrations were examined, there were ponds at each site that were consistently highest in CO_2 concentration and others that were always had the lowest concentration (Tables 12, 13,

Table 14a. Interior Fen Mean* Pond CO₂ Concentration (μmol/L) on Diel Sampling Days.

Date	19	20	21	22	23	24
July 3			410	72		
July 9	79	100	200	49	93	65
July 24	110	190	570	64	90	330
Aug 14	Dry	320	370	100	220	190
Sept 10	32	140	490	81	230	120
Oct 10	64	70	120	110	55	110

*Note: The data was treated equally, the means presented are statistical means, not time weighted.

Table 14b. Order of Ponds (highest to lowest CO₂ Concentration)

Date	Order of Ponds (highest → lowest)
July 3	21 > 22
July 9	21 > 20 > 23 > 19 > 24 > 22
July 24	21 > 24 > 20 > 19 > 23 > 22
Aug 14	21 > 22 > 23 > 24 > 22
Sept 10	21 > 23 > 20 > 24 > 22 > 19
Oct 10	21 > 24,22 > 20 > 19 > 23

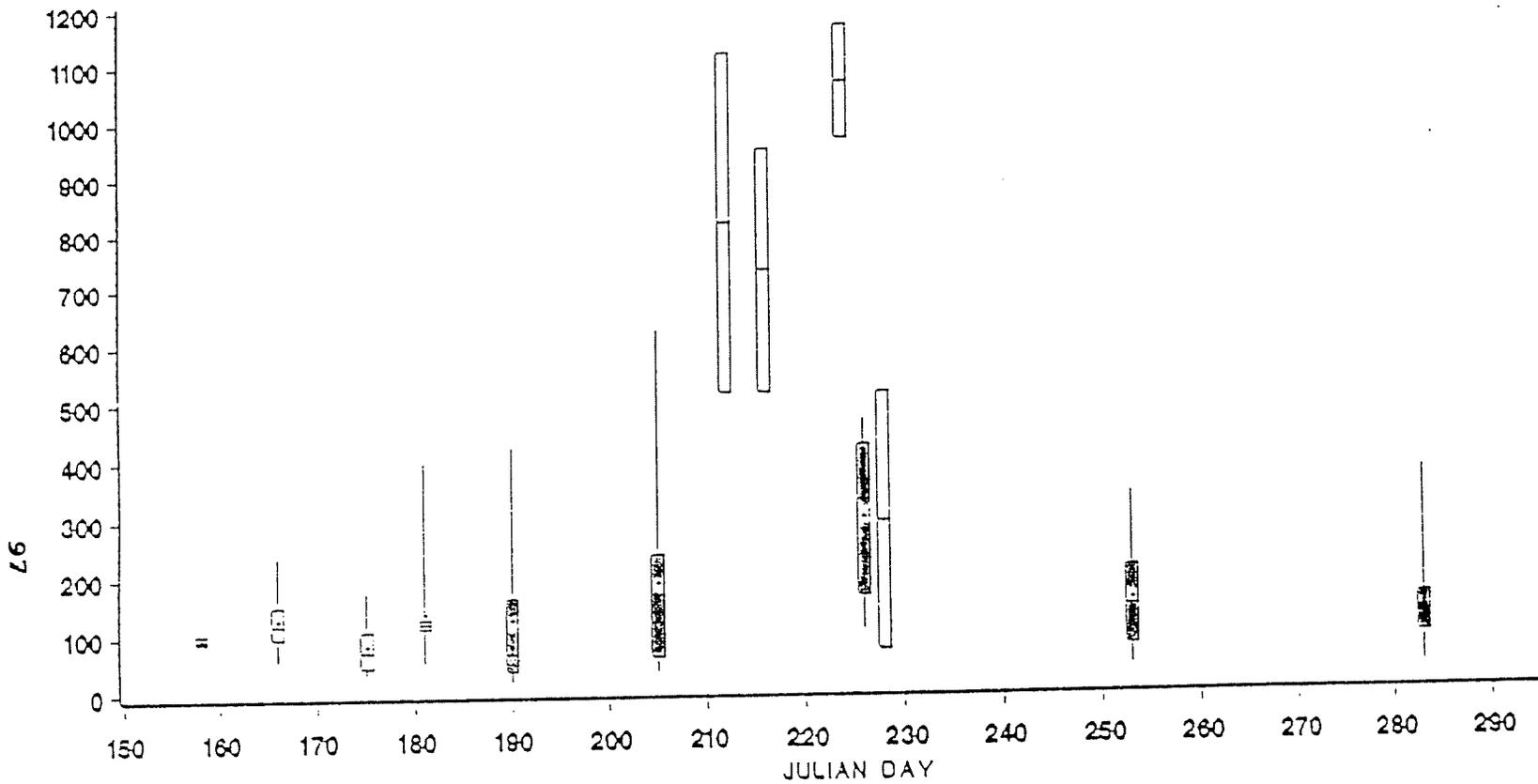


Figure 9a. Coastal Fen Seasonal CO₂ Concentration Pattern.
 (includes all concentration measurements done on each date, not time-weighted June-October, 1990). See Figure 6a for details.

Table 15. Monthly Carbon Dioxide Concentrations in the Hudson's Bay Lowlands (June-October, 1990).

Location	Month	Mean CO ₂ Concentration (μmol/L)	Median CO ₂ Concentration (μmol/L)	Minimum CO ₂ Concentration (μmol/L)	Maximum CO ₂ Concentration (μmol/L)
Coastal Fen	June	12	110	33	460
	July	175	110	10	1100
	August	550	490	69	1170
	September	150	150	35	470
	October	140	110	25	550
Interior Fen	June	100	80	13	330
	July	360	130	6.8	1100
	August	240	180	30	570
	September	180	120	20	640
	October	89	70	45	250
Kinosheo Lake	June	60	35	22	270
	July	60	35	15	375
	August	50	37	10	160
	September	100	66	21	620
	October	90	44	20	330

Note: The data was treated equally, the means and medians presented are statistical means and medians, not time weighted.

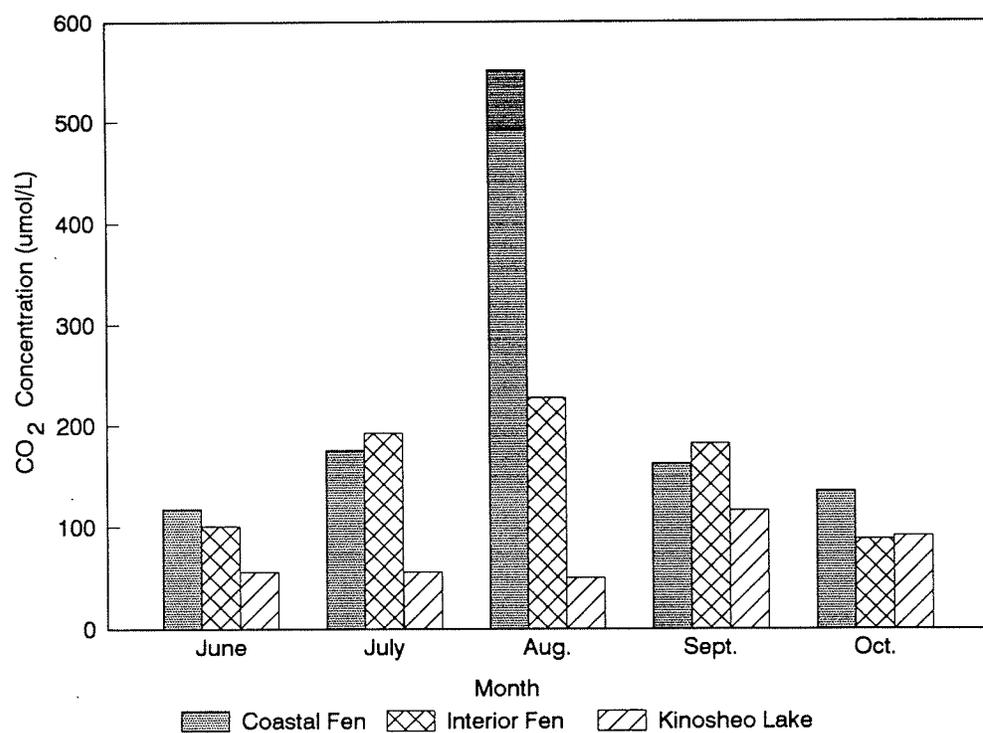


Figure 10. Average Monthly CO₂ Concentrations.
 (All data treated equally, i.e. not time weighted)

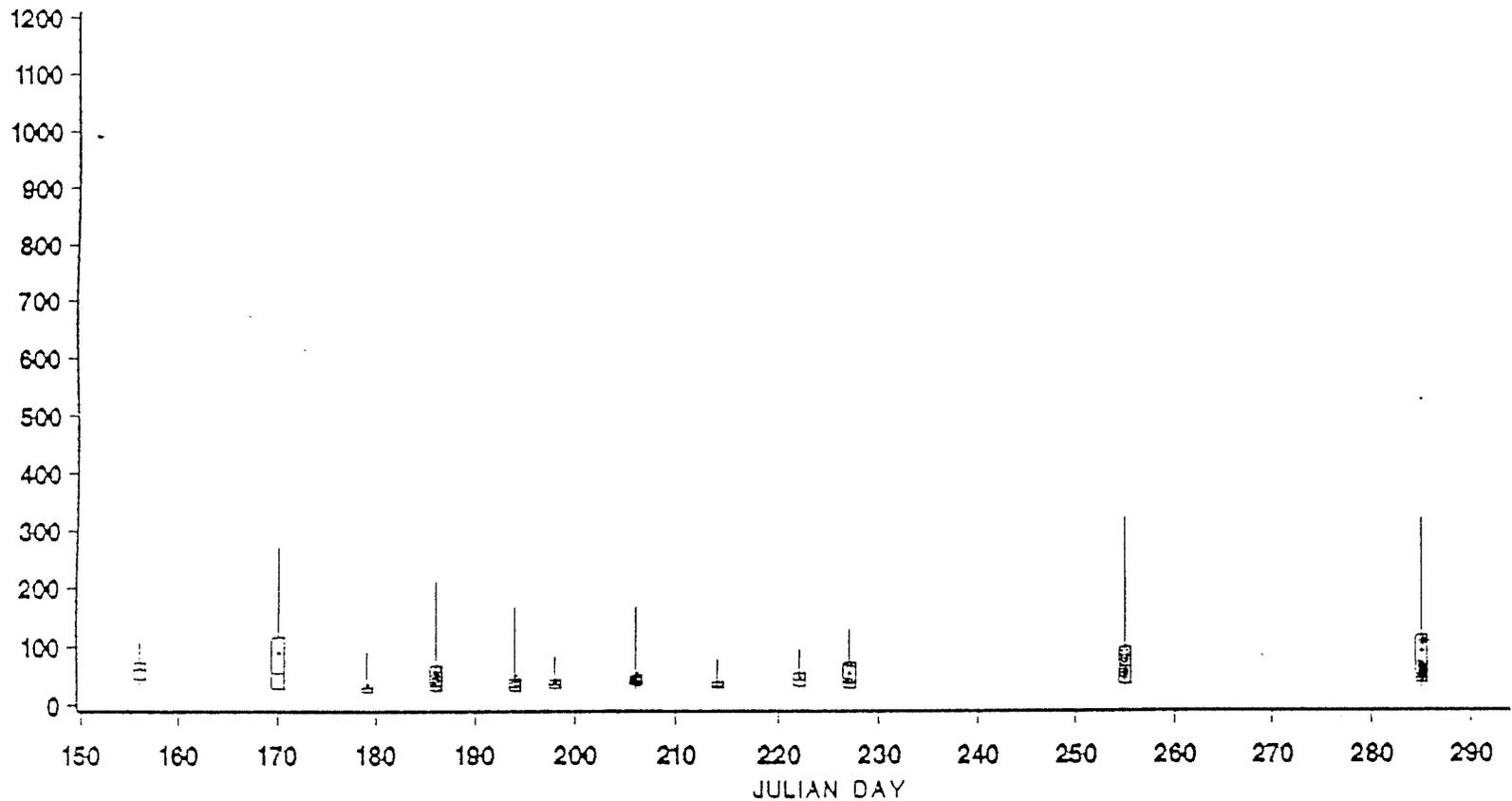


Figure 9c. Kinosheo Lake Bog Seasonal CO₂ Concentration Pattern. (includes all concentration measurements done on each date, not time-weighted June-October, 1990). See Figure 6a for details.

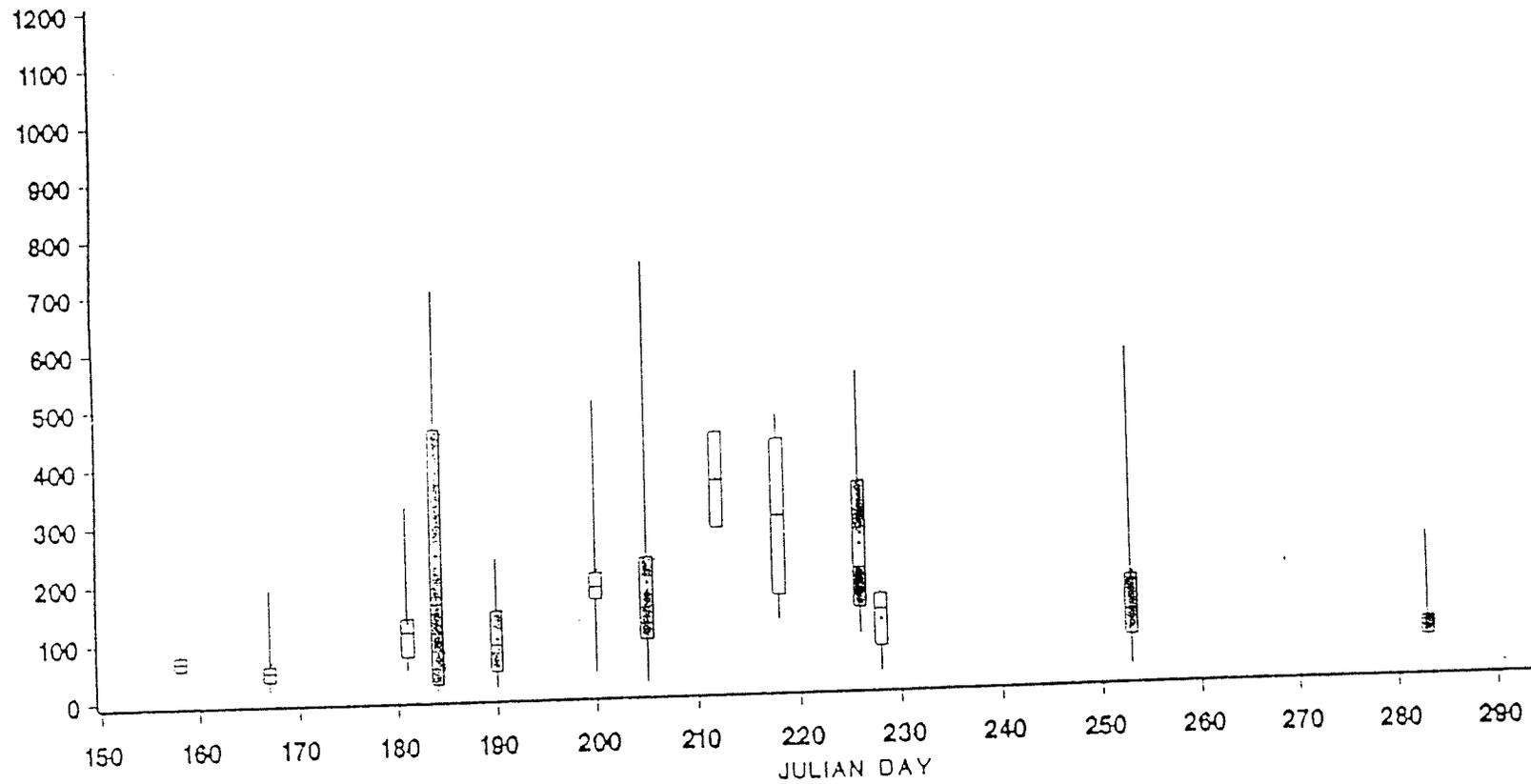


Figure 9b. Interior Fen Seasonal CO₂ Concentration Pattern (includes all concentration measurements done on each date, not time-weighted June-October, 1990). See Figure 6a for details.

14).

Dissolved CO₂ concentrations varied widely among the ponds within each site (Figure 8 and Tables 12, 13, 14) as well as seasonally (Figures 9a, 9b, 9c, 10 and Table 15).

In the Coastal Fen mean CO₂ concentrations ranged from 12 (110, 33-460) μmol/L in June to a maximum of 550 (490, 69-1170) μmol/L in August. The mean concentration decreased through the autumn to 140 (110, 25-550) μmol/L in October (Figure 9a and Table 15).

In the Interior Fen CO₂ concentrations averaged 100 (80, 13-330) μmol/L in June with a peak in August of 240 (180, 30-570) μmol/L. There was a decline in the mean concentration during the fall to a level of 89 (70, 45-250) μmol/L in October (Figure 9b and Table 15).

The mean concentration of CO₂ at the Kinosheo Lake bog site was lower than those of the fen sites (Figure 9c and Table 15). The June concentrations averaged 60 (35, 22-270) μmol/L and declined slightly during the summer to 50 (37, 10-160) μmol/L in August. The mean CO₂ concentration peaked in September at 100 (66, 21-620) μmol/L. By mid October the mean concentration had dropped slightly to 90 (44, 20-330) μmol/L.

Carbon Dioxide concentrations at the two fen sites increased throughout the summer to reach a peak concentration in August. The Kinosheo Lake bog site had significantly lower CO₂ concentrations than at the two fen sites and did not peak in concentration until September.

The concentrations of CO₂ observed in September, 1990 corresponded well with the values observed in September, 1989. In 1989, the range of CO₂ concentrations at the Interior Fen (185-190 μmol/L) and the Kinosheo Lake bog (30-50 μmol/L) were within the range observed in September, 1990 (Tables 10 and 15). Coastal Fen CO₂ concentrations for September, 1989 (590-670 μmol/L) were higher than the range seen for 1990 of 35-470 μmol/L (Tables 10 and 15). Thus, the Interior Fen and Kinosheo Lake bog sites were similar for both CH₄ and CO₂ in September 1989 and 1990, but both were higher in the Coastal fen in 1989 than 1990. Most significantly the 1989 data supported the findings that the aqueous gas concentrations in the ponds of the Hudson Bay Lowland are consistently in excess of the atmospheric equilibrium concentration.

III Observed Patterns of CH₄ and CO₂ Concentration

As figures 5 and 8 demonstrate, the concentration of both CH₄ and CO₂ varied throughout day. Concentrations often increased during the night and early morning hours. The concentrations were usually highest in the late morning and decreased rapidly through out the afternoon (see figures in the appendix). However this diel pattern was not always observed (see appendix). Sometimes the morning concentration maximum was not observed for either gas and the concentrations remained fairly constant throughout the day.

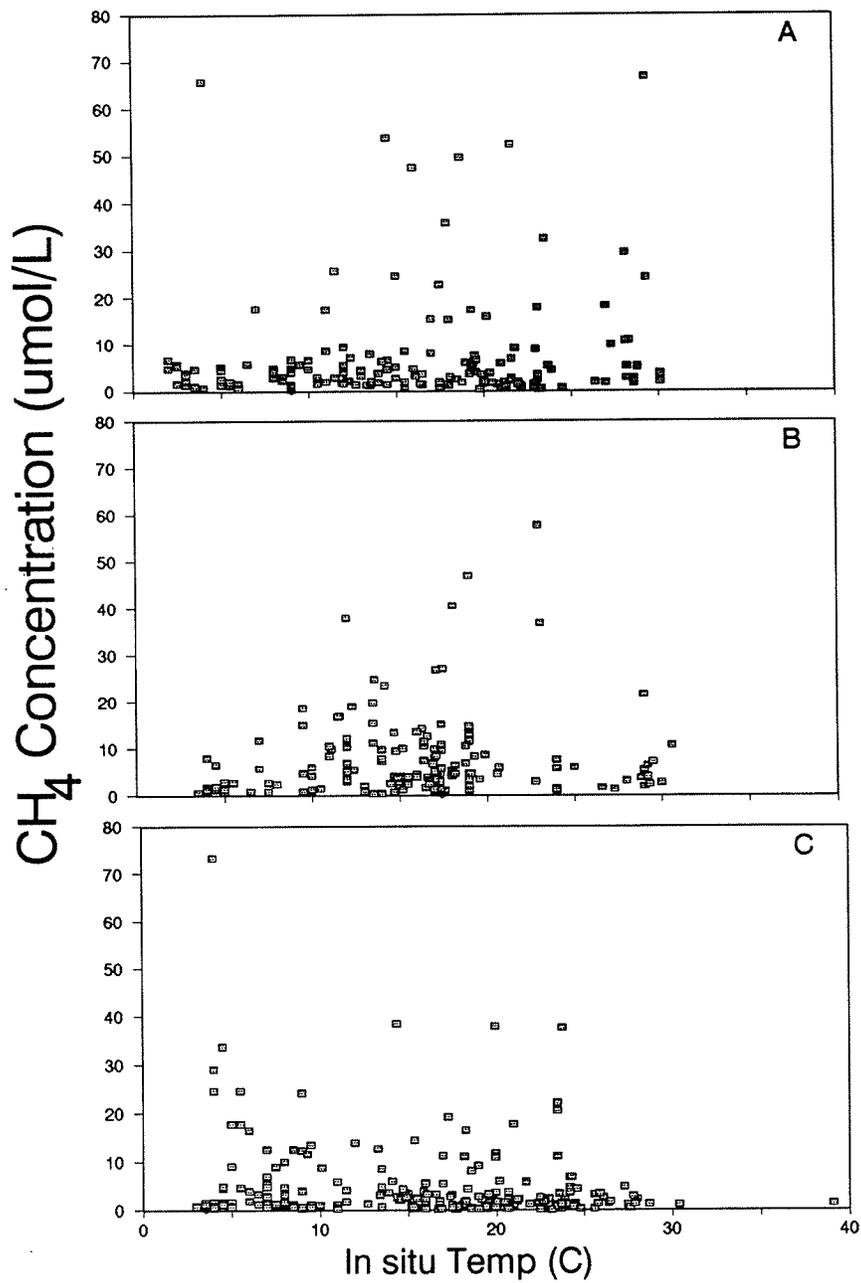


Figure 11. Methane Concentration vs *in situ* water Temperature
 A) Coastal Fen B) Interior Fen C) Kinosheo Lake Bog
 (Includes all instantaneous concentrations, June-October, 1990).

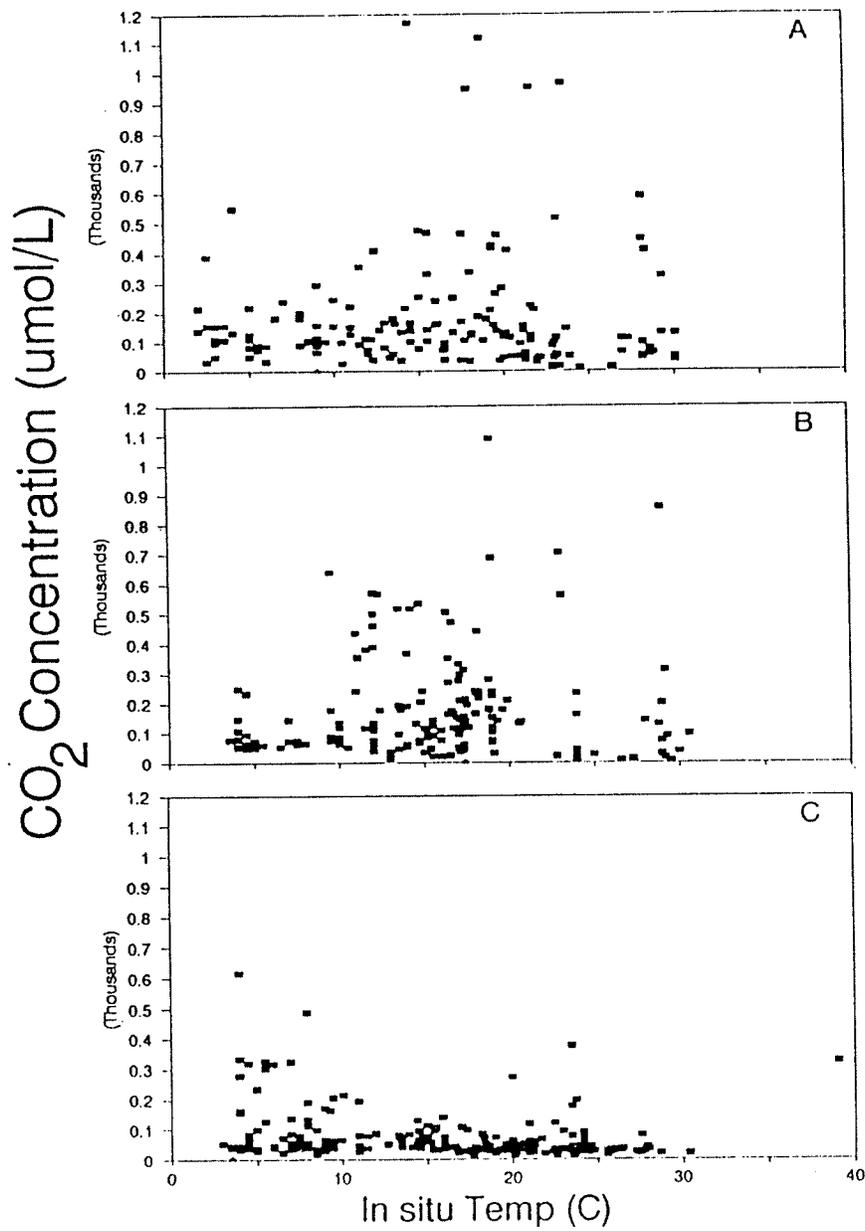


Figure 12. Carbon Dioxide Concentration vs insitu water Temperature
 A) Coastal Fen B) Interior Fen and C) Kinosheo Lake.
 (Includes all instantaneous concentrations, June-October, 1990).

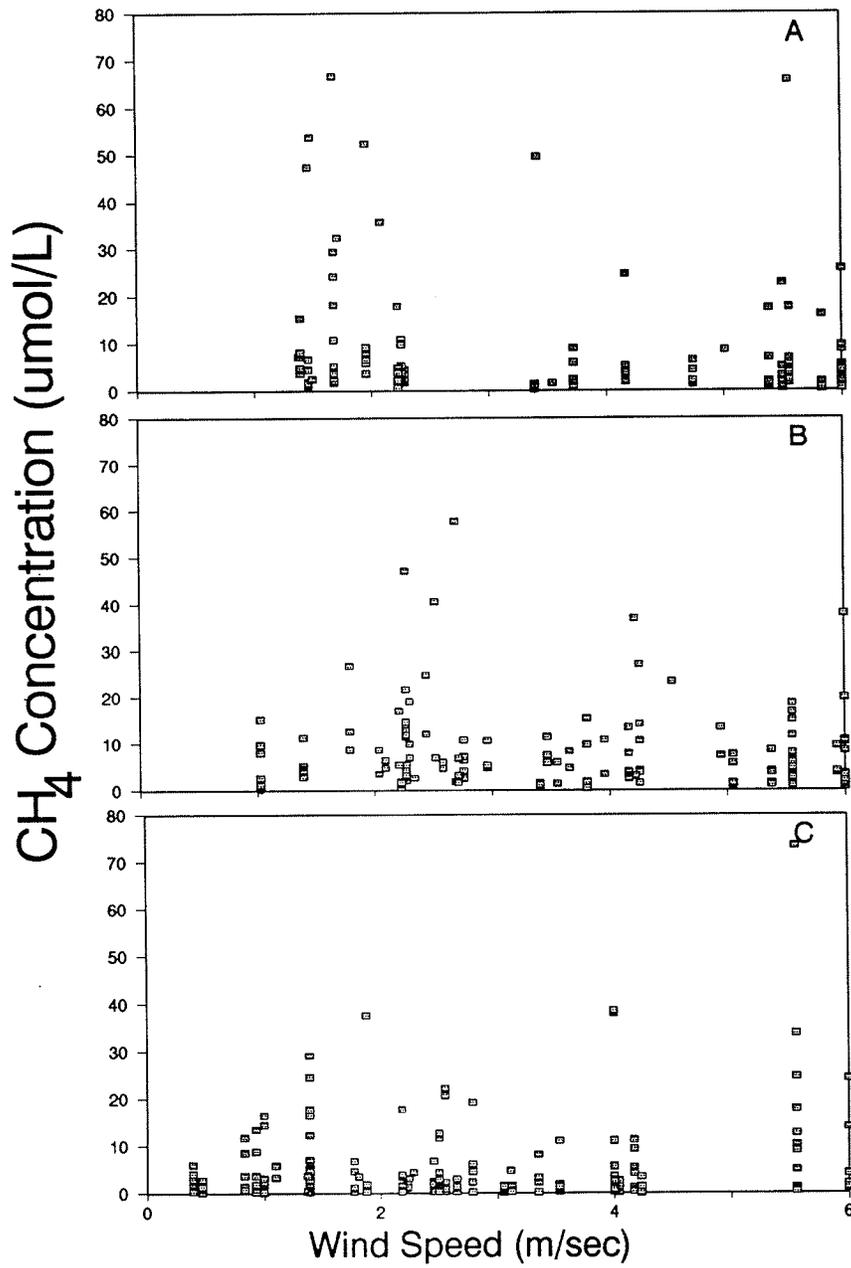


Figure 13. Methane Concentration vs Wind Speed
 A) Coastal Fen B) Interior Fen and C) Kinosheo Lake.
 (Includes all instantaneous concentrations, June-October, 1990).

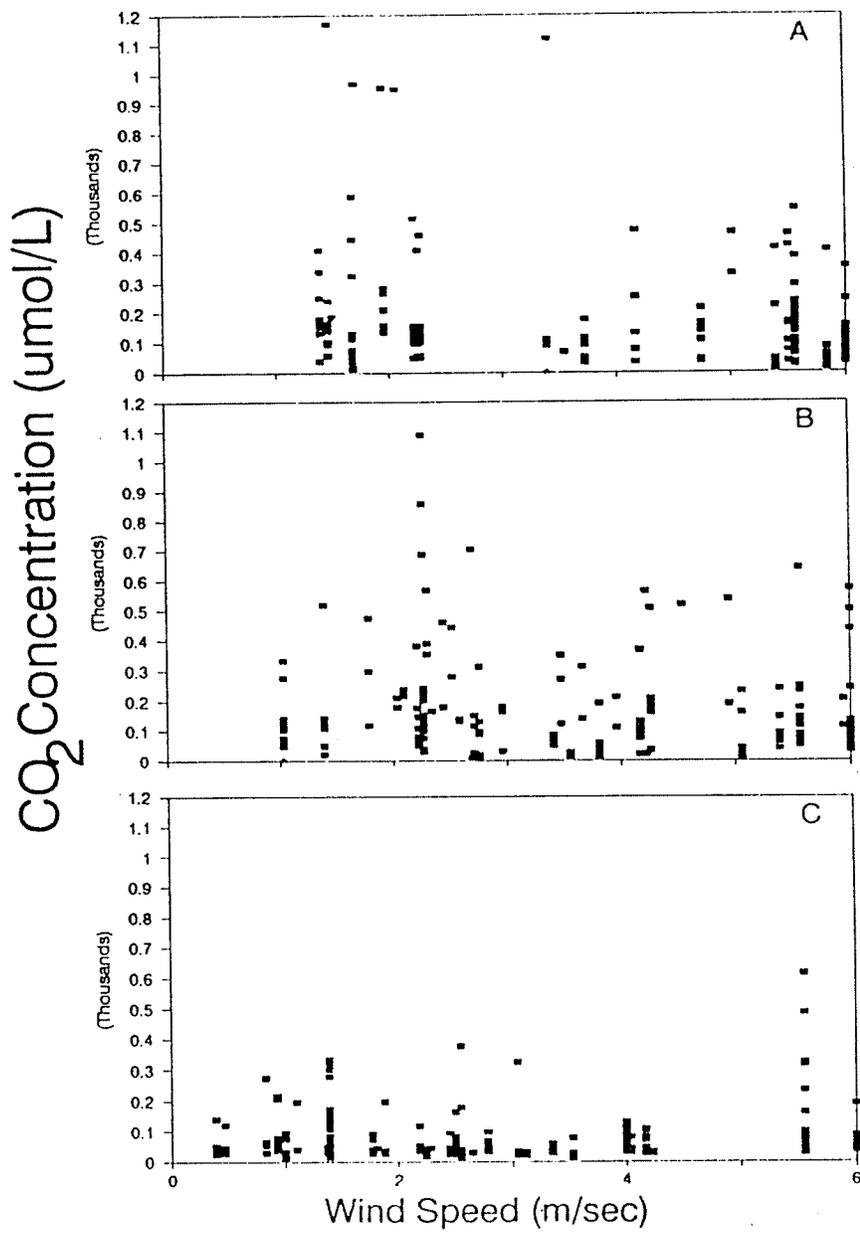


Figure 14. Carbon Dioxide Concentration vs Wind Speed.
 A) Coastal Fen B) Interior Fen and C) Kinosheo Lake.
 (Includes all instantaneous concentrations, June-October, 1990).

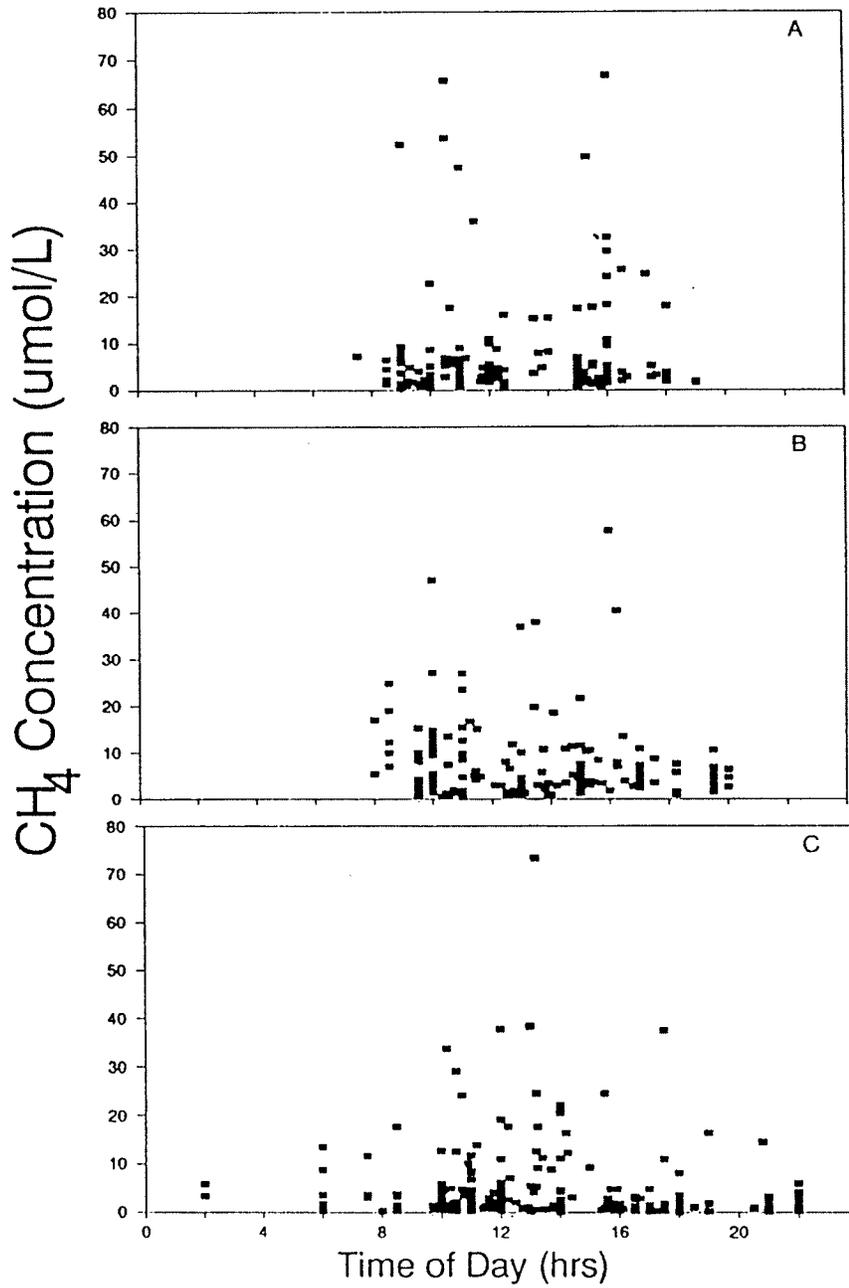


Figure 15. Methane Concentration vs Time of Day.
 A) Coastal Fen B) Interior Fen and C) Kinosheo Lake.
 (Includes all instantaneous concentrations, June-October, 1990).

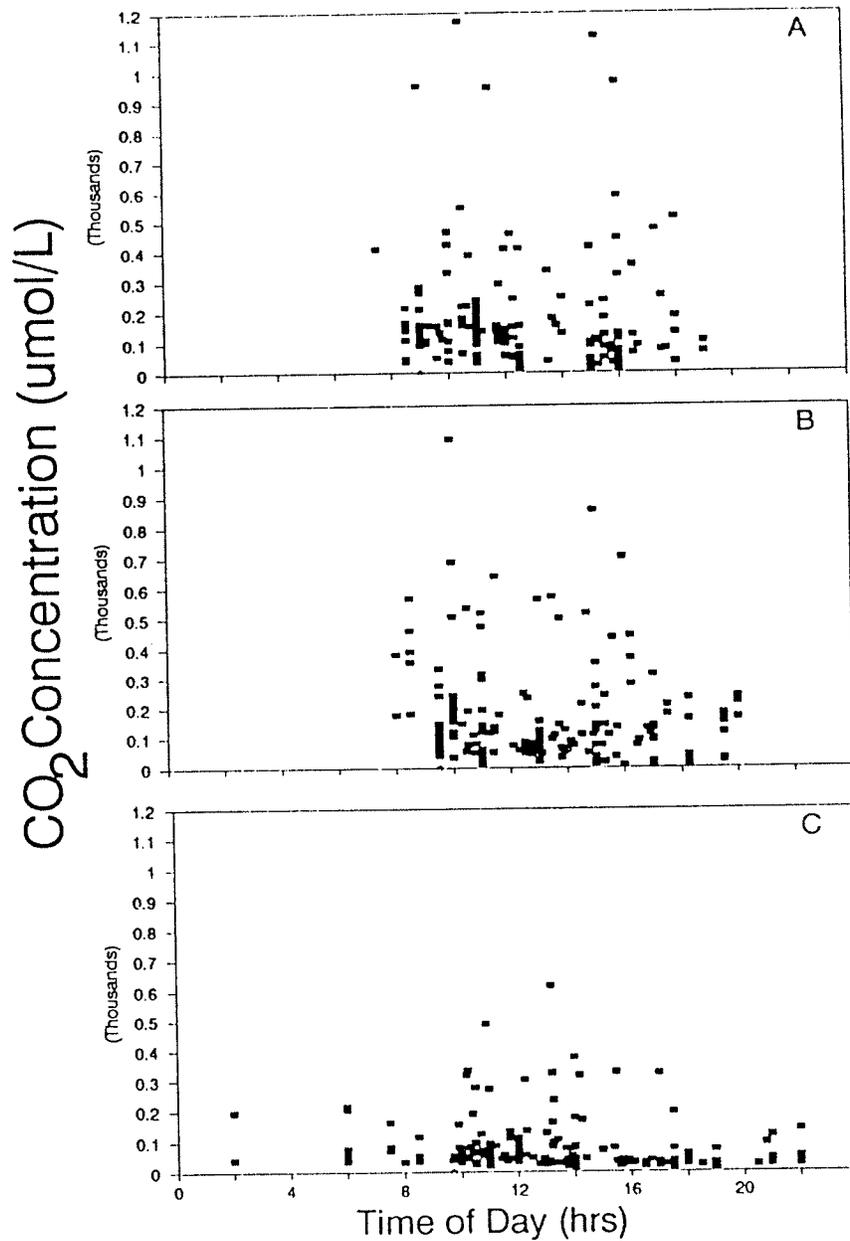


Figure 16. Carbon Dioxide Concentration vs Time of Day.
 A) Coastal Fen B) Interior Fen and C) Kinosheo Lake.
 (Includes all instantaneous concentrations, June-October, 1990).

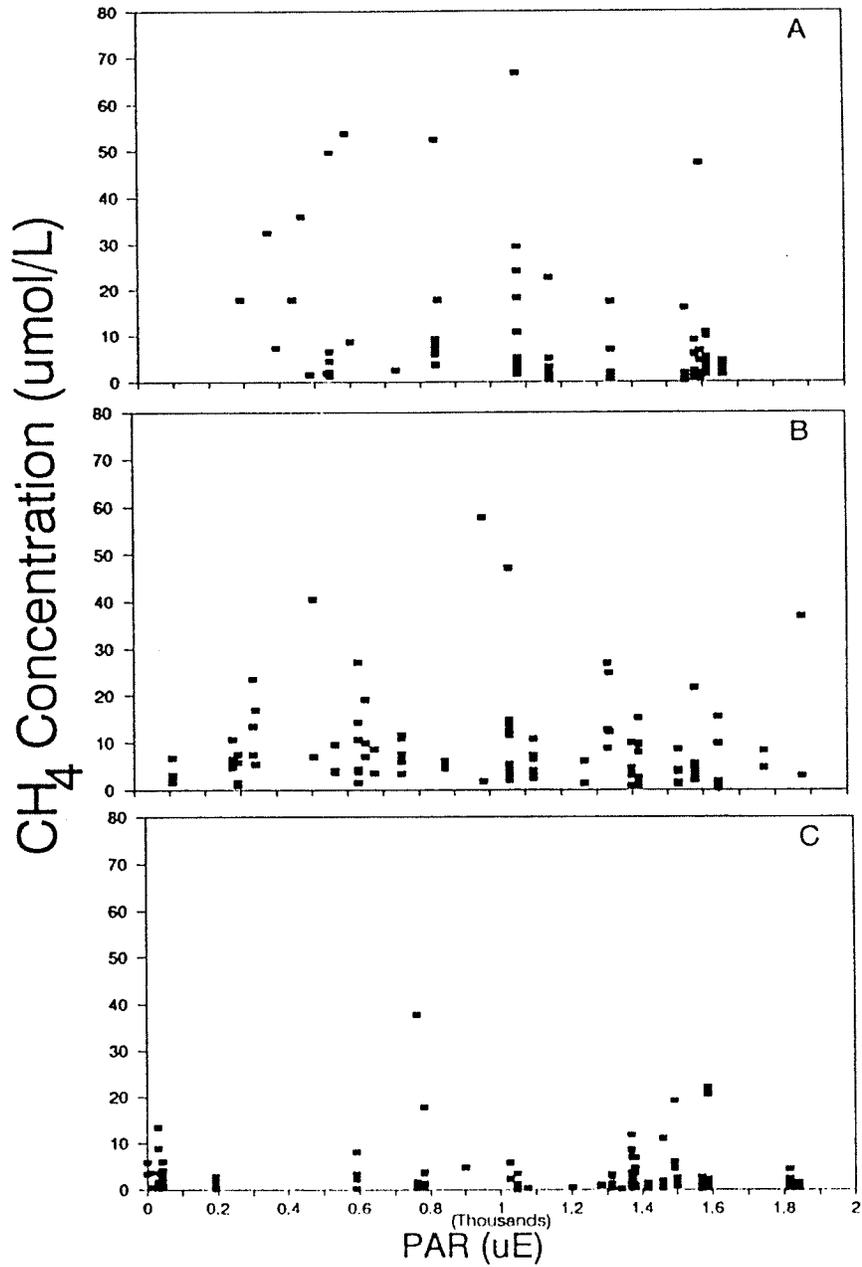


Figure 17. Methane Concentration vs Photosynthetically Active Radiation (PAR).
 A) Coastal Fen B) Interior Fen and C) Kinosheo Lake.
 (Includes all instantaneous concentrations, June-October, 1990).

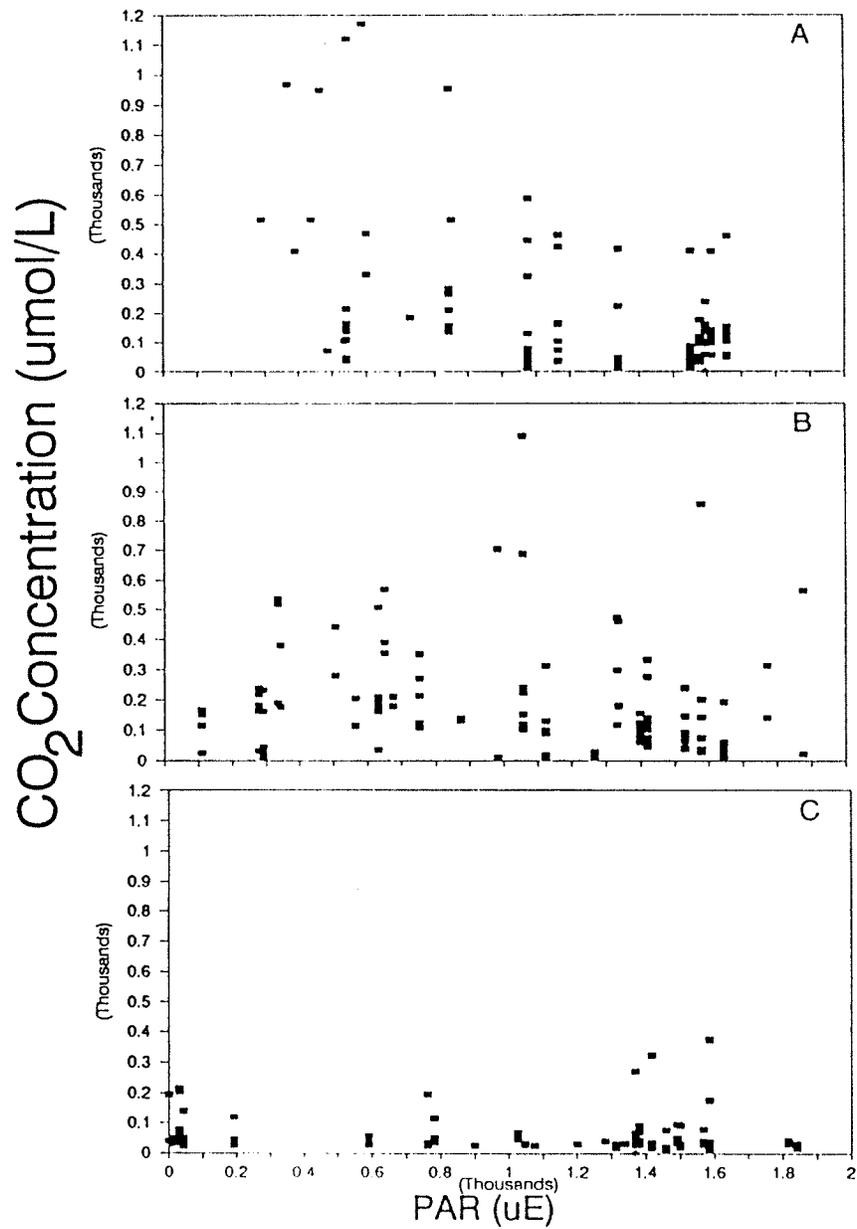


Figure 18. Carbon Dioxide Concentration vs PAR.
 A) Coastal Fen B) Interior Fen and C) Kinosheo Lake.
 (Includes all instantaneous concentrations, June-October, 1990).

To explore which factors might be controlling CH₄ and CO₂ concentrations, concentrations were plotted against possible controlling parameters. No obvious relationships were observed between CH₄ or CO₂ concentrations and *in situ* water temperature (Figure 11 and 12), wind speed (Figure 13 and 14), time of day (Figure 15 and 16) and photosynthetically active irradiance (PAR) (Figure 17 and 18).

To further examine possible controlling factors, the data set was divided into individual ponds for the whole openwater season as well as individual ponds on individual days. When individual ponds were examined there were no apparent correlations between gas concentration and possible controlling factors (data not shown) except that both gas concentrations change in a progressive manner throughout the day.

While no obvious patterns were seen, Figures 15 and 16 do suggest that concentration is distributed around 12 noon. Also, wind speed appears to have some effect on the gas concentrations (Figures 13 and 14). There was some tendency, at the fen sites, for concentrations to be generally low at high wind speeds, where as at low wind speeds it is possible to have a whole range of concentrations. The lower gas concentrations at high wind speeds is expected. At high wind speeds, the sediment production of CH₄ or CO₂ would have to be very high to maintain high concentrations of these gases. At low wind speeds it is possible to have a range in

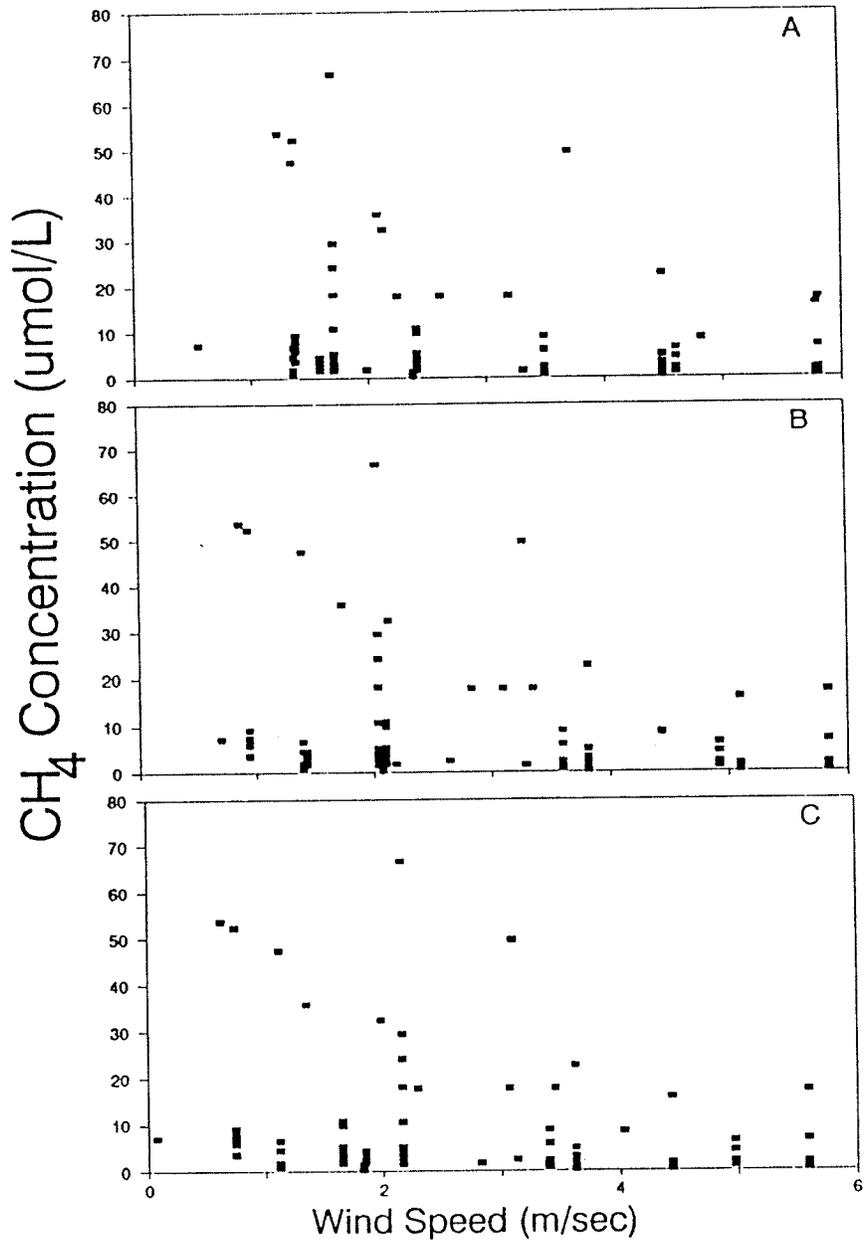


Figure 19. Coastal Fen CH₄ Concentration vs Wind History
 A) Previous 2 hours B) Previous 4 hours and C) Previous 6
 hours. (Includes June-August only).

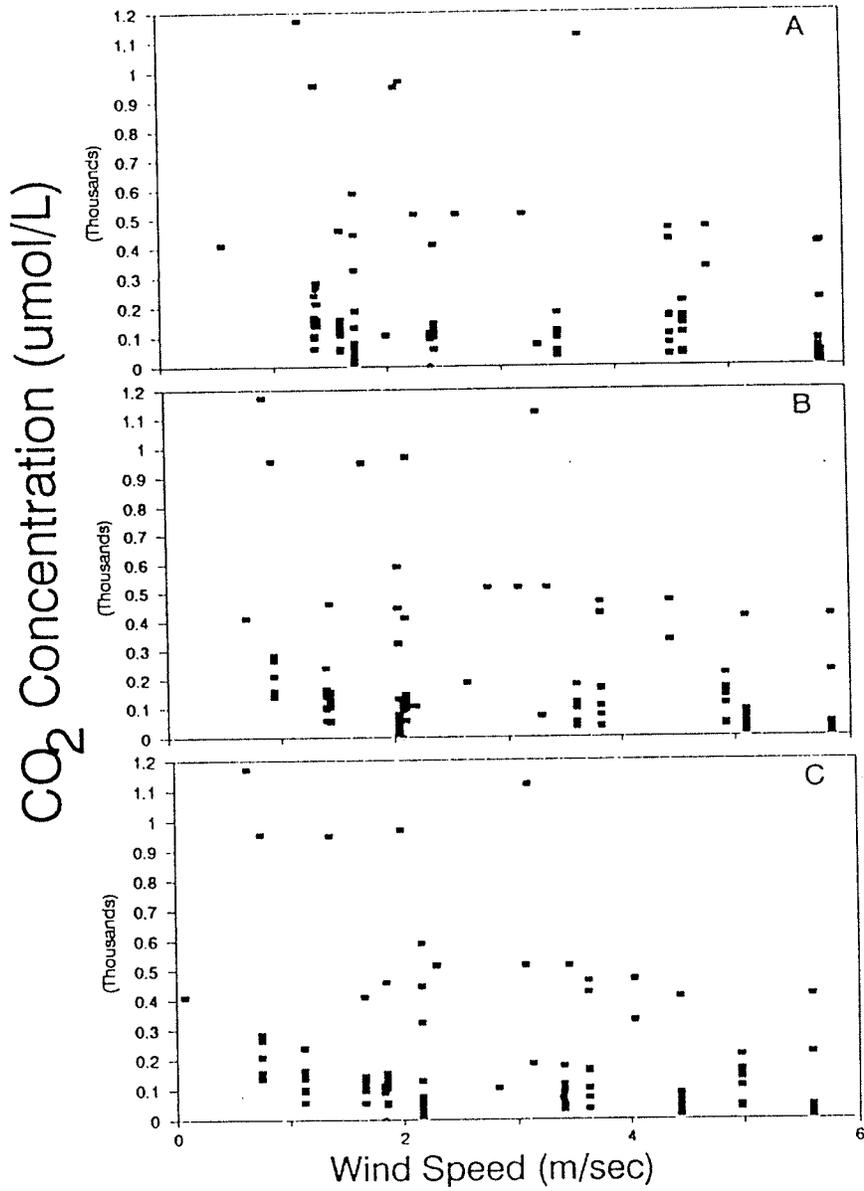


Figure 20. Coastal Fen CO₂ Concentration vs Wind History
 A) Previous 2 hours B) Previous 4 hours and C) Previous 6 hours. (Includes June-August only).

concentrations as the low wind speed allows higher concentrations to build up.

IV Influence of Wind History on CH₄ and CO₂ Concentration

As the ponds in the study area were extremely shallow and the dissolved gases were above atmospheric equilibrium concentration, it might be expected that concentrations would decrease after prolonged periods of high wind. This possibility was considered. Gas concentrations were plotted against the average wind speed of the previous two, four and six hour periods. However, Figures 19 and 20 demonstrate that the wind history did not correspond with the *in situ* CH₄ and CO₂ concentrations, except that, as with instantaneous wind speeds and concentrations a broader range was seen at low wind speed histories. At high wind speed histories the range was smaller, and at the low end of the total range. The possibility that any pattern might be missed because of the overall variability when all the ponds at a site are used in a data set was also considered. Individual pond data sets were examined for any correlations between wind history and *in situ* CH₄ and CO₂ concentrations. There was no correlations between individual ponds and wind history (data not shown).

However wind history should not be completely discarded as a possible controlling influence on gas concentrations. Wind history still needs to be examined with a statistical time

Table 16. Mean Dissolved Inorganic Carbon in the Hudson's Bay Lowlands (June-October, 1990).

Location	Date	Mean DIC Conc. ($\mu\text{mol/L}$)	Median DIC Conc. ($\mu\text{mol/L}$)	Maximum DIC Conc. ($\mu\text{mol/L}$)	Minimum DIC Conc. ($\mu\text{mol/L}$)
Coastal Fen	July 09	720	670	1010	450
	July 24	1030	1010	1660	700
	Aug. 14	1420	1440	2000	1050
	Sept 10	1050	990	1730	720
	Oct. 10	480	435	1200	250
Interior Fen	July 09	1200	1125	1200	1060
	July 24	1590	1465	2530	1000
	Aug. 14	2040	2040	2780	1360
	Sept 10	1790	1710	3160	1175
	Oct. 10	990	950	1320	830
Kinosheo	July 05	110	30	410	30
	July 13	60	40	145	30
	July 17	70	60	145	30
	July 25	85	60	190	30
	Aug. 15	90	80	280	20
	Sept 12	150	95	620	20
	Oct. 12	130	80	400	30

Note: The data was treated equally, the means and medians presented are statistical means and medians, not time weighted.

course analysis. This would require a more detailed data set (i.e. two or three days of continuous sampling) which was not possible to obtain.

V Dissolved Inorganic Carbon Concentrations

The Dissolved Inorganic Carbon (DIC) concentrations exhibited seasonal variability (Table 16). The Coastal Fen DIC concentration ranged from 720 (670, 450-1010) in early July $\mu\text{mol/L}$ to 1050 (990, 720-1730) $\mu\text{mol/L}$ in September with a dramatic decline in October down to approximately 480 (435, 250-1200) $\mu\text{mol/L}$ (Table 16). The Interior Fen DIC concentrations were higher throughout the summer ranging from 1200 (1125, 1060-1200) $\mu\text{mol/L}$ in early July to a maximum of 2040 (2040, 1360-2780) $\mu\text{mol/L}$ in August. The concentration had declined to approximately half of the maximum, to a level of 990 (950, 830-1320) $\mu\text{mol/L}$ by October (Table 16).

The Kinosheo bog ponds exhibited DIC concentrations approximately an order of magnitude lower than the fen sites. DIC concentrations averaged between 110 (30, 30-410) $\mu\text{mol/L}$ in early July and 90 (80, 20-280) $\mu\text{mol/L}$ in August. There was a slight increase in September to a maximum of 150 (95, 20-620) $\mu\text{mol/L}$. By October the DIC concentrations had decreased to 130 (80, 30-400) $\mu\text{mol/L}$ (Table 16).

To a large extent changes in DIC concentration reflected the changing aqueous CO_2 concentrations. At the two fen sites

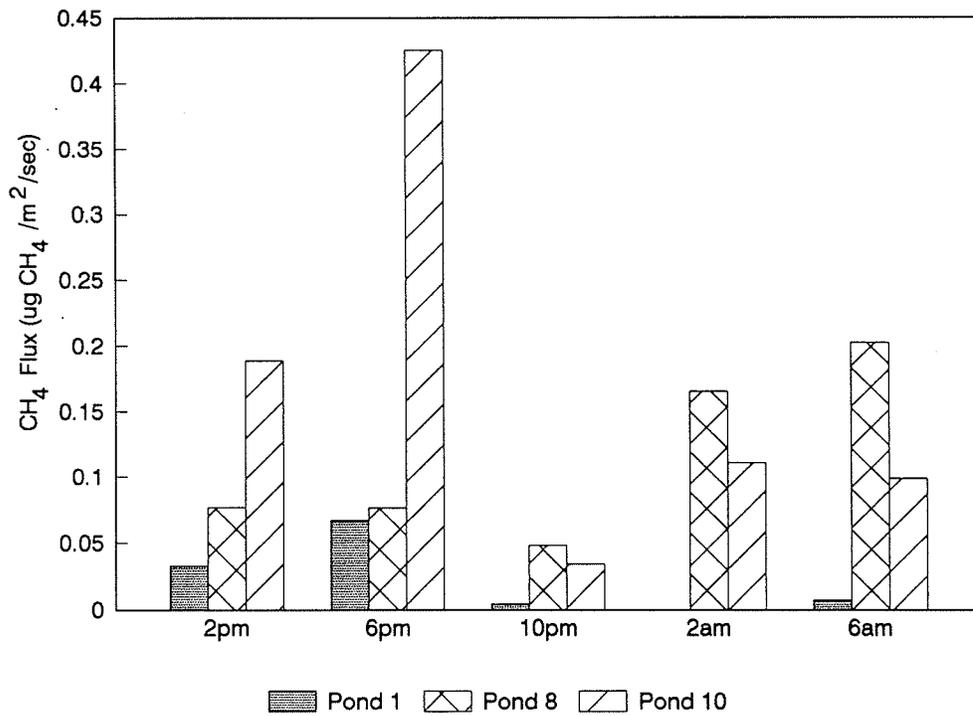


Figure 21. Diel CH₄ Flux at the Kinosheo Lake Bog (July 05-06, 1990).

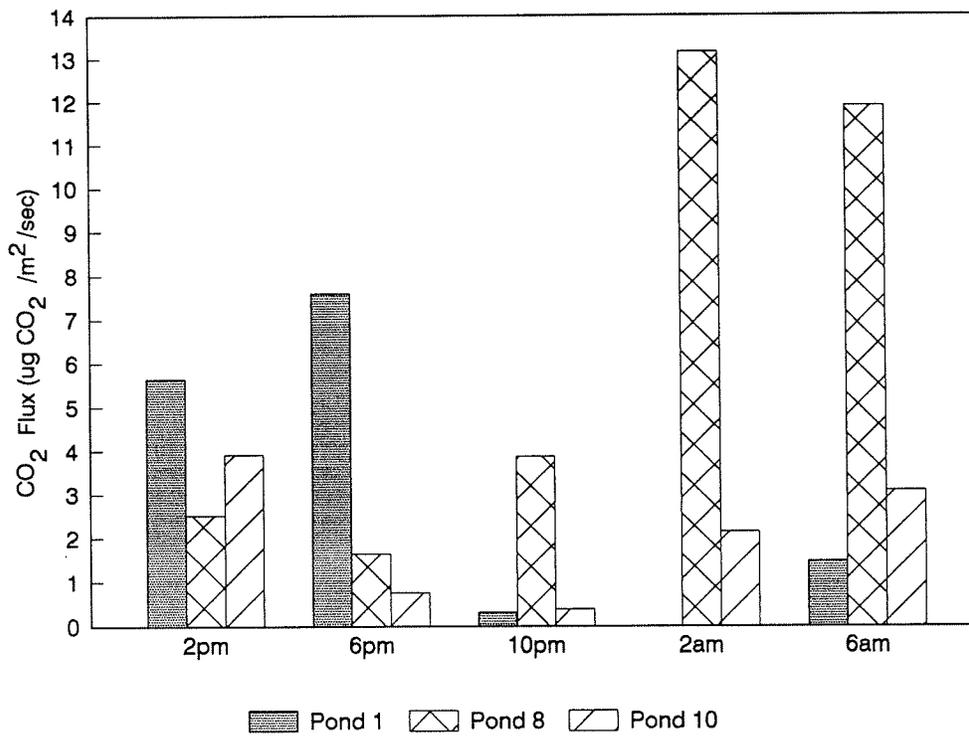


Figure 22. Diel CO₂ Flux at the Kinosheo Lake Bog (July 05-06, 1990).

120

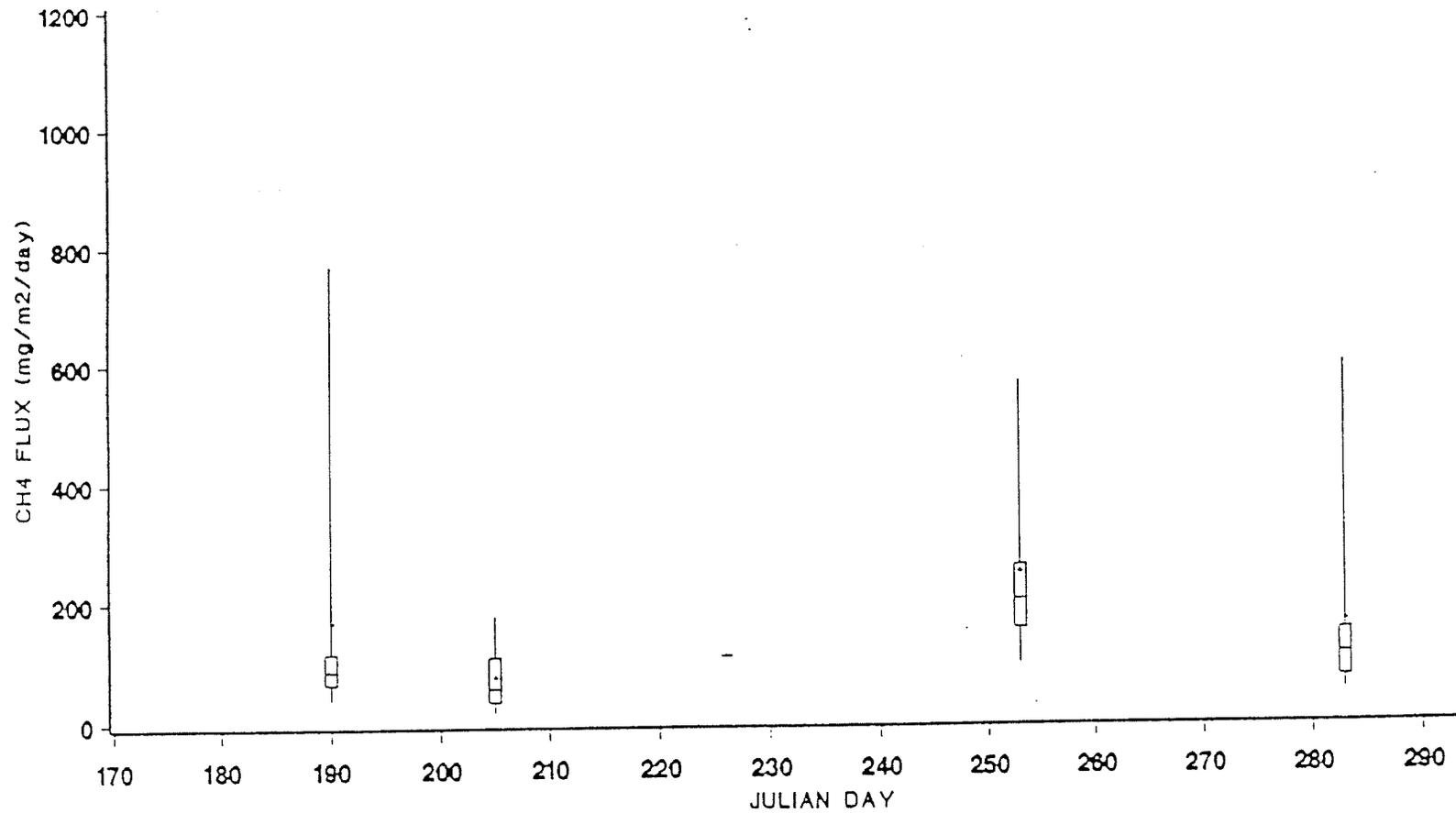


Figure 23a. Coastal Fen Seasonal CH₄ Flux.
(Only includes data from days on which a complete diel sampling was done, July-October, 1990). See Figure 6a for details.

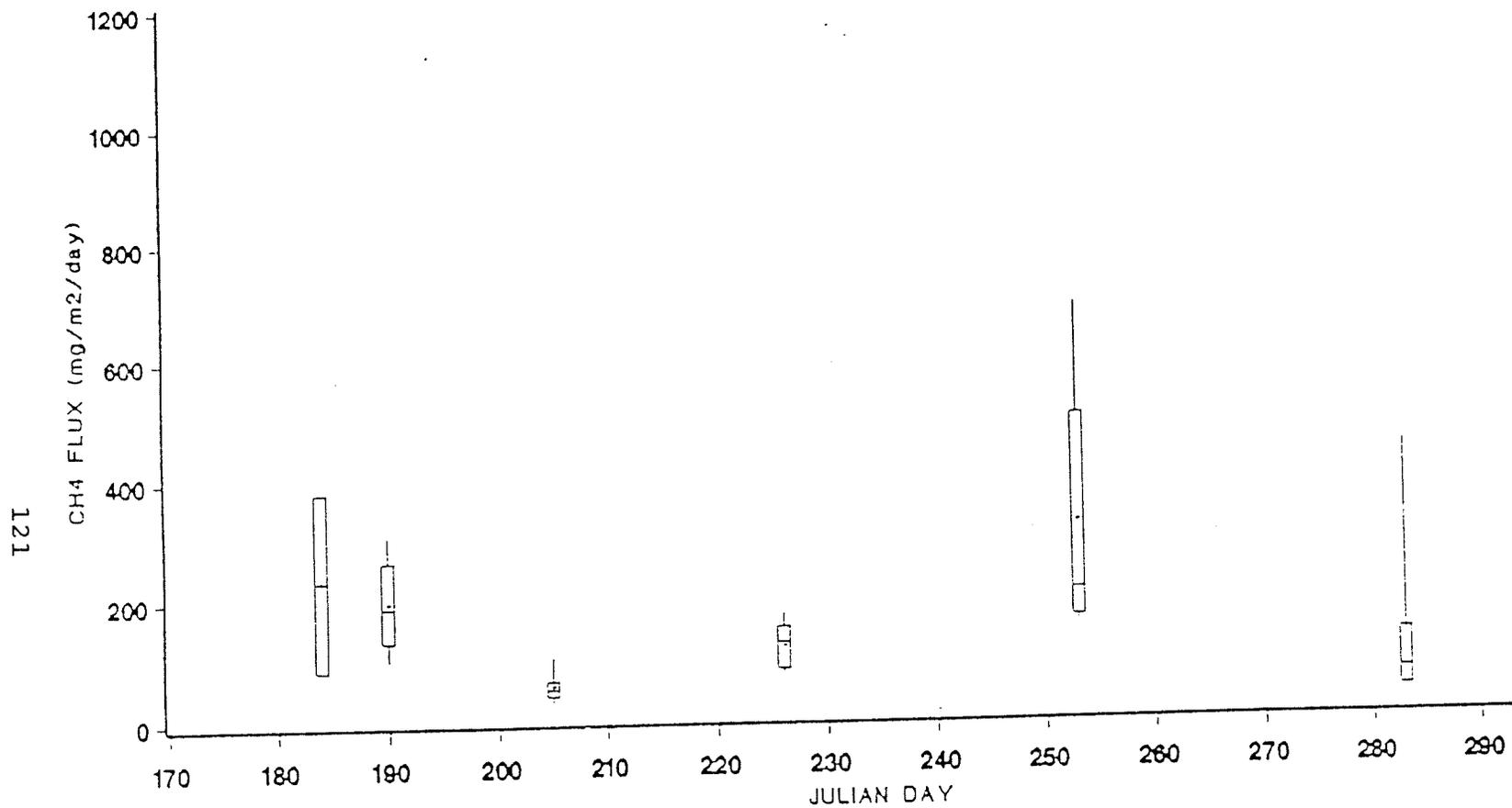


Figure 23b. Interior Fen Seasonal CH₄ Flux.
(Includes data from days on which a complete diel sampling was done, July-October, 1990). See Figure 6a for details.

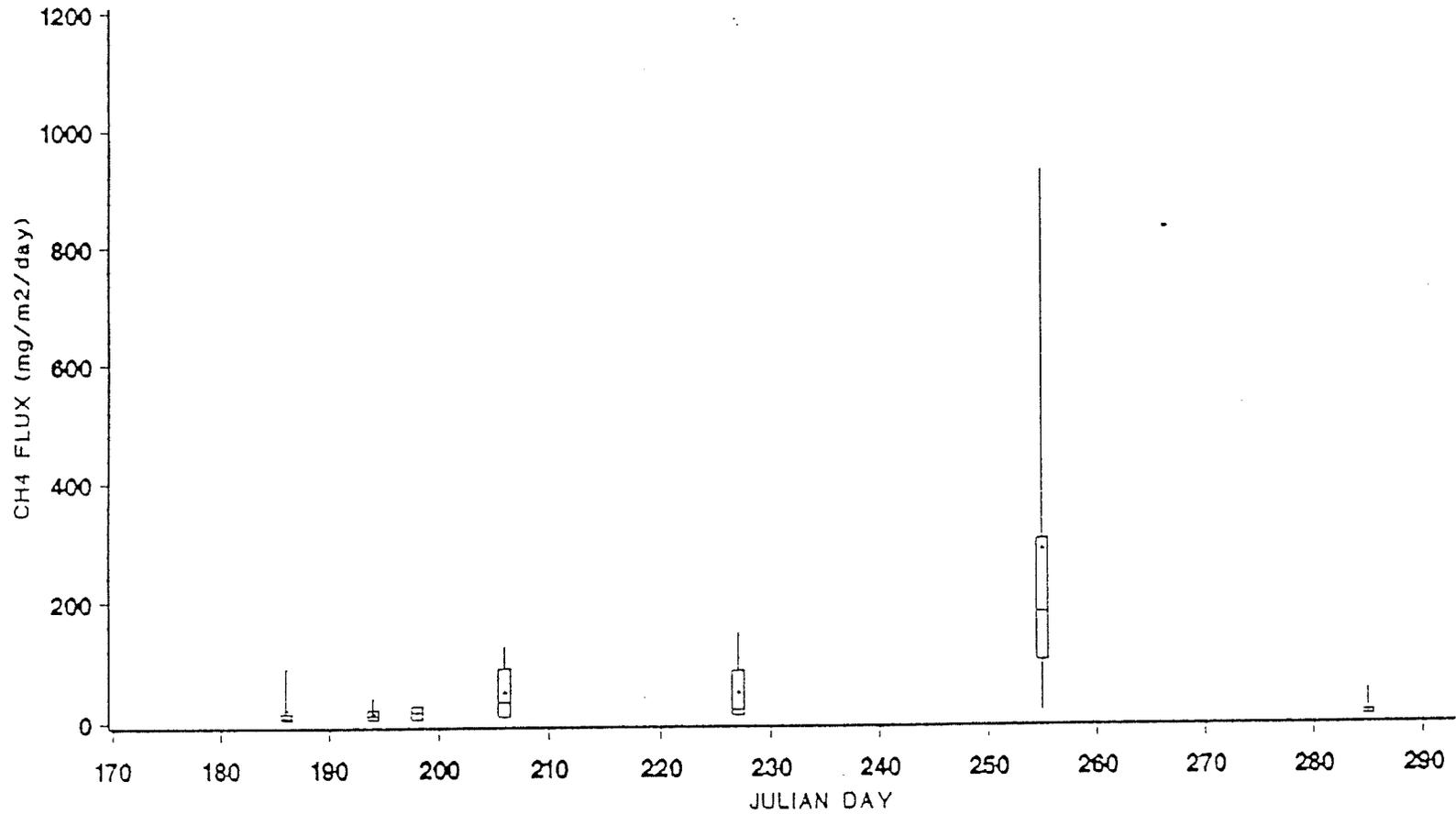


Figure 23c. Kinosheo Lake Bog Seasonal CH₄ Flux. (Only includes data from days on which a complete diel sampling was done, July-October, 1990). See Figure 6a for details.

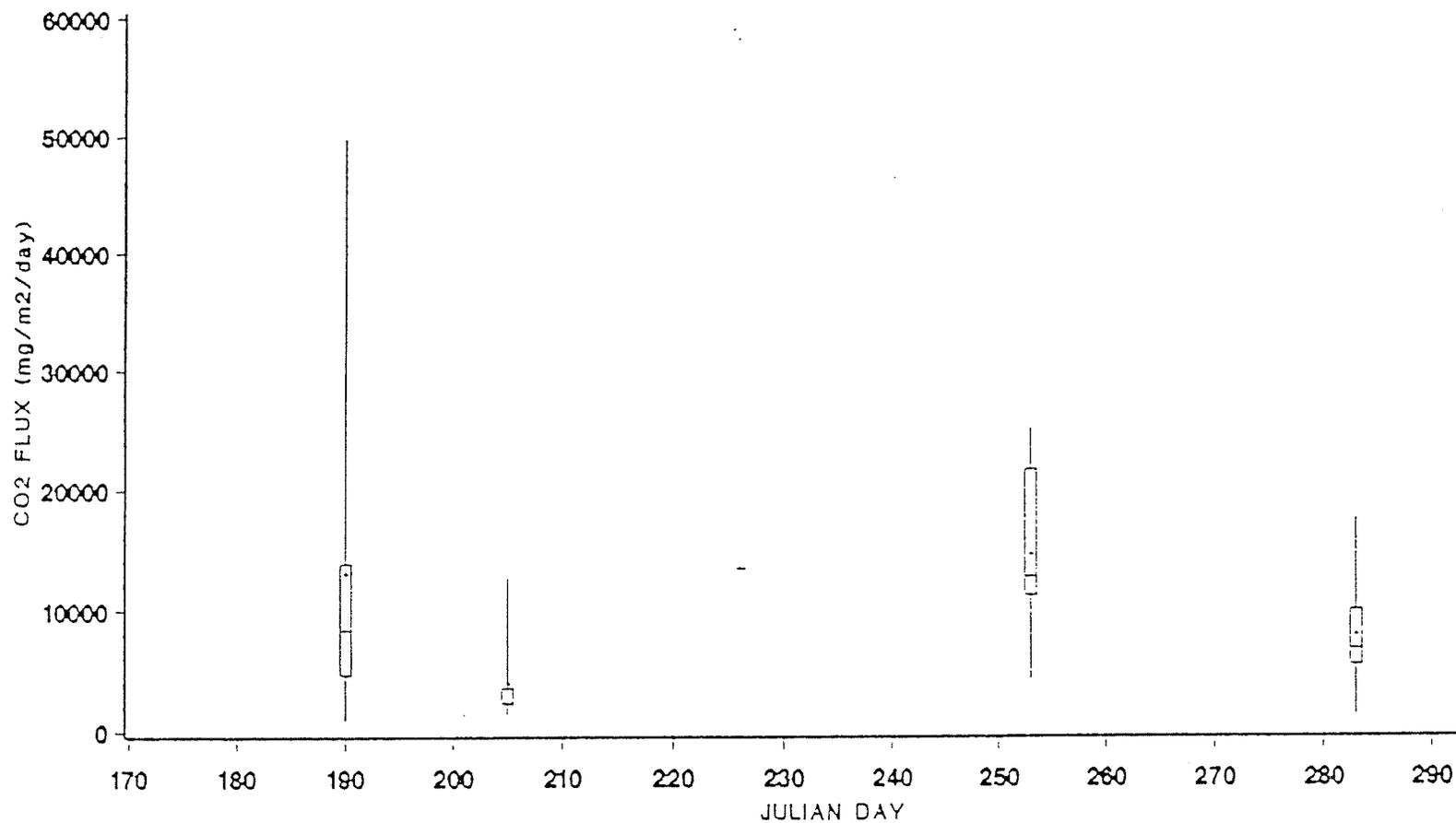


Figure 24a. Coastal Fen Seasonal CO₂ Flux.
(Only includes data from days on which a complete diel sampling was done, July-October, 1990). See Figure 6a for details.

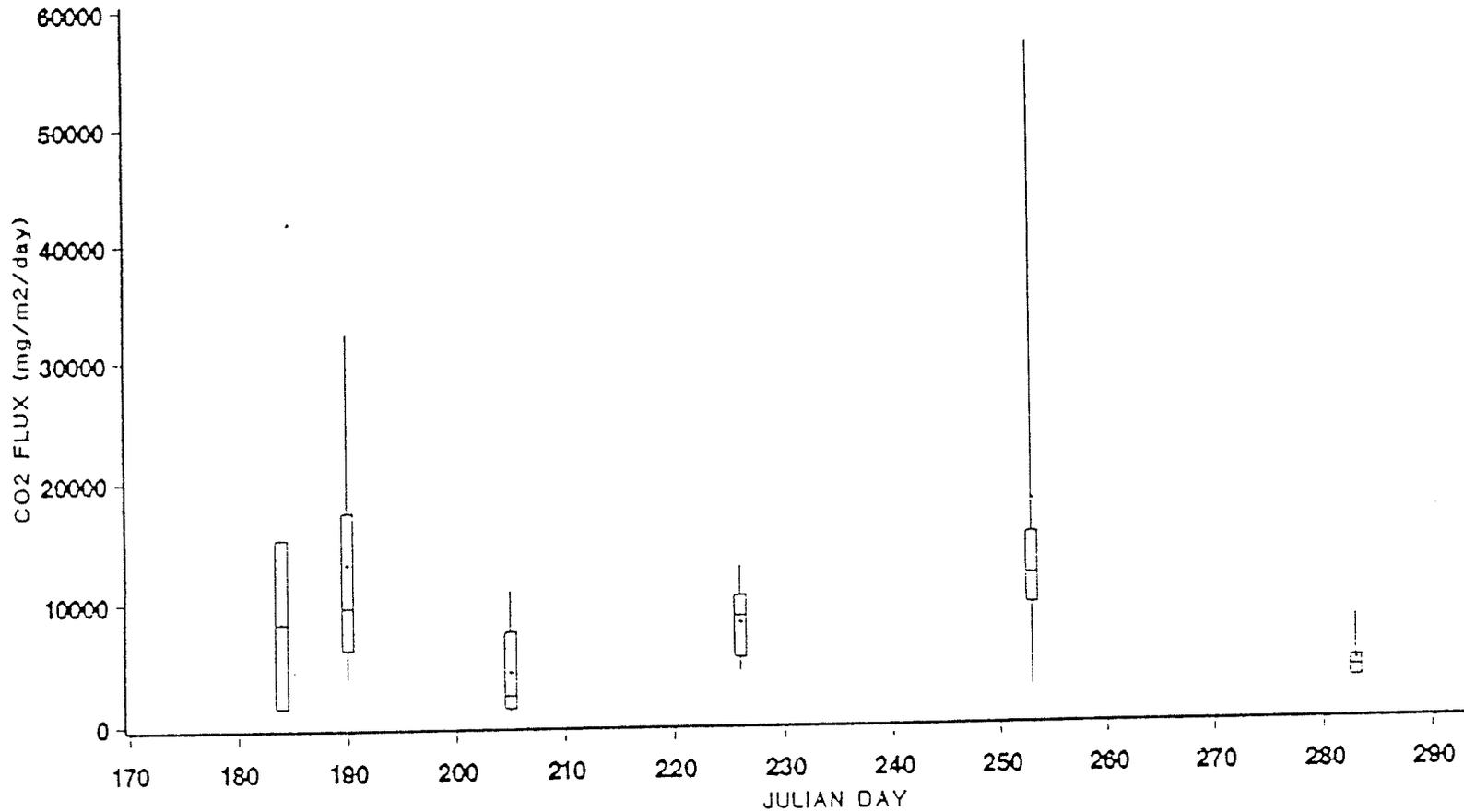


Figure 24b. Interior Fen Seasonal CO₂ Flux.
(Only includes data from days on which a complete diel sampling was done, July-October, 1990). See Figure 6a for details.

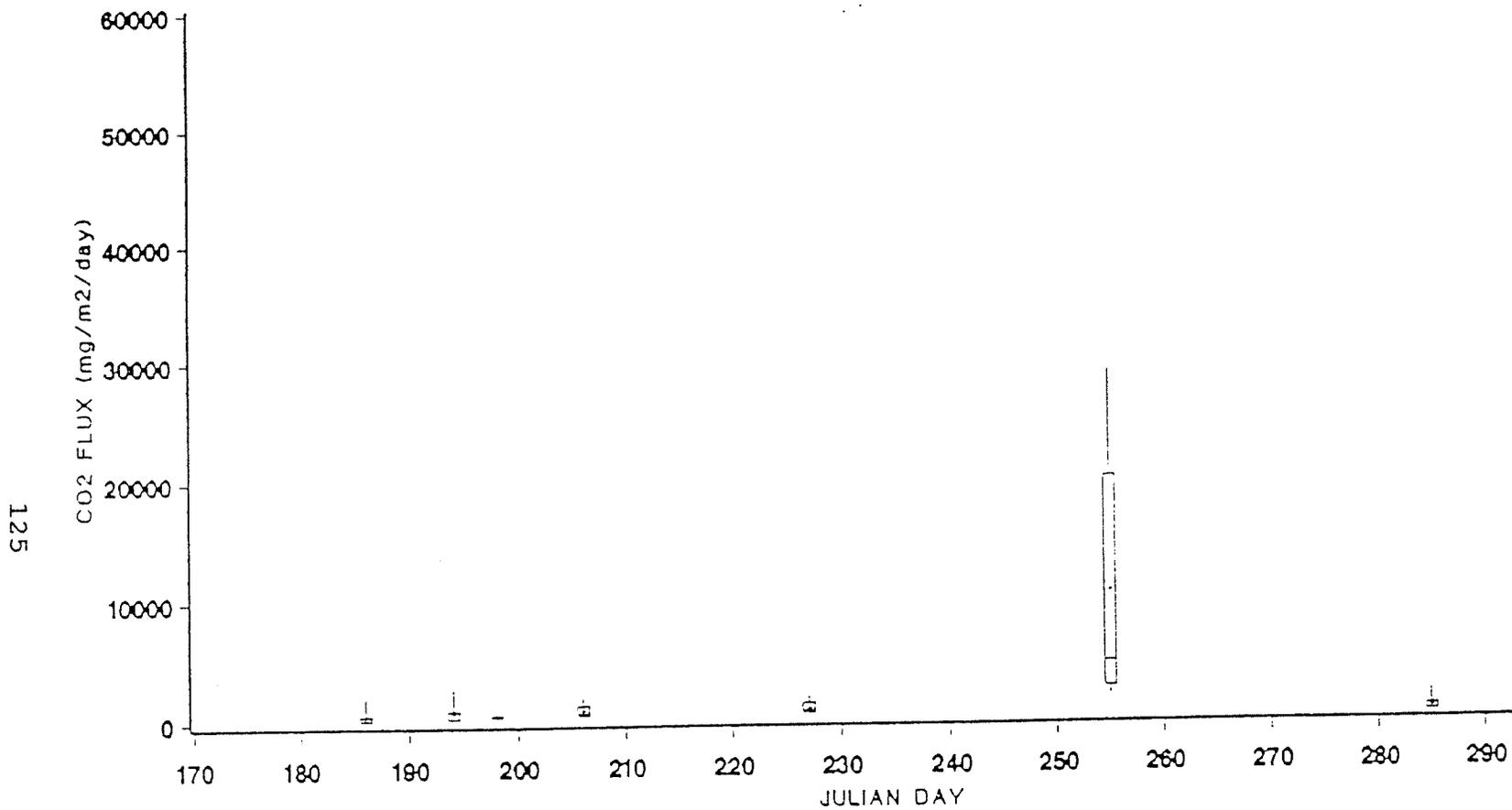


Figure 24c. Kinosheo Lake Bog Seasonal CO₂ Flux.
 (Only includes data from days on which a complete diel sampling was done, July-October, 1990). See Figure 6a for details.

Table 17. Daily Methane Flux in the Hudson's Bay Lowlands (June-October, 1990)(mg CH₄/m²/d).

Location	Date	Average CH ₄ Flux	Median CH ₄ Flux	Minimum CH ₄ Flux	Maximum CH ₄ Flux
Coastal Fen	July 09	170	85	40	770
	July 24	75	56	16	180
	Aug. 14	108	56		
	Sept. 10	244	200	90	570
	Oct. 10	160	106	45	600
Interior Fen	July 9	200	190	100	300
	July 24	57	50	30	100
	Aug. 14	120	120	70	170
	Sept. 10	320	210	150	690
	Oct. 10	130	60	30	440
Kinosheo Lake	July 5	22	9	2	90
	July 13	15	12	1	40
	July 17	16	17	3	30
	July 25	50	30	4	130
	Aug. 15	50	20	3	150
	Sept. 12	280	180	13	930
	Oct. 12	10	4.2	2	50

Table 18. Daily CO₂ Flux in the Hudson's Bay Lowlands (June-October, 1990)(mg CH₄/m²/d).

Location	Date	Average CO ₂ Flux	Median CO ₂ Flux	Minimum CO ₂ Flux	Maximum CO ₂ Flux
Coastal Fen	July 09	13000	8400	900	50000
	July 24	4000	2400	2300	13000
	Aug. 14	14000	14000		
	Sept. 10	15000	12800	4200	25000
	Oct. 10	7900	6800	1200	18000
Interior Fen	July 9	13000	6900	3700	32000
	July 24	4200	2300	750	11000
	Aug. 14	4200	8700	4000	13000
	Sept. 10	18000	12000	2500	57000
	Oct. 10	4300	3800	2900	8000
Kinosheo Lake	July 5	590	480	140	2100
	July 13	840	360	330	2800
	July 17	500	490	380	660
	July 25	900	660	360	2000
	Aug. 15	930	700	300	2000
	Sept. 12	10000	4600	1800	30000
	Oct. 12	440	190	80	1900

aqueous CO₂ could account for approximately one-half of the total DIC. At the Kinosheo Lake bog aqueous CO₂ was responsible for almost all of the DIC in the water. Therefore as the CO₂ concentration declined in the fall the DIC concentration also decreased.

VI Flux of Methane and Carbon Dioxide to the Atmosphere

As with concentrations, the instantaneous flux fluctuated during the day (Figure 21 and 22). The daily flux was calculated from the integration of the diel data sets. The daily flux of both gases was always positive, that is, from the water to the atmosphere, and very large in magnitude.

As with the dissolved gas concentrations, the flux of both CH₄ and CO₂ exhibited a considerable variability among the individual ponds (Appendix Tables A2-A33). The fluxes calculated for all the ponds at each site were compiled, computing means, medians, upper and lower quartiles for each day on which a diel sampling was done (Figure 23a, b, c, Figure 24 a, b, c, Table 17 and Table 18).

The magnitude of the CH₄ flux showed a seasonal trend. The Coastal Fen CH₄ flux averaged approximately 100 (82, 18-770) mg CH₄/m²/day⁶ during we months of July and August

⁶ Authors Note: Although it would be more appropriate to present the flux in units of $\mu\text{mol}/\text{m}^2/\text{day}$, it was decided that in order to facilitate the comparison of data amongst the groups participating in the Northern Wetland Studies that all daily flux data would be presented as mg/m²/day and instantaneous flux as

(Figure 23a and Table 17). CH_4 flux peaked in September at a rate of 240 (200, 90-570) $\text{mg CH}_4/\text{m}^2/\text{day}$. The rate of flux had declined by mid-October to 160 (106, 45-600) $\text{mg CH}_4/\text{m}^2/\text{day}$.

The Interior Fen exhibited a similar seasonal pattern, (Figure 23b and Table 17). The rate of CH_4 flux for July and August was more variable than that of the Coastal Fen, ranging from 232 (190, 85-380) $\text{mg CH}_4/\text{m}^2/\text{day}$ at the beginning of July to a low of 57 (50, 31-110) $\text{mg CH}_4/\text{m}^2/\text{day}$ at the end of July. The rate of flux increased during August and peaked in September at 320 (210, 150-690) $\text{mg CH}_4/\text{m}^2/\text{day}$. By mid-October the rate had dropped to 130 (60, 30-440) $\text{mg CH}_4/\text{m}^2/\text{day}$.

The bog site at Kinosheo Lake also showed a seasonal CH_4 flux pattern but absolute rates were much lower than those seen at the two fen sites (Table 17). The average rate of flux during the months of July and August was approximately 30 (14, 1.4-150) $\text{mg CH}_4/\text{m}^2/\text{day}$. The September peak was very pronounced at 280 (180, 13-930) $\text{mg CH}_4/\text{m}^2/\text{day}$ but by October the rate of CH_4 flux fell to 10 (4.2, 2-50) $\text{mg CH}_4/\text{m}^2/\text{day}$ (Figure 23c and Table 17).

The rate of CO_2 flux showed a similar seasonal pattern, however, it was nearly 2 orders of magnitude higher than that of CH_4 (Table 18).

At the Coastal Fen, CO_2 flux was high at the beginning of July with an average rate of 13000 (8400, 900-50000) $\text{mg CO}_2/\text{m}^2/\text{day}$. The rate of flux fell to a minimum of 4000 (2400,

$\mu\text{g}/\text{m}^2/\text{sec}$.

2300-13000) mg CO₂/m²/day by the end of July. The rate of CO₂ flux increased through August and peaked in September at an average rate of 15000 (13000, 4200-25000) mg CO₂/m²/day. By October this rate had declined to 7900 (6800, 1200-18000) mg CO₂/m²/day (Figure 24a and Table 18).

The Interior Fen pattern of CO₂ flux was similar to that of the Coastal Fen (Figure 24b and Table 18) being higher early in July with an average rate of 13000 (6900, 3700-32000) mg CO₂/m²/day, dropping to 4200 (2300, 750-11000) mg CO₂/m²/day by the end of the month. During August the rate of CO₂ flux increased and peaked in September at 18000 (12000, 2600-57000) mg CO₂/m²/day. In mid-October the rate of flux was one quarter of the maximum rate, with a CO₂ flux rate of 4300 (3800, 2900-8000) mg CO₂/m²/day.

The rate of CO₂ flux from the ponds within the bog site at Kinosheo Lake was only 600 mg CO₂/m²/day during July and August. The peak in September had an average flux of 10000 (4600, 1800-29000) mg CO₂/m²/day. By October the rate of CO₂ flux was back down to 440 (190, 80-690) mg CO₂/m²/day (Figure 24c and Table 18).

As mentioned above, the concentrations changed during the day, the flux of CH₄ and CO₂ varied throughout the day (Figure 21 and 22). The highest flux rates were usually observed during the late morning although on some occasions this did not occur. During the day a wide range of fluxes were seen at all times, especially around mid day. In contrast, the few

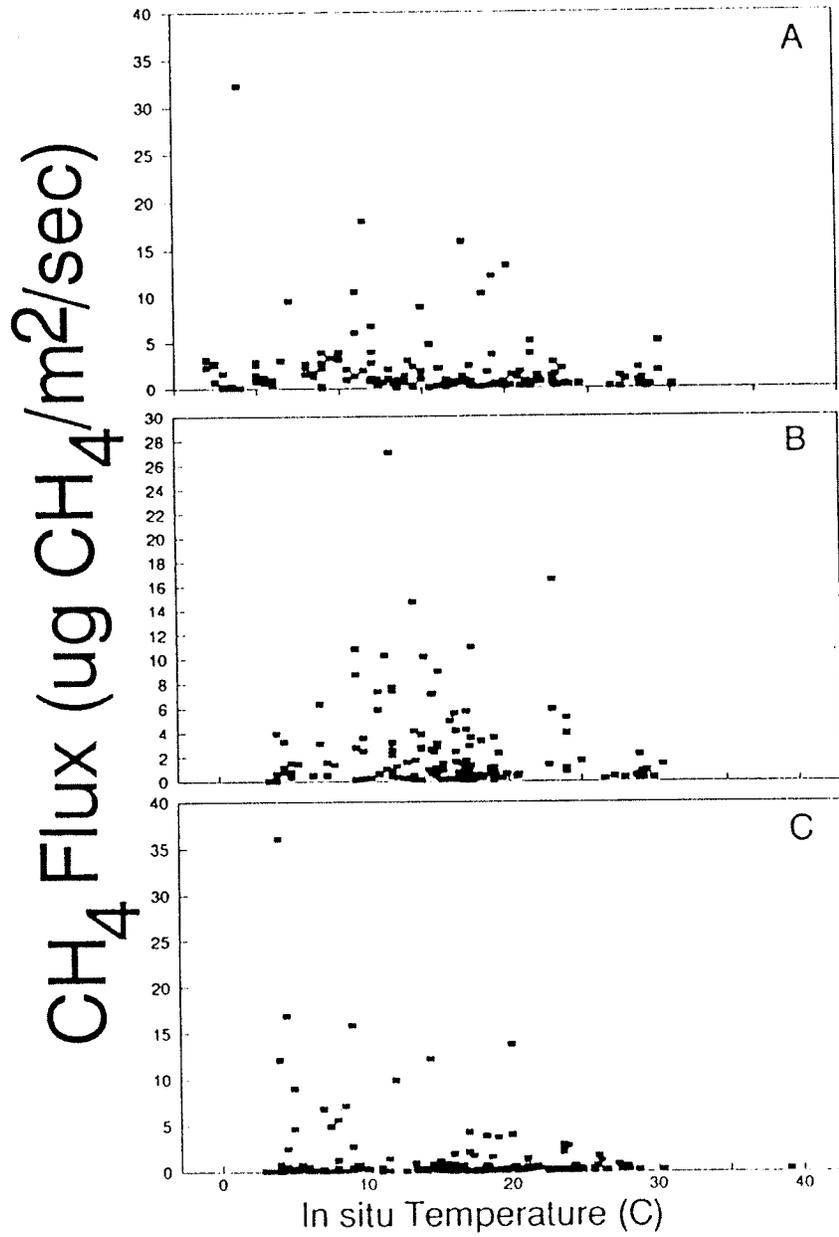


Figure 25. Methane Flux vs *in situ* water Temperature.
 A) Coastal Fen B) Interior Fen C) Kinosheo Lake Bog
 (Includes all instantaneous flux data, June-October, 1990).

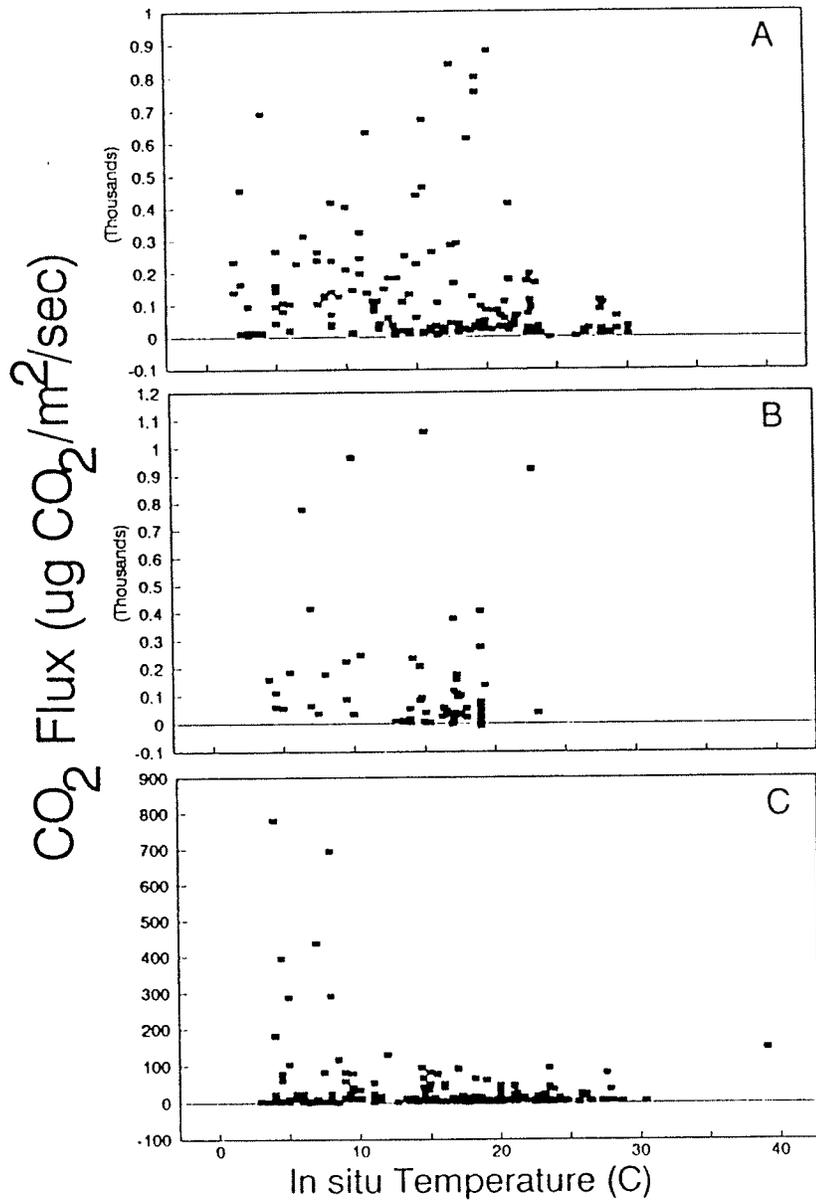


Figure 26. Carbon Dioxide Flux vs *in situ* water Temperature
 A) Coastal Fen B) Interior Fen and C) Kinosheo Lake Bog.
 (Includes all instantaneous flux data, June-October, 1990).

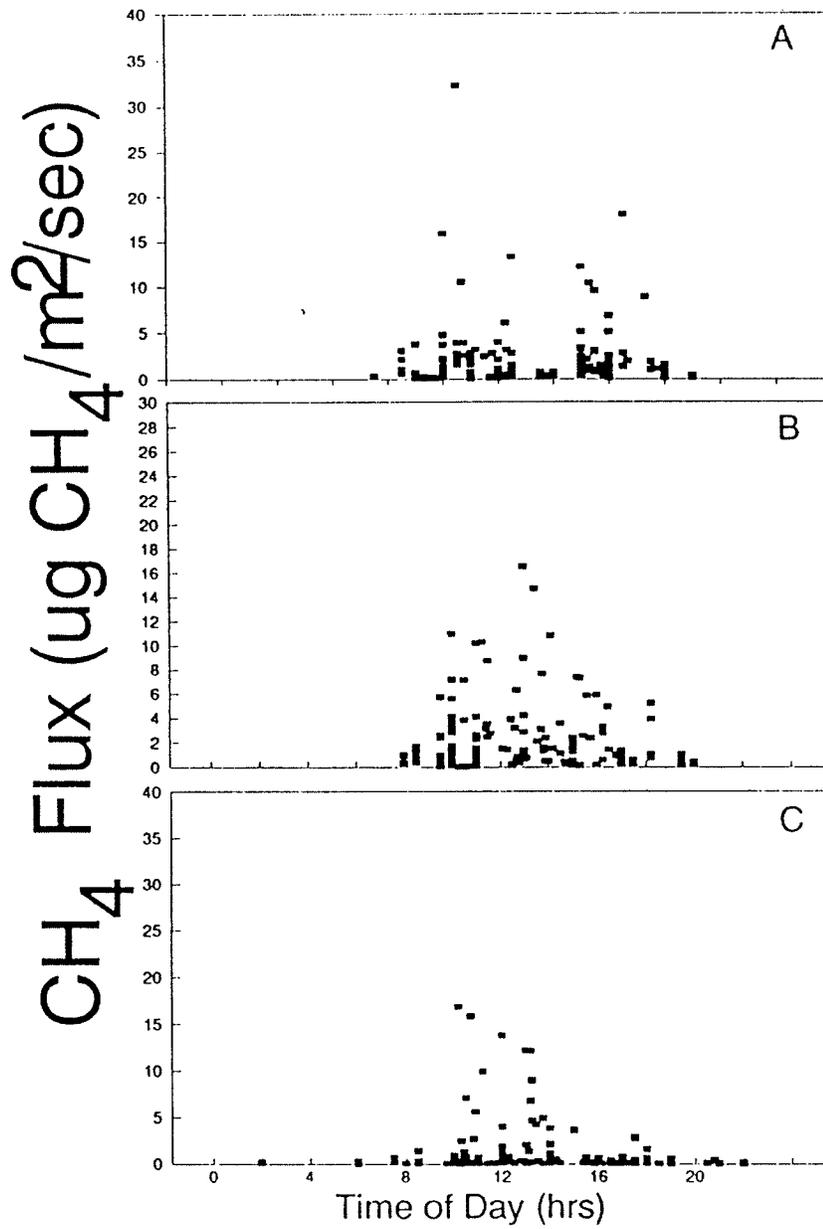


Figure 27. Methane Flux vs Time of Day.
 A) Coastal Fen B) Interior Fen and C) Kinosheo Lake.
 (Includes all instantaneous flux data, June-October, 1990).

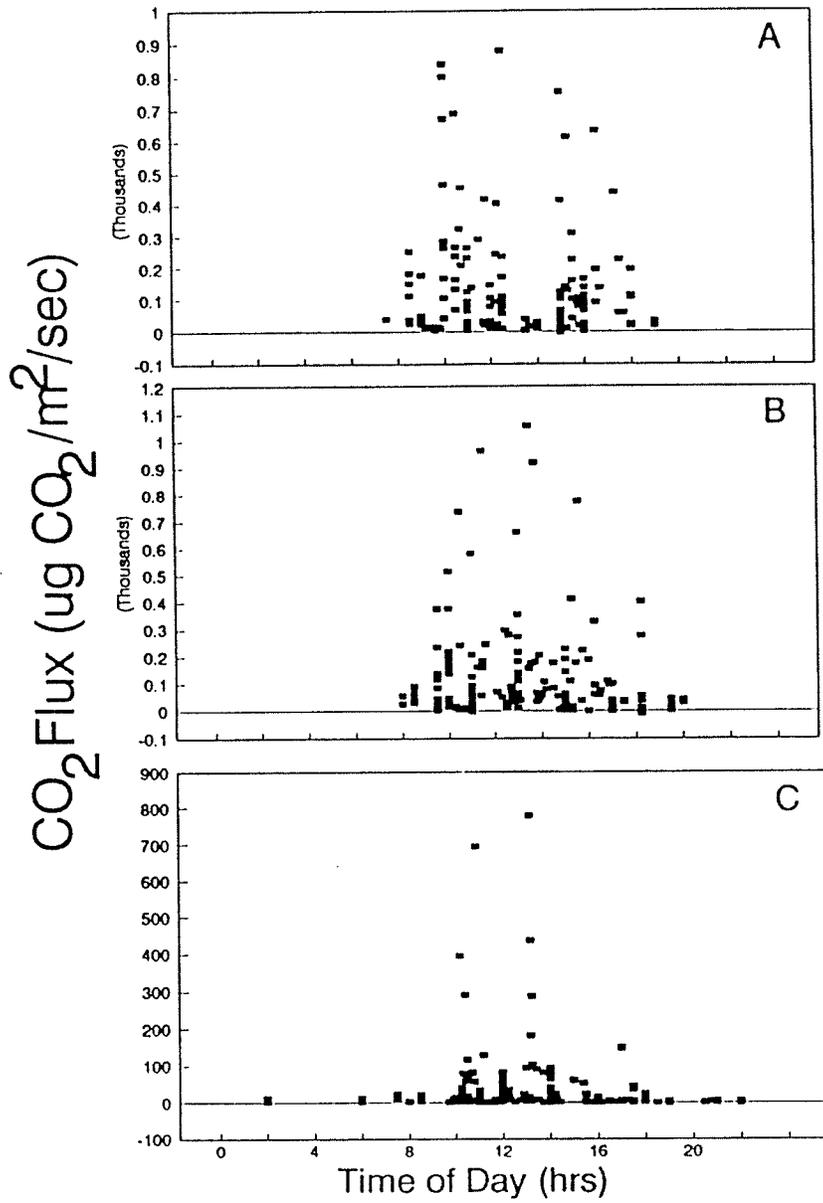


Figure 28. Carbon Dioxide Flux vs Time of Day.
 A) Coastal Fen B) Interior Fen and C) Kinosheo Lake.
 (Includes all instantaneous flux data, June-October, 1990).

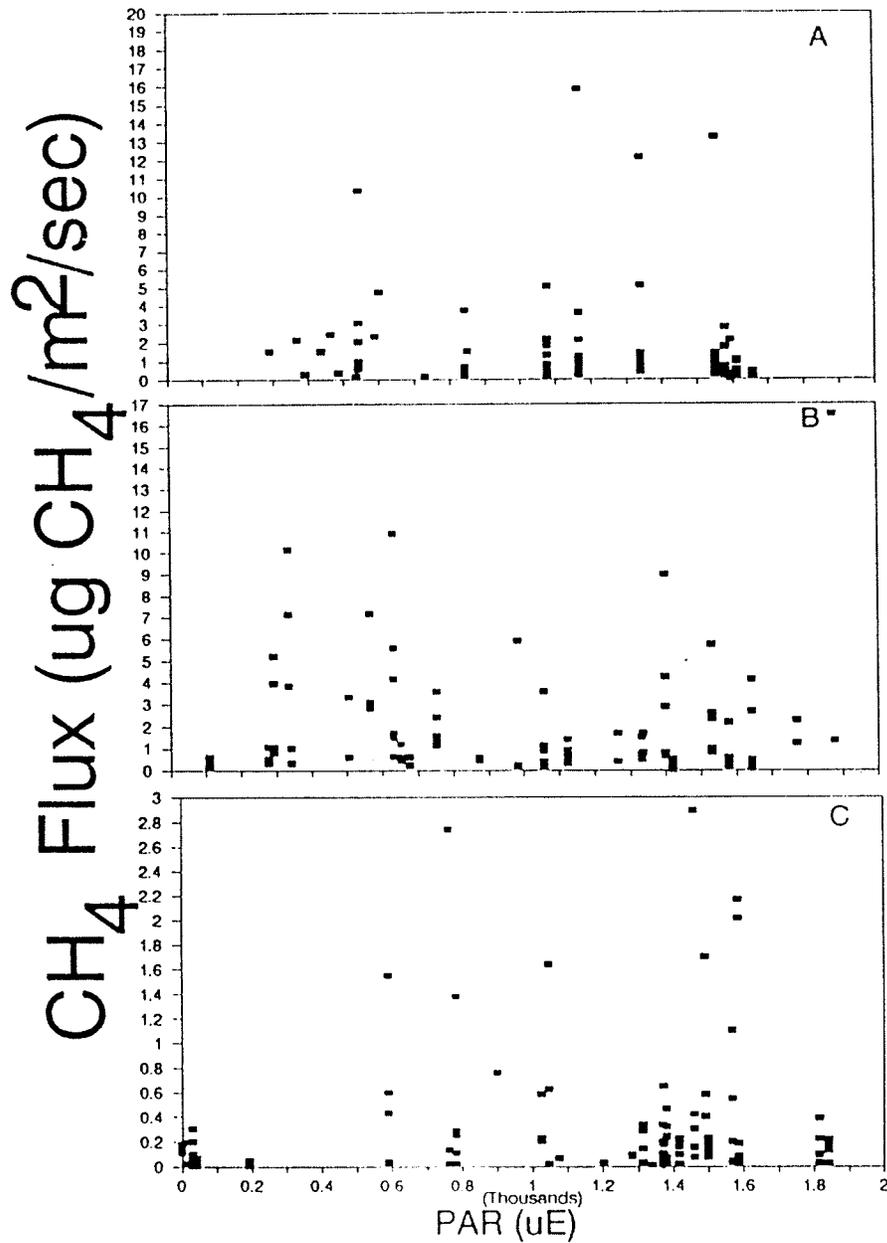


Figure 29. Methane Flux vs PAR.
 A) Coastal Fen B) Interior Fen and C) Kinosheo Lake.
 (Includes all instantaneous flux data, June-October, 1990).

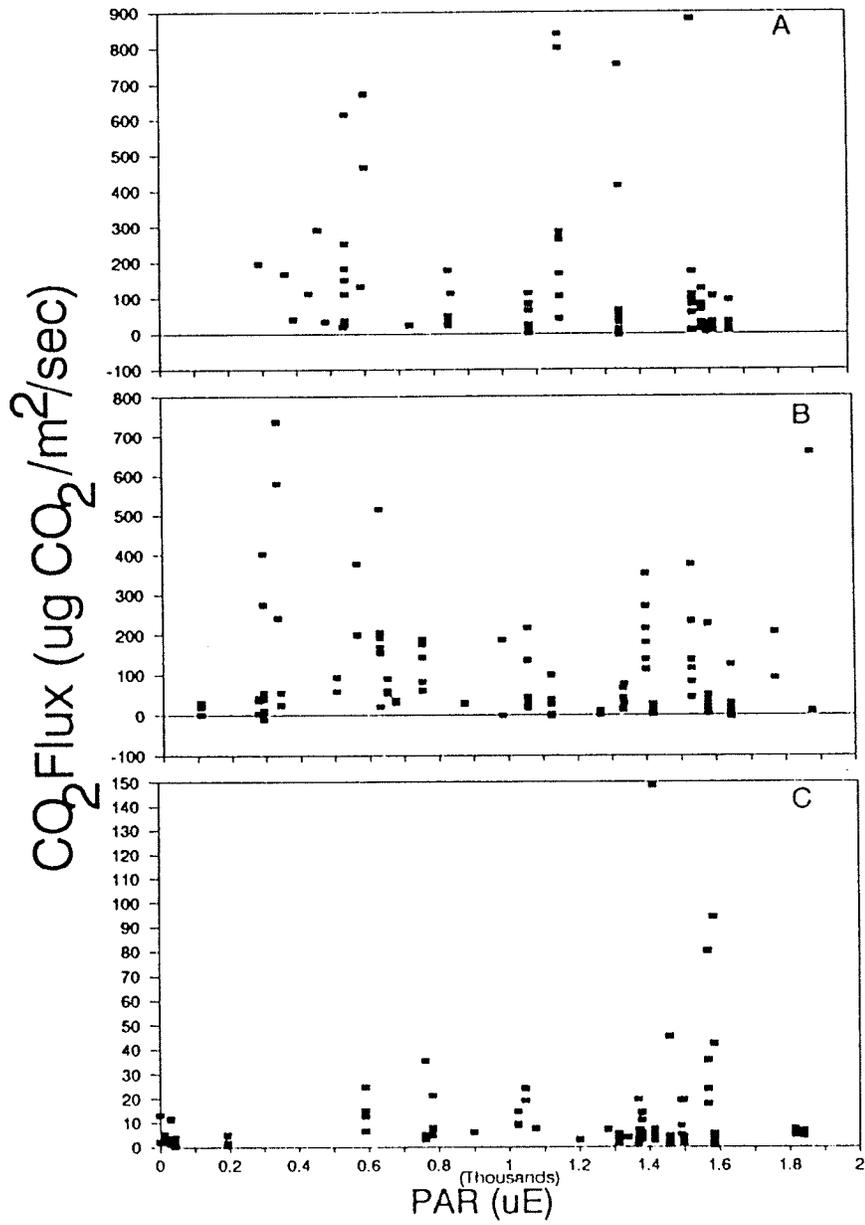


Figure 30. Carbon Dioxide Flux vs PAR.
 A) Coastal Fen B) Interior Fen and C) Kinosheo Lake.
 (Includes all instantaneous flux data, June-October, 1990).

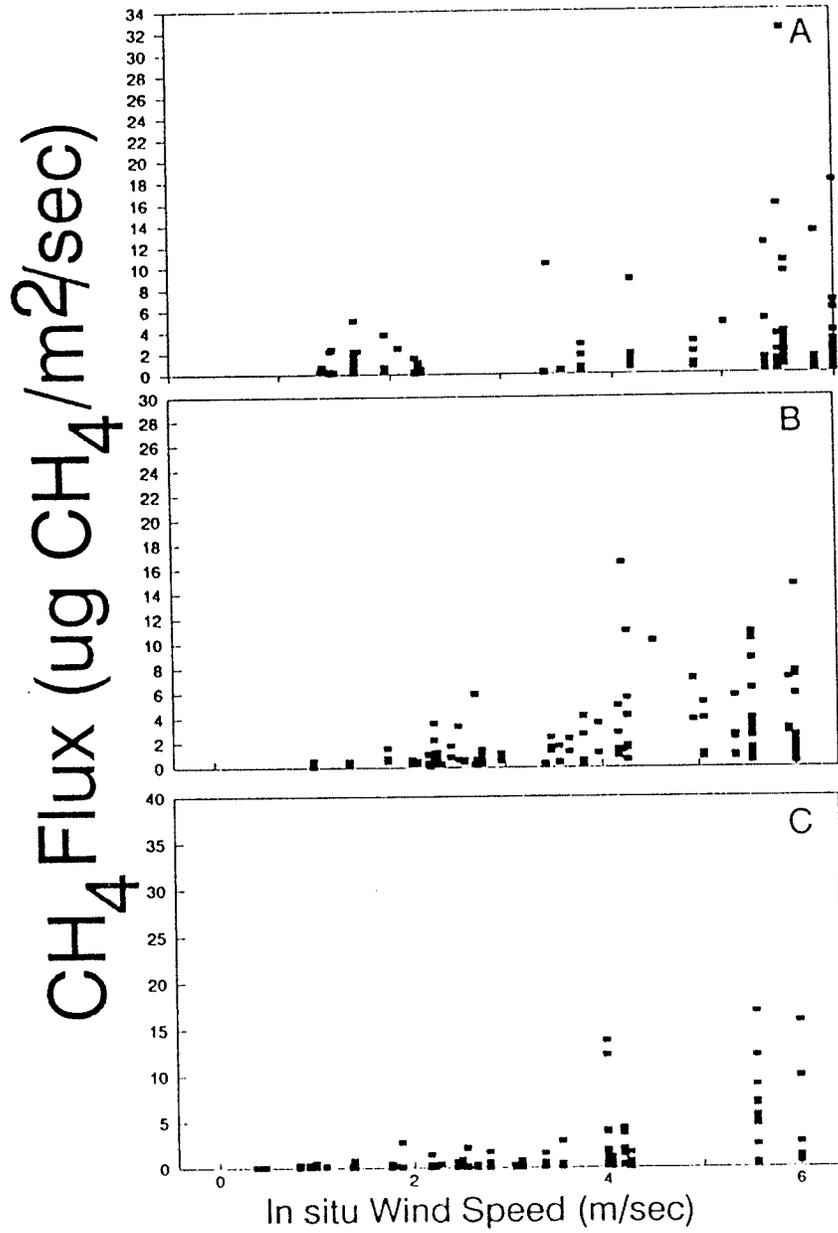


Figure 31. Methane Flux vs. Wind Speed.
 A) Coastal Fen B) Interior Fen and C) Kinosheo Lake.
 (Includes all instantaneous flux data, June-October, 1990).

Table 19a. Kinosheo Lake Bog Mean Pond Instantaneous CH₄ Flux ($\mu\text{g CH}_4/\text{m}^2/\text{sec}$) on Diel Sampling Days.

Date	1	2	3	4	5	6	7	8	9	10
July 5	0.03	1.49	Dry	Dry	Dry	0.11	0.06	0.11	Dry	0.17
July 13	0.02	Dry	Dry	Dry	Dry	0.16	0.09	0.50	Dry	0.18
July 17	0.02	Dry	Dry	Dry	Dry	0.34	0.09	Dry	Dry	0.29
July 25	0.05	Dry	Dry	Dry	Dry	1.1	0.20	Dry	Dry	0.53
Aug 15	0.06	Dry	Dry	Dry	Dry	3.1	0.32	Dry	Dry	0.27
Sept 12	0.03	2.9	Dry	Dry	Dry	3.8	3.2	1.4	Dry	2.8
Oct. 12	0.02	0.04	0.05	0.04	0.03	0.13	0.04	0.23	0.09	0.62

Table 19b. Order of Ponds (highest to lowest CH₄ flux)

Date	Order of Ponds (highest → lowest)
July 5	2 > 10 > 8,6 > 7 > 1
July 13	8 > 10 > 6 > 7 > 1
July 17	6 > 10 > 7 > 1
July 25	6 > 10 > 7 > 1
Aug 15	6 > 7 > 10 > 1
Sept 12	6 > 7 > 10 > 2 > 8 > 1
Oct 12	10 > 8 > 6 > 9 > 7,4,2 > 3 > 5 > 1

Table 20a. Coastal Fen Mean Pond Instantaneous CH₄ Flux ($\mu\text{g CH}_4/\text{m}^2/\text{sec}$) on Diel Sampling Days.

Date	11	12	13	14	15	16	17	18
July 9	0.89	0.93	11	1.7	0.74	0.96	0.04	2.7
July 24	1.9	0.28	0.68	0.33	0.16	0.48	1.93	Dry
Aug 14	Dry	Dry	Dry	1.7	Dry	Dry	Dry	Dry
Sept 10	3.3	1.1	9.5	1.7	1.7	3.0	Dry	Dry
Oct 10	1.3	1.5	1.1	2.0	0.65	1.4	0.69	2.0

Table 20b. Order of Ponds (highest to lowest CH₄ flux)

Date	Order of Ponds (highest → lowest)
July 9	13 > 18 > 14 > 16 > 12 > 11 > 15 > 17
July 24	17 > 11 > 13 > 16 > 14 > 12 > 15
Aug 14	14
Sept 10	13 > 11 > 16 > 14,15 > 12
Oct 10	18 > 14 > 12 > 16 > 11 > 13 > 17 > 15

Table 21a. Interior Fen Mean Pond Instantaneous CH₄ Flux ($\mu\text{g CH}_4/\text{m}^2/\text{sec}$) on Diel Sampling Days.

Date	19	20	21	22	23	24
July 3			5.2	1.2		
July 9	1.6	1.8	2.8	1.4	3.6	3.6
July 24	0.60	1.7	5.6	11	4.2	1.5
Aug 14	Dry	2.8	2.1	1.6	2.7	1.3
Sept 10	1.6	1.7	5.1	7.5	7.9	1.7
Oct 10	4.5	0.80	1.2	1.3	0.88	1.2

Table 21b. Order of Ponds (highest to lowest CH₄ flux)

Date	Order of Ponds (highest → lowest)
July 3	21 > 22
July 9	24,23 > 21 > 20 > 19 > 22
July 24	22 > 21 > 23 > 20 > 24 > 19
Aug 14	20 > 23 > 21 > 22 > 24
Sept 10	23 > 22 > 21 > 24,20 > 19
Oct 10	19 > 22 > 24,21 > 23 > 20

Table 22a. Kinosheo Lake Bog Mean Pond Instantaneous CO₂ Flux ($\mu\text{g CO}_2/\text{m}^2/\text{sec}$) on Diel Sampling Days.

Date	1	2	3	4	5	6	7	8	9	10
July 5	3.6	39	Dry	Dry	Dry	2.9	3.1	5.6	Dry	2.3
July 13	4.7	Dry	Dry	Dry	Dry	4.2	5.1	37	Dry	4.2
July 17	4.1	Dry	Dry	Dry	Dry	9.1	4.9	Dry	Dry	5.1
July 25	4.9	Dry	Dry	Dry	Dry	18	7.6	Dry	Dry	10
Aug 15	5.6	Dry	Dry	Dry	Dry	34	10	Dry	Dry	11
Sept 12	20	95	Dry	Dry	Dry	32	55	270	Dry	300
Oct. 12	0.96	2.0	1.3	4.9	8.9	1.7	1.3	8.8	2.4	21

Table 22b. Order of Ponds (highest to lowest CO₂ flux)

Date	Order of Ponds (highest → lowest)
July 5	2 > 8 > 1 > 7 > 6 > 10
July 13	8 > 1 > 7 > 10,6
July 17	6 > 10 > 7 > 1
July 25	6 > 10 > 7 > 1
Aug 15	6 > 7 > 10 > 1
Sept 12	10 > 8 > 2 > 7 > 6 > 1
Oct 12	10 > 5 > 8 > 4 > 9 > 2 > 6 > 7,3 > 1

Table 23a. CoastalFen Mean Pond Instantaneous CO₂ Flux (μg CO₂/m²/sec) on Diel Sampling Days.

Date	11	12	13	14	15	16	17	18
July 9	17	90	680	139	159	95	44	380
July 24	38	12	15	22	24	20	120	Dry
Aug 14	Dry	Dry	Dry	290	Dry	Dry	Dry	Dry
Sept 10	59	120	360	140	250	122	Dry	Dry
Oct 10	120	78	290	210	63	120	31	92

Table 23b. Order of Ponds (highest to lowest CO₂ flux)

Date	Order of Ponds (highest → lowest)
July 9	13 > 18 > 15 > 14 > 16 > 12 > 17 > 11
July 24	17 > 11 > 15 > 14 > 16 > 13 > 12
Aug 14	14
Sept 10	13 > 15 > 14 > 16 > 12 > 11
Oct 10	13 > 14 > 16,11 > 18 > 12 > 15 > 17

Table 24a. Interior Fen Mean Pond Instantaneous CO₂ Flux (μg CO₂/m²/sec) on Diel Sampling Days.

Date	19	20	21	22	23	24
July 3			230	26		
July 9	150	170	350	70	160	100
July 24	20	40	130	11	19	81
Aug 14	Dry	170	220	65	140	84
Sept 10	26	160	610	97	340	130
Oct 10	55	51	110	86	38	100

Table 24b. Order of Ponds (highest to lowest CO₂ flux)

Date	Order of Ponds (highest → lowest)
July 3	21 > 22
July 9	21 > 20 > 23 > 19 > 24 > 22
July 24	21 > 24 > 20 > 19 > 23 > 22
Aug 14	21 > 20 > 23 > 24 > 22
Sept 10	21 > 23 > 20 > 24 > 22 > 19
Oct 10	21 > 24 > 22 > 19 > 20 > 23

night time flux measurements were uniformly low. No obvious relationship was observed between the instantaneous rate of flux of either CH_4 or CO_2 and *in situ* temperature (Figure 25 and 26), time of day (Figure 27 and 28) and PAR (Figure 29 and 30). The data set was also divided into individual ponds to examine relationships with the above physical parameters. There were no relationships found. If the gas flux is plotted against wind speed there was an obvious relationship, which is expected because flux is a function of both gas concentration and windspeed (Crusius and Wanninkhof 1991) (Figures 2 and 31).

Although there was a large variation in the flux rates between the individual ponds and an apparent lack of any strong correlation between flux rate and any single controlling factor of CH_4 and CO_2 concentration, it is important to understand that, as with concentrations, the flux from these ponds was not random. At each of the three sampling sites there were ponds that always had high rates of flux and others that were always low (Tables 19-21; 22-24). For example Pond 1 at the Kinosheo site (which is situated on an old beach ridge and lacked a thick organic sediment) was always the lowest producer of CH_4 or CO_2 on any given day and Ponds 8 and 10 were usually the highest producers.

It is also important to note that fluxes and concentration did not vary randomly within a pond. Both fluxes and concentration usually followed a discernable pattern over

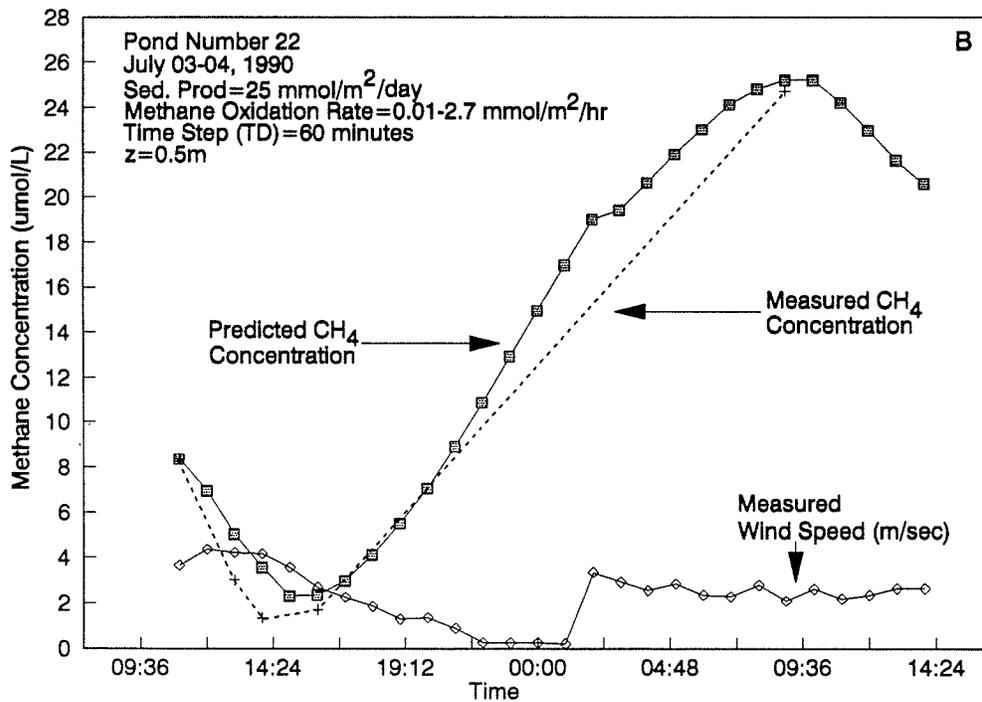
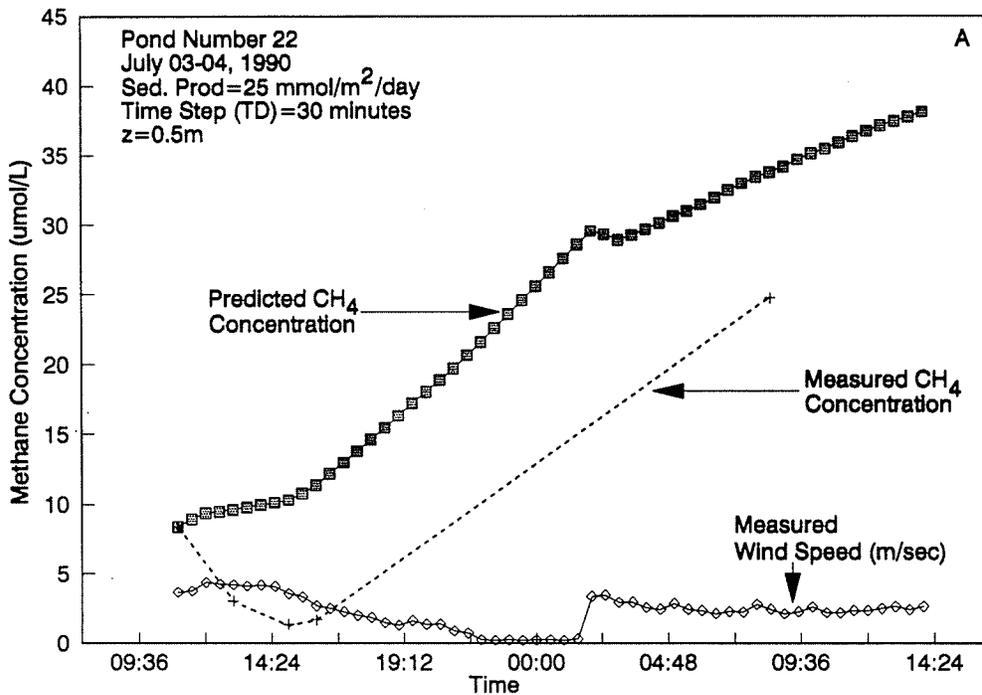


Figure 32. Predicted CH₄ Concentrations.
 A) Constant sediment CH₄ release rate B) As (A) but with CH₄ oxidation added.

a 24 hour period, although the factors controlling the pattern were not immediately apparent.

VII Computer Modelling of CH₄ and CO₂ Concentration

As Section VI shows there was no single physical parameter that dominated the control of gas flux from the ponds in the HBL. In Section VI, I examined the whole data set for each site, as well as individual ponds, looking at only one factor at a time. With the computer modelling (Hesslein et al. 1991) I was able to look at how several factors at once might explain the concentration changes seen in a single pond over a period of one day.

I examined two types of scenarios: 1) with a constant sediment production rate, a measured starting concentration and measured wind speed throughout the day; 2) a more complex scenario, with all of the data used in scenario 1, but with methane oxidation rate (for CH₄) or algal photosynthetic and respiration rates (for CO₂) introduced.

Figure 32a demonstrates the simplest scenario and shows the predicted and measured CH₄ concentration with a sediment flux rate of 10 mmol CH₄/m²/day at observed wind speeds. As the Figure 32a shows, at a constant sediment flux rate, the predicted CH₄ concentrations did not have as strong a diel change pattern as did the actual concentrations. The influence of wind speed on the predicted concentrations was only minor.

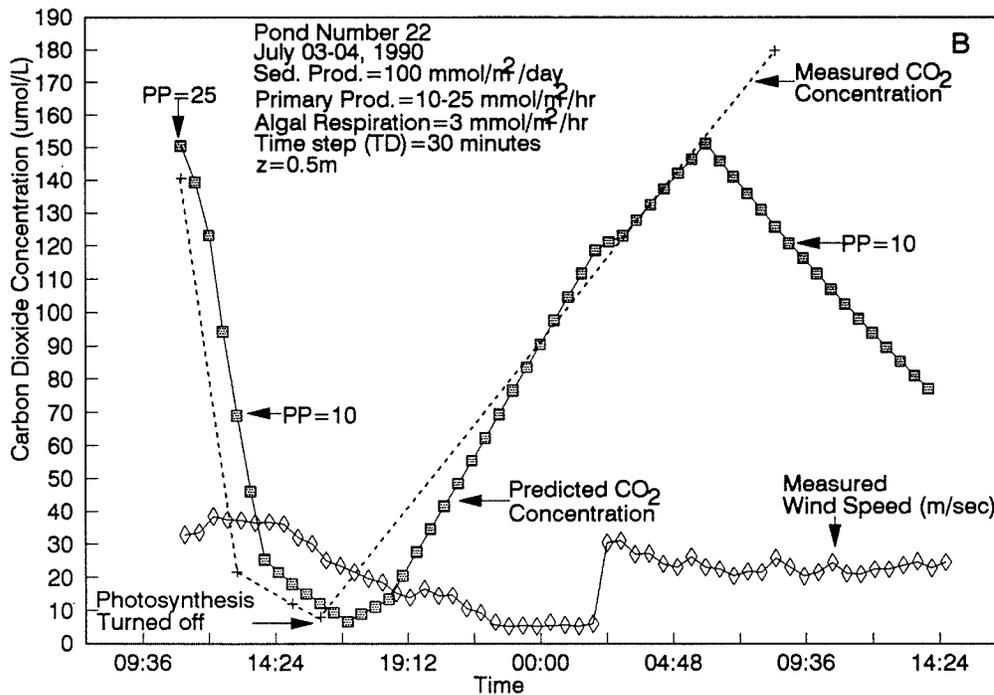
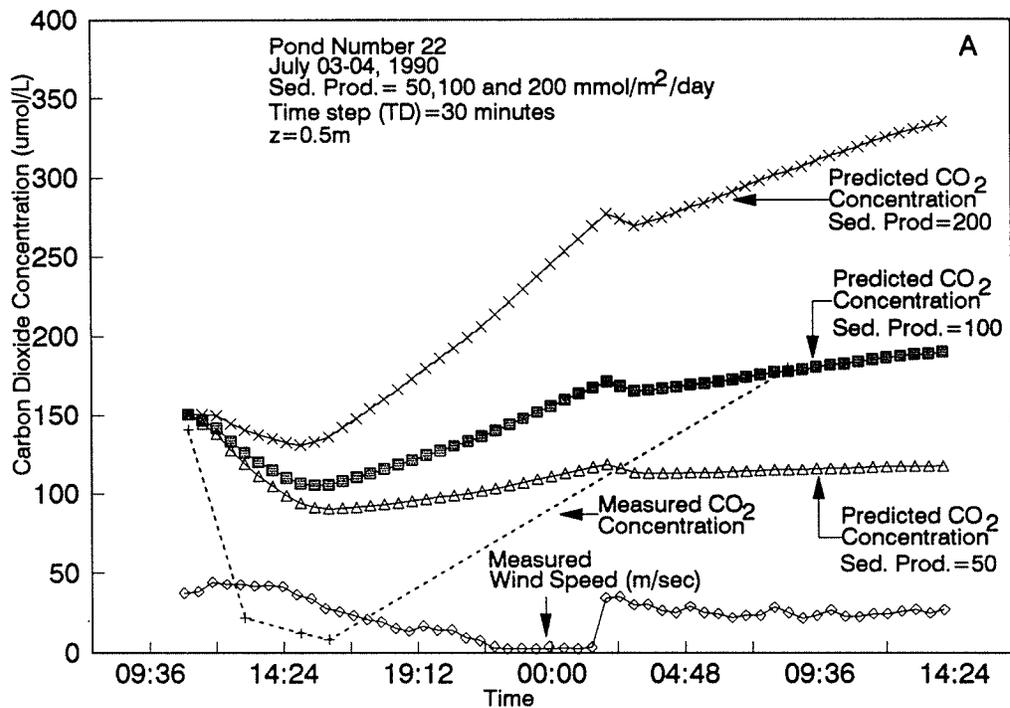


Figure 33. Predicted CO₂ Concentrations.

A) Constant sediment release rate and measured wind speed
 B) As with (A) but with algal photosynthesis and respiration added.

Note: Wind speed is at 10x.

Scenario 2 shows how the fit of the predicted CH_4 concentration to the measured CH_4 concentration can be improved if a CH_4 oxidation rate of $1 \text{ mmol CH}_4/\text{m}^2/\text{hr}$ is factored in during daylight hours (Figure 32b). Increased CH_4 oxidation during daylight hours has been shown by King (1990) to occur as a response of CH_4 oxidizers (at the sediment water interface) to the availability of oxygen from photosynthesis. Therefore, in the model CH_4 oxidation was started at 11 a.m. (the time of the first sample) and shut off at 6 p.m. and started again at 7 a.m. the next morning.

The CH_4 oxidation value of $1 \text{ mmol CH}_4/\text{m}^2/\text{hr}$ was chosen as it provided the best fit of the predicted concentrations to the observed concentrations. Higher and lower CH_4 oxidation rates were also tested with the model but the fit of the line was not as good. The fit of the predicted line could possibly be improved if the CH_4 oxidation was turned on as a function of light (hence the photosynthetic rate). This was not possible to do at the time the computer modeling was carried out.

The simplest scenario for predicting the CO_2 concentration (Figure 33a) shows what the predicted CO_2 concentration would be if the concentration is controlled by wind driven gas exchange to the atmosphere and a constant sediment release rate of CO_2 ($50, 100$ or $200 \text{ mmol}/\text{m}^2/\text{day}$) at observed wind speeds. As with CH_4 , there is only a minor influence of the wind driven gas exchange on the predicted concentration of CO_2 . Clearly, gas exchange alone does not

control the concentrations in the model nor does changing the constant sediment production rate. If a photosynthetic rate of 10-25 mmol CO₂/m²/hr (120-300 mg C fixed/m²/hr) and an algal respiration rate of 3 mmol CO₂/m²/hr is factored into the model the fit of the predicted CO₂ concentration is much closer to the measured CO₂ concentration (Figure 33b). Two different photosynthetic rates were used to simulate the increase in photosynthesis during peak light (i.e. between the hours of 10 a.m. and 2 p.m.). As with the CH₄ modeling, it was not possible to have a light function controlling the photosynthetic rates which would make the fit of the predicted line more realistic. The photosynthetic and respiration rates shown here were developed from the data for benthic algal communities of ponds in Delta Marsh, Manitoba (Robinson pers. com.)⁷ which is approximately at the same latitude as the Northern Wetlands Study site and therefore has similar light regimes.

The computer model results suggest that the concentrations of CH₄ and CO₂ within the ponds are controlled by a combination of biological production and consumption as well as physical processes such as wind speed.

VIII Ebullitive Flux

⁷Dr. G. Robinson, Dept. of Botany, University of Manitoba, Winnipeg, Manitoba, R3T 2N2.

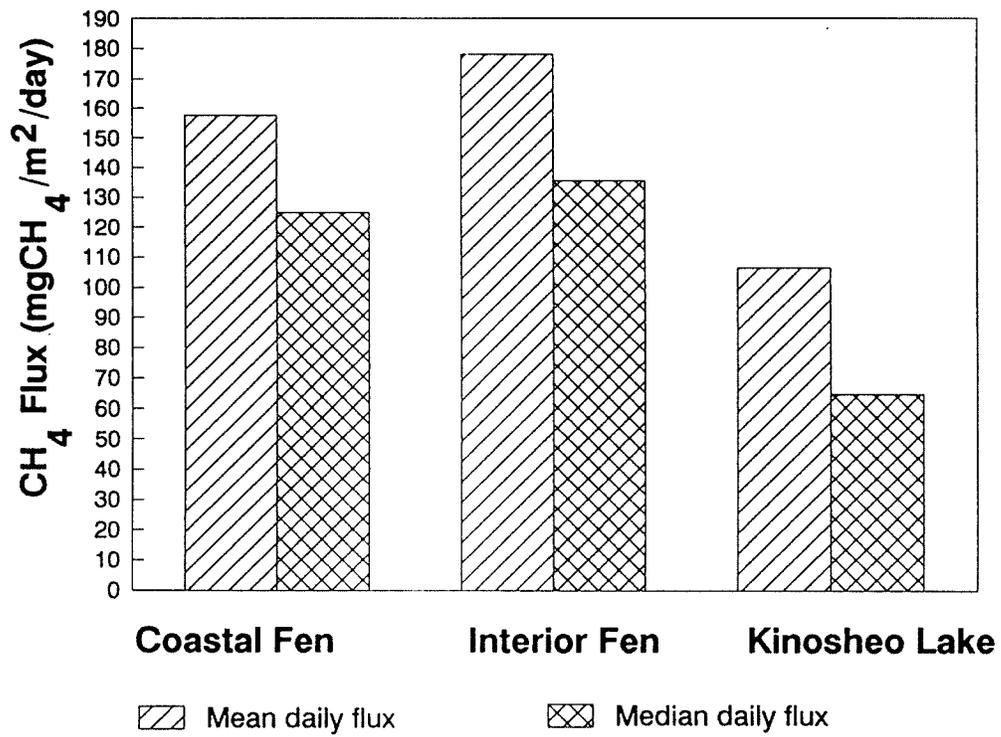


Figure 34. Time Weighted CH₄ Flux.
(Calculated from diel data only)

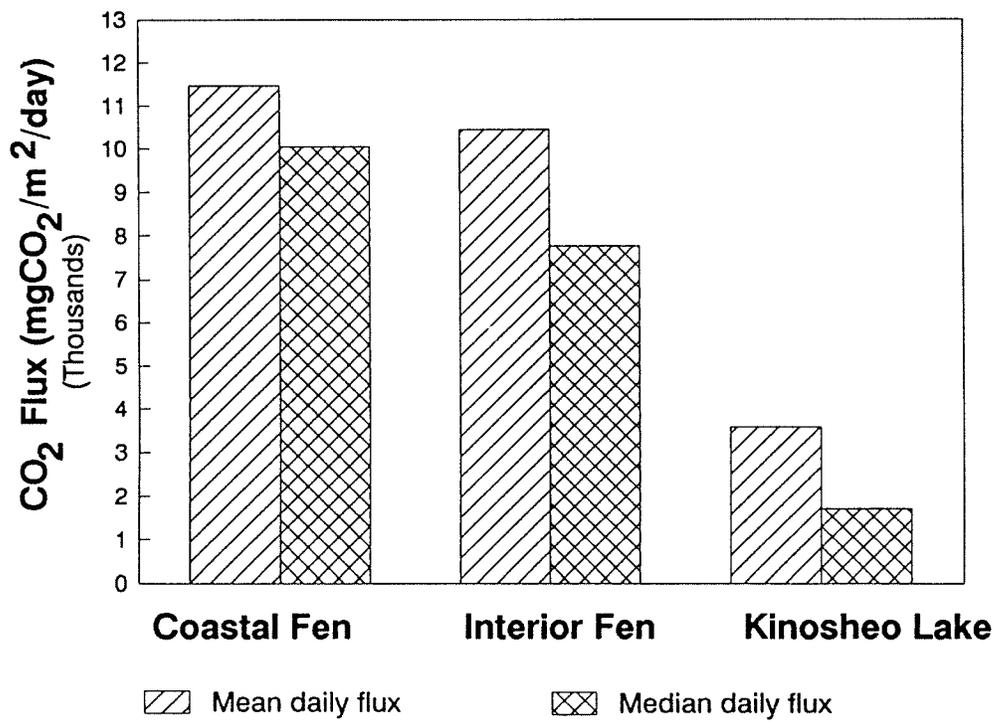


Figure 35. Time Weighted CO₂ Flux.
 (Calculated from diel data only)

Bubble traps were deployed during each diel sampling trip if there was sufficient depth of water to permit sampling. During the course of the 1990 open water season no natural ebullition was observed. This does not mean that there were no bubbles in the sediments. One pond at the Kinosheo site was observed to release large gas bubbles for three or four minutes after the sediments were physically disturbed. The lack of any observed ebullition does not rule out the possibility that some does occur in these ponds during periods when the bubble traps were not deployed.

IX Geographic Trend

There appears to be a geographic pattern to the magnitude of CH₄ and CO₂ from the Hudson's Bay Lowland which reflects the difference in flux rates from the different types of wetlands.

Figures 34 and 35 show the average time weighted flux, calculated from the daily means and daily medians, using diel fluxes from July through October (99 days). This was done by the following equation:

$$\frac{\sum \left(\frac{A+B}{2} \right) * n}{N} \quad (33)$$

where:

a= mean or median daily flux for the first sampling date.

b= mean or median daily flux for the second sampling date.

n= number of days between the sampling dates.

N= number of days between the first and last sampling dates.

The fen sites have higher flux rates of CH₄ and CO₂ to the atmosphere than the bog site (Figures 34 and 35). The Coastal Fen had an average seasonal flux of 125 mg CH₄/m²/day (median of 55 mg CH₄/m²/day). While the Interior Fen was slightly higher at approximately 145 mg CH₄/m²/day (median of 120 mg CH₄/m²/day). The bog pools at Kinosheo Lake had the lowest rate of 95 mg CH₄/m²/day (median of 50 mg CH₄/m²/day).

The average seasonal flux of CO₂ from the Coastal Fen was approximately 10,000 mg CO₂/m²/day (median of 3500 mg CO₂/m²/day) and the Interior Fen average was slightly lower at 9,500 mg CO₂/m²/day (median of 7,000 mg CO₂/m²/day). The bog pools at Kinosheo Lake had a seasonal flux rate of only 2,000 mg CO₂/m²/day (median of 1,500 mg CO₂/m²/day).

The geographic pattern of higher concentrations at the fen sites than at the Kinosheo site was also seen during a one time survey of other ponds and lakes the study area, which was carried out at the end of July. A transect was flown from the Coastal Marsh inland to a point about 3 km west of Kinosheo

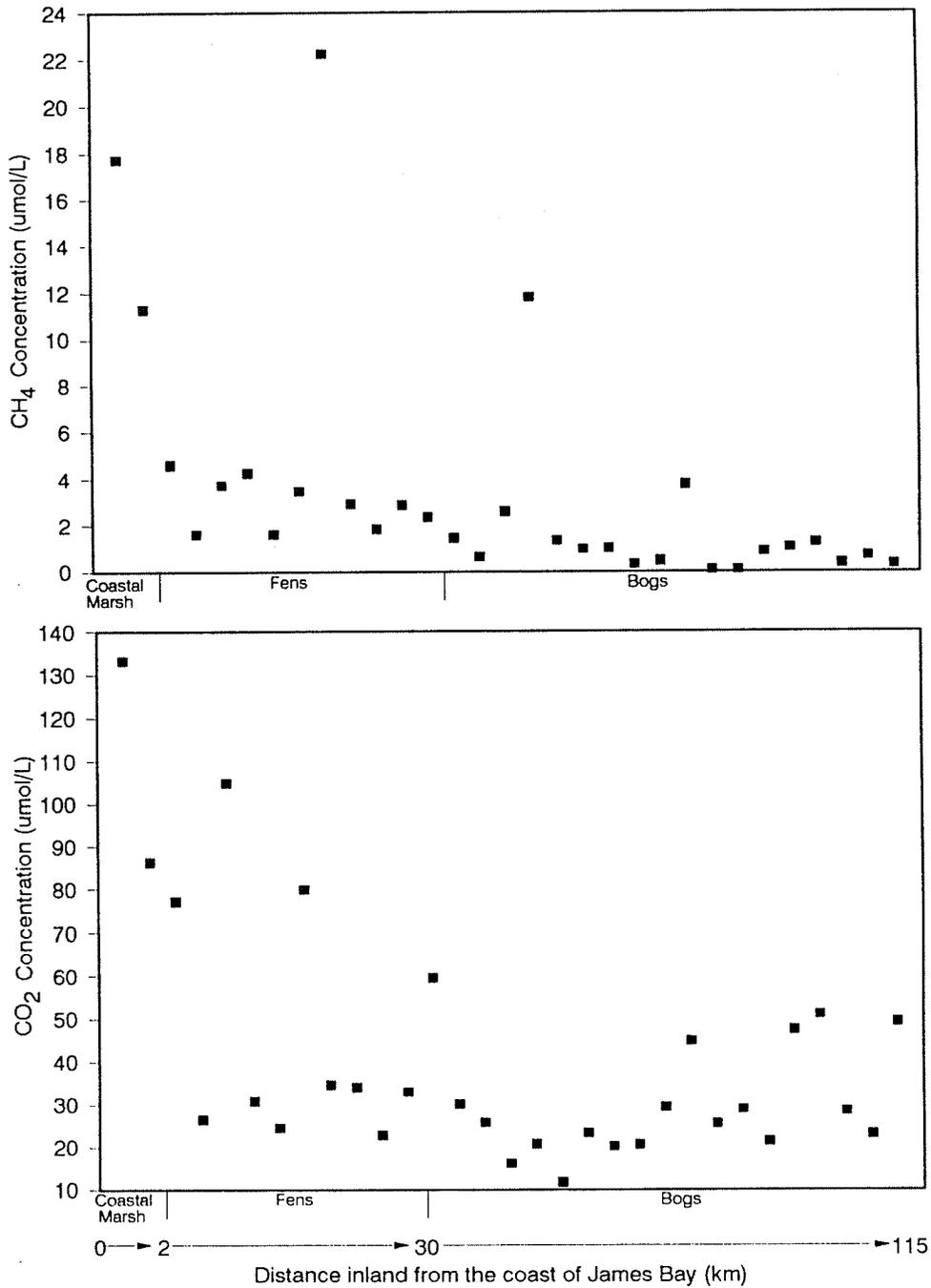


Figure 36. Geographical Pattern of CH₄ and CO₂ Concentrations. Samples taken on July 28 and July 30, 1990.

Lake. On this transect the CH_4 and CO_2 concentrations were usually highest in the waters associated with the fens and declined rapidly once the bogs were encountered (Figure 36), although there are some bog pools which showed higher concentrations than the fens.

Discussion

I Dissolved Gas Concentration

The surface water of lakes and oceans have above atmospheric equilibrium concentrations for CH₄ (Miller and Oremland 1988; Hunt 1974). As Table 9 shows all of the ponds studied in the Hudson Bay Lowland were above equilibrium concentration for CH₄ by 2 to 2000 fold.

It is difficult to compare the CH₄ concentration observed in the Hudson Bay Lowland to other wetlands as most reports discuss CH₄ in terms of CH₄ flux to the atmosphere. There is not enough information given in these papers (i.e. water temperature and wind speed) to enable me to back calculate to determine the CH₄ concentrations. There is one study with which direct comparison of dissolved CH₄ gas concentrations in wetland ponds are possible. Crill *et al.* (1988a) observed for a lake in the Amazon that the CH₄ concentrations ranged from 50-250 μmol CH₄/L. In the Hudson's Bay lowlands all three of my study sites fell well below these values (Figure 6 and Table 9) probably as a result of higher evasion rates due to higher wind speeds at the Hudson Bay Lowland (see later in discussion). Figure 6 demonstrates that even in the more productive fen ponds, CH₄ concentrations are still well below the values of Amazon lakes.

The surface water CO₂ concentration can be greatly affected by the rate of algal photosynthesis (Hesslein *et al.* 1991). Algal photosynthesis can draw the concentration down

below atmospheric equilibrium values so that the net movement is from the atmosphere into the water. In the Hudsons Bay Lowland ponds the concentration of CO₂ was usually above atmospheric equilibrium concentrations (Table 15) indicating that even when photosynthesis was occurring, respiration was greater, resulting in net CO₂ production in the day as well as the night. It is impossible to compare the CO₂ concentrations observed in the Hudson Bay Lowland ponds to other wetlands as this is the first study to intensively study ponds and lakes within a wetland ecosystem.

II Diel Variations in Flux

Diel variation of CH₄ and CO₂ flux has been observed by a number of authors in wetland systems. Crill *et al.* (1988b) observed diel changes in the terrestrial zone of a Minnesota peatland, Schutz *et al.* (1989;1990) observed diel patterns in Italian rice paddies and Yavitt *et al.* (1990a) observed them in beaver ponds of a temperate forest. Crill *et al.* (1988b) and Schutz *et al.* (1990) correlate the flux patterns observed in the rice paddies with the soil temperature during a diel period. This is an important finding as the rate of microbial activity is affected by temperature (when sufficient substrates are present). In contrast to the findings of Crill *et al.* (1988b), Schutz *et al.* (1989; 1990) and Yavitt *et al.* (1990a) however, concentrations (or flux) in this study were

not related to temperature (Figures 11, 12, 25 and 26), with high concentrations even at the lowest temperatures.

Svensson (1984) showed that in a Swedish bog methanogens that are capable of utilizing acetate had an optimum temperature for CH_4 production of 20 °C. Methanogens that oxidize H_2 had an optimum temperature of 28 °C. Schutz *et al.* (1990) demonstrated that methanogens from a rice paddy were inactivated when the temperature exceeded 40 °C. It should be noted that the experiments by Svensson (1984) were conducted over the course of weeks or months. The ponds within the Hudson's Bay Lowland undergo large temperature changes during the course of a day (see appendix), frequently during July the ponds would go through a 15 °C temperature change daily. On one occasion a pond temperature at Kinosheo was recorded to be 39 °C. Without further work, however, it is not known how these temperature changes might affect the CH_4 and CO_2 fluxes.

A further difference between the findings of Yavitt *et al.* (1990a) and this work is the finding by Yavitt's group that the flux of CH_4 was 2x higher from beaver ponds at midnight than at noon. This peak in flux may be an artifact of the chamber method employed by Yavitt *et al.* . If the wind speed at the sites that Yavitt's group were studying, decreased in the evening, this would allow the dissolved gas concentration in the water increase because of reduced flux and hence increase the concentration of gas in the chambers which would give the impression that flux increased at

midnight.

In the Hudson Bay Lowland there appeared to be some relation between both CH₄ or CO₂ concentration and time of day (Figures 15 and 16) and CH₄ or CO₂ flux and time of day (Figures 27 and 28). Often but not always, the highest concentrations and fluxes were recorded at approximately 1000 hrs (Local time). Since there were no apparent relationships between physical controls and gas concentration or gas flux, this suggests that there are additional controlling mechanisms.

There are a number of biological processes that occur simultaneously within these ponds that could affect CH₄ and CO₂ concentration. These processes are anaerobic decomposition, methane oxidation, aerobic respiration and decomposition, and phytoplankton primary productivity. Methane is only produced from anaerobic decomposition yet it is consumed by aerobic methane oxidation as the CH₄ diffuses across the oxic/anoxic interface (Rudd and Hamilton 1978), which in these ponds is probably at or just below the sediment water interface. Methane oxidation requires CH₄, O₂ and fixed nitrogen (Rudd et al. 1976). Preliminary investigations suggest that there are large numbers of nitrogen-fixing cyanobacteria in the benthic communities of these shallow ponds (Kling pers. com.). These cyanobacteria would also be producing O₂ during daylight hours, and it is expected that there would be a narrow layer of high CH₄ oxidation activity just below the zone of algal growth (King 1990).

III Computer Modelling

The heterogenous set of biological processes (CH_4 production, CH_4 oxidation, photosynthesis, etc.) along with the physical-chemical controls on gas evasion of wind and temperature lead to a very complex system which does not lend itself to easy determination of the ultimate processes controlling observed concentrations and flux of CH_4 and CO_2 . In an attempt to examine the degree to which the most obvious biological and physical processes might be important controlling factors, a computer model (Hesslein *et al.* 1991) was employed to simulate their effects on the CO_2 and CH_4 fluxes from the ponds.

The results of the computer modelling (Figure 33a and 33b) showed that constant CO_2 release from sediments could not account for observed changes. The inclusion of algal respiration and algal photosynthesis was necessary to model CO_2 concentrations similar to CO_2 concentrations observed in these ponds over 24 hour cycle.

There are no measurements of benthic photosynthesis for peatland ponds that could be used in the model. The photosynthetic rate used in the model of 120-240 mg C fixed/ m^2 /hr is was derived from measurements of the epilithic algal communities in the Delta Marsh ponds in Southern Manitoba of 30-300 mg C fixed/ m^2 /hr (Robinson pers.comm.). The ponds of the Hudson's Bay Lowlands are very shallow and

therefore the benthic algal community is probably not light limited. However the algae could potentially be limited by nutrient availability as the water chemistry results indicate that the ponds are severely phosphorous limited and moderately to severely nitrogen limited.

Figures 32a and 32b demonstrate that suggest that CH_4 oxidation could have considerable influence on the CH_4 concentration. The CH_4 oxidation rate used in the model is in the upper range seen by Rudd and Hamilton (1978) for a small eutrophic Shield lake of 0.02-32 mmol $\text{CH}_4/\text{m}^2/\text{day}$. The use of increased CH_4 oxidation during daylight hours in the model to affect the predicted CH_4 concentration is a reasonable assumption as King (1990) has shown that for sediment cores from Danish wetlands the CH_4 oxidation was sensitive to light. That is, oxidation was highest during light periods and reduced during the dark. As well, King (1990) shows that total CH_4 emissions from the cores decreases as a light intensity increases. King explains this light/dark variation in CH_4 oxidation as a function of available oxygen in the sediments due to the presence or absence of benthic photosynthesis.

The hypothesis that CH_4 concentration in the ponds is controlled in part by CH_4 oxidation is supported by the work of Rudd and Hamilton (1978) who found that in a eutrophic lake the epilimnetic CH_4 concentration was controlled by in situ rates of CH_4 oxidation. Also Yavitt et al. (1990b) found that for water saturated peat sediments from the Big Run Bog, West

Virginia, CH₄ oxidation could consume up to 72% of the total CH₄ produced. Methane oxidation has also been observed to control the magnitude of CH₄ flux from rice paddies (Schutz et al. 1989).

Therefore the model suggests that the diel CH₄ concentration and flux could be controlled by the combined action of CH₄ oxidation, which is ultimately controlled by the rate of benthic photosynthesis (i.e. the supply of oxygen), and the supply of fixed nitrogen by the cyanobacteria.

IV Seasonal Flux

An important point to be kept in mind for an ecosystem such as that encountered in the Hudson Bay Lowland is that the daily flux can not be extrapolated from a single data point. Because of the daily variation in the data set, the daily flux was derived by the integration of the diel data points.

The average daily flux rates of from ponds CH₄ shown in Figure 23 and Table 17 are much higher than those reported in the literature for other wetlands. For example the rate of flux from the two fen sites is more than double that reported for vegetated surfaces of fens in the Schefferville area of Quebec of 65.9 mg CH₄/m²/day (Moore et al. 1990). Indeed they were more than 5x those reported by Bartlett et al. (1988) of 27 mg CH₄/m²/day for a lake in the Amazon floodplain. The average rate of CH₄ flux from the Kinosheo lake bog is

approximately 3x the reported values of 21 mg CH₄/m²/day for pools in the Alaskan tundra (Whalen and Reeburgh 1989). The high rates observed for the ponds in the Hudson's Bay Lowland may be a result of the high CH₄ production rates and wind speeds on the relatively open terrain which exposes the ponds to wind affects.

The flux of CO₂ from the pools (Table 18) in the fens is nearly 20x that of the dark flux reported for the vegetated surfaces of the fens in Schefferville by Moore and Knowles (1987) of 300-500 mg CO₂/m²/day.

The average seasonal CO₂ flux from the Kinosheo bog is 100x and the fens 5,000x the flux (20.9 mg CO₂/m²/day) reported by Kling et al. (1991) for tundra ponds. Kling et al. attribute the CO₂ flux seen in the Alaskan tundra ponds to CO₂ that originates from terrestrial environments which is transported into the lakes by ground water movement. The Hudson's Bay Lowland fens and bogs within the study site had very little to no lateral ground water flow (Roulet pers.com.). The CO₂ that fluxes from these ponds must have originated from the decomposition of organic material within the pond sediments (see section VII for further discussion of this point).

The flux of both CH₄ and CO₂ followed a strong seasonal pattern (Figure 23 and 24), as has been observed in other wetlands for both terrestrial and aquatic ecosystems. Svensson (1980) observed a seasonal pattern to the CH₄ and CO₂ flux from

the terrestrial portion of a Swedish mire, with peaks in flux observed in July. Moore and Knowles (1987) observed that CH₄ flux from the vegetated surfaces increased during the summer in fens at Schefferville, Quebec.

Yavitt *et al.* (1987) showed that in the Big Run Bog, West Virginia, there was a strong seasonal pattern to CH₄ and CO₂ flux. The rates were lowest in February and the highest in September. Schutz *et al.* (1989 and 1990) also observed seasonal patterns of CH₄ in Italian rice paddies, and concluded that the July and September peaks they observed are correlated with the stages of the rice plant growth. They suggest that the July peak is a result of increased release of organic nutrients from plant roots during the growth of the plant which are readily used by methanogens. The September peak occurs at a time when there is a large amount of decaying root material present in the soil which provides a readily usable source of organic material.

The September peaks in CH₄ and CO₂ flux observed in the Hudson's Bay Lowland ponds (Figure 23 and 24 and Table 17 and 18) might be due to death and decomposition of the benthic algal mats in the fall. This would be analogous to the September peaks seen by Schutz *et al.* (1989) as well as with the fall turn over seen in lakes (Strayer and Teidje 1974, Rudd and Hamilton 1978 and Kelly and Chynoweth 1981) when there is a new input of organic material, in the form of sedimenting algae, into the sediments. These observations

would support the hypothesis of Kelly and Chynoweth (1981) that the microorganisms involved in anaerobic decomposition are adapted to respond to the availability of organic substrates and not necessarily inhibited by low temperature.

By comparing the average flux rates of CH₄ and CO₂ from all three sites (Figure 34 and 35) as well as the data collected on the regional transect of 32 additional ponds (Figure 36) it is apparent that the fens generally had a much higher production rate of CH₄ and CO₂ than the bog sites. This has been observed in other wetland ecosystems (Svensson and Rosswall (1984) in Sweden and Sebacher et al. (1986) in Alaska).

V Effect of Ponds on the Total Gas Flux from the Hudson Bay Lowland

On an areal basis the ponds and lakes in the Hudson's Bay Lowlands were large sources of CO₂ to the atmosphere. However, while the ponds are producing CO₂ at a high rate (Figure 24) the vegetated surfaces are fixing carbon at an equal rate. For example the vegetated bog surface at Kinosheo is fixing carbon at a rate of 3000 mg CO₂/m²/day (King et.al 1991) which is equivalent to the flux from the ponds at Kinosheo (Figure 35). As the ponds only make up approximately 30% (Roulet pers. comm.) of the total area of the Hudson's Bay Lowlands the overall impact on the total CO₂ budget is smaller than the

larger vegetated surfaces. The result is that there is a net fixation of carbon and peat accumulation by the vegetated surfaces. It has been estimated that the Hudson's Bay Lowlands store approximately 0.03 Gt of carbon per year (King *et al.* 1991).

The ponds and lakes in the Hudson's Bay Lowlands are a large source of CH₄ to the atmosphere when compared to the flux of CH₄ from the vegetated surfaces. The flux from the ponds at the fens is 15-20x (125-140 mg CH₄/m²/day Figure 34) that of the vegetated surfaces reported by Roulet *et al.* (1991) of 6-8 mg CH₄/m²/day. The flux from the ponds located in the bog at Kinosheo were approximately double that of the vegetated surface rate of 35 mg CH₄/m²/day Roulet *et al.* (1991). Interestingly, the vegetated fluxes were higher in the bog than in the fens, while pond fluxes were lower in the bog than in the fens. The impact of the ponds on the total CH₄ budget for the Hudson's Bay Lowlands is quite large. These ponds make up approximately 30% of the total surface area in the Hudson's Bay Lowlands. By averaging the openwater season CH₄ flux rate of the fens and bogs, the ponds and lakes can account for between 60 and 70% of the total CH₄ budget of 1-2 Teragrams CH₄/year (Roulet *et al.* 1991).

The estimate of 30% coverage by ponds and lakes is a somewhat rough estimate as many of the small ponds are below the pixal size resolution of aerial photographs and satellite images. This is especially a problem in the fens were the pond

margins are not very distinct.

VI Ebullition

One of the more interesting results to come out of the current work was the apparent lack of any natural ebullition. The ponds were always supersaturated with CH_4 and CO_2 at high enough concentrations for bubbles to form and when the sediments were physically disturbed bubbles were released. But when bubble traps were in place no bubbles were collected. There are few studies of ebullition in ponds of this type, but other sites have been shown to have a large percentage of the total CH_4 flux to the atmosphere in the form of bubbles. For example Holzapfel-Pschorn *et al.* (1985) found that 35% of the total flux from a rice paddy was in the form of gas bubbles. Crill *et al.* (1988a) found that up to 100% of the daily flux from an Amazon lake could be from bubbles.

The most probable reason for this lack of natural ebullition is that the bubbles are trapped in the sediments by a thick layer of fibrous peat material which prevents the escape of bubbles. Cylmo (1984) has shown that as the peat increases in depth it compresses. Gas bubbles are formed deep in the peat and as they move upwards through the peat they become trapped in the narrow passages. The CH_4 trapped in these bubbles remains until it is either oxidized or removed by physical disturbances such as a large animal transit or by

the processes of peat harvesting and wetland drainage. Some CH_4 bubbles can also be redissolved in the pore water and transported out of the peat or moved through the peat by the physical processes of freezing and thawing.

VII Degradation of Peat Within the Ponds

From the large flux rates of both CH_4 and CO_2 to the atmosphere and known low ground water movement (Roulet pers.com.) I conclude that the peat in the sediments of these ponds is being degraded and supporting a large portion of the total gas flux from the ponds in the Hudson Bay Lowland. This conclusion is supported primarily by the fact that the net carbon flux (including both CH_4 and CO_2) from the ponds was always to the atmosphere thus these ponds were net sources of carbon, not net fixers. Methane fluxes were far greater than fluxes from lakes (Miller and Oremland 1988). There must be a source of organic material during the summer for the methanogens to maintain these relatively high rates throughout the summer. The largest source of organic material would be the underlying peat. As the flux rates during the summer were one quarter to one half that of the fall peak this would suggest that in the fall an additional carbon source becomes available probably the dying algal populations.

The physical characteristics of the ponds also suggest that the peat material is being degraded. The larger ponds at

all three of the sample sites had a vary abrupt, straight edge. For example, in Ponds 1 and 10 in the Kinosheo Lake Bog, the water was 2m in depth at the edge of the pond. There was no gradual sloping shore line. This would indicate that the ponds are eroding down into the underlying peat layer. Also, Pond 1, which is situated on an old ridge where there is less peat than other areas at the Kinosheo Lake Bog site, has already eroded down to the inorganic layer.

Peat is high in organic carbon content but very deficient in other nutrients especially nitrogen (Clymo 1984). Preliminary data shows that benthic algal mats in the Hudson Bay Lowland ponds were composed of 10-30% heterocysts (Kling pers.com.), the N_2 fixing benthic algae would be able to supply the N_2 necessary for peat degradation to take place. If this hypothesis is true then as the wetlands age the surface area of ponds will gradually increase in size. As well long stored carbon will be released to the atmosphere by the methanogens in the form of CH_4 and CO_2 .

Using a peat bulk density of 50 mg/cm^3 (Mitsch and Gosselink 1986) and an average total carbon loss from the ponds to the atmosphere of $844 \text{ mg C/m}^2/\text{day}$ (that is the total carbon flux in the form of CH_4 and CO_2) it was calculated that the ponds are eroding peat at a rate of 0.25 cm/year . At this rate it would take the ponds at the Kinosheo Lake Bog approximately 4000 years to erode through the peat to reach the underlying substrate. As one travels inland from the coast

of James Bay there are obvious changes in the appearance of the peatland. In the young peat fens near the coast, such as the Coastal Fen, the pools are shallow and only just starting to erode the peat surface to increase the pool size and depth. In the intermediate area such as that seen at the Interior Fen, were the pools form long shallow strings. Further inland is the mature bog with very large ponds and lakes. Pond formation as discussed is an important component of peatland evolution. The participation of the N_2 fixation process may explain the peatland pond evolution process discussed by Foster *et al.* (1988).

VIII Potential Impact of Global Warming on the Hudson Bay Lowland Gas Flux

The fact that CH_4 and CO_2 fluxes from the ponds of the Hudson's Bay Lowland are so different from the terrestrial surfaces means that any factor that changes the ratio of water to land will change the overall emissions from the Lowland. Climate change could mean more or less precipitation in this area and lead to changes in the water to land ratio. Another factor to consider is that since most of the Hudson Bay Lowland is only a few meters above sea level, the area will become inundated if sea level increases from global warming (AES Report 1985). If this were to happen the carbon flux in the Hudson Bay Lowland will shift from net fixation of carbon

to a net flux of carbon to the atmosphere (albeit with the new influence of sulfate reduction which could initially decrease CH_4 production) as the area will behave as one large pond and the Lowland will become a positive feedback of the greenhouse warming.

Conclusions

The ponds within the Hudson's Bay Lowlands are very complex ecosystems in which the rate of flux of CH_4 and CO_2 is apparently controlled by the interactions of wind speed and the biological processes of CH_4 and CO_2 production, algal photosynthesis and bacterial CH_4 oxidation.

As a result of these interactions the ponds usually demonstrated a strong diel variation in both dissolved gas concentration and instantaneous flux to the atmosphere. To develop a reasonable estimate of the daily rate of flux it is necessary to sample frequently through out the day.

All three of the sample sites exhibit a seasonal pattern of flux of CH_4 and CO_2 to the atmosphere. The ponds are large net sources of CH_4 and CO_2 to the atmosphere. Even with the concentration changes observed during the day, the concentrations were always greater than atmospheric equilibrium concentrations.

Methane flux from the ponds occurs at a much higher rate than from the terrestrial surface, and probably accounts for 60-70% of the total flux of CH_4 from the Hudson's Bay Lowlands.

The Hudson Bay Lowland is undergoing successional changes in peatland ecology. The young peat accumulating systems, such as the Coastal Fen, have very few ponds. The older areas such as the Kinosheo Lake Bog have larger ponds and lakes. These

ponds apparently form through the action of microorganisms that decompose the underlying peat. There is some evidence that this decomposition is made possible through the activity of N_2 fixation by Cyanobacteria that grow in mats on the bottoms of these ponds.

The fact that the gas flux from these ponds is so different from the surrounding terrestrial surfaces means that any change in the pond-lake ratio due to climate change area will affect the total Hudson Bay Lowland flux.

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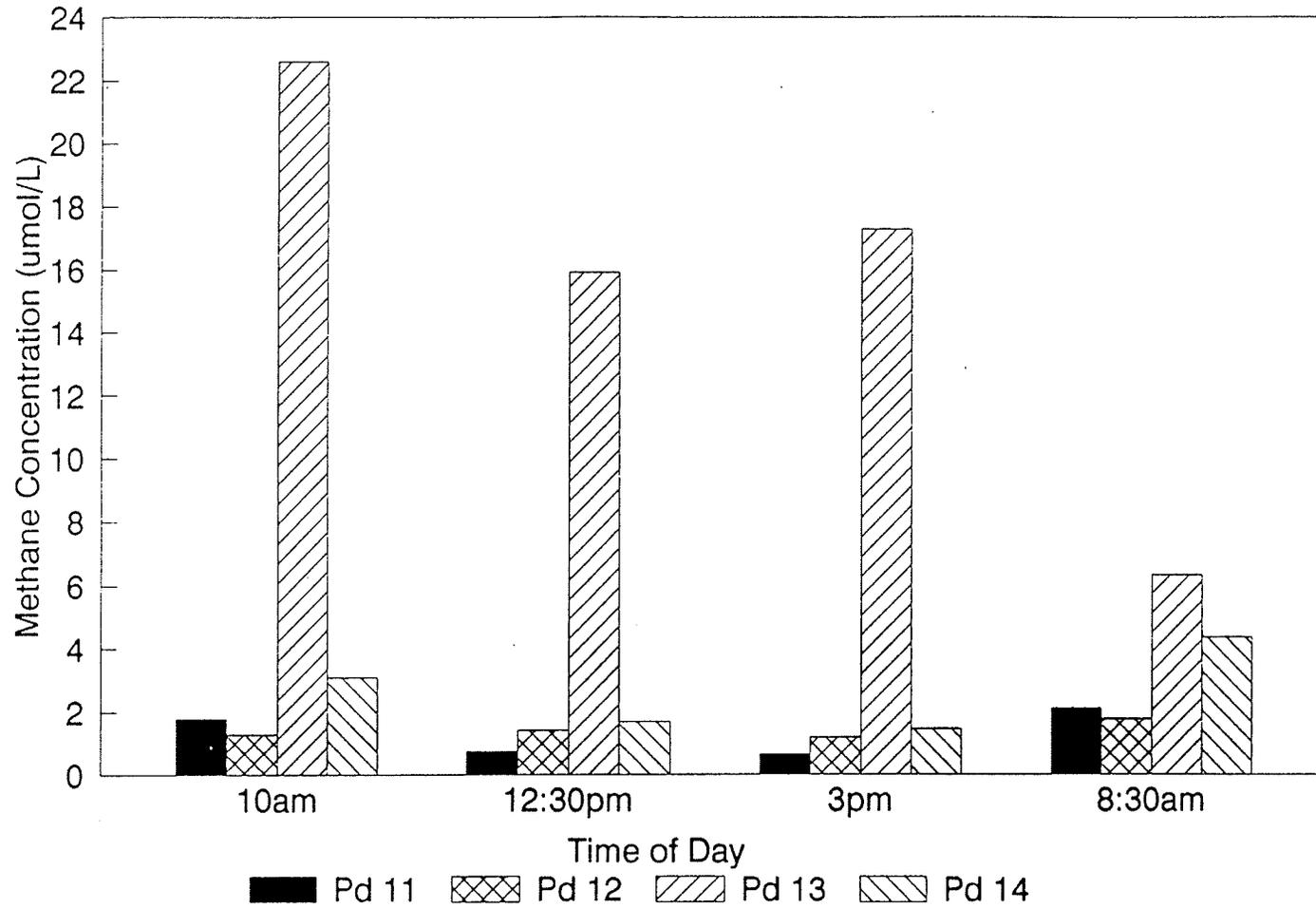


Figure A1. Methane concentration vs. time of day. Coastal Fen (Ponds 11-14), July 09-10, 1990.

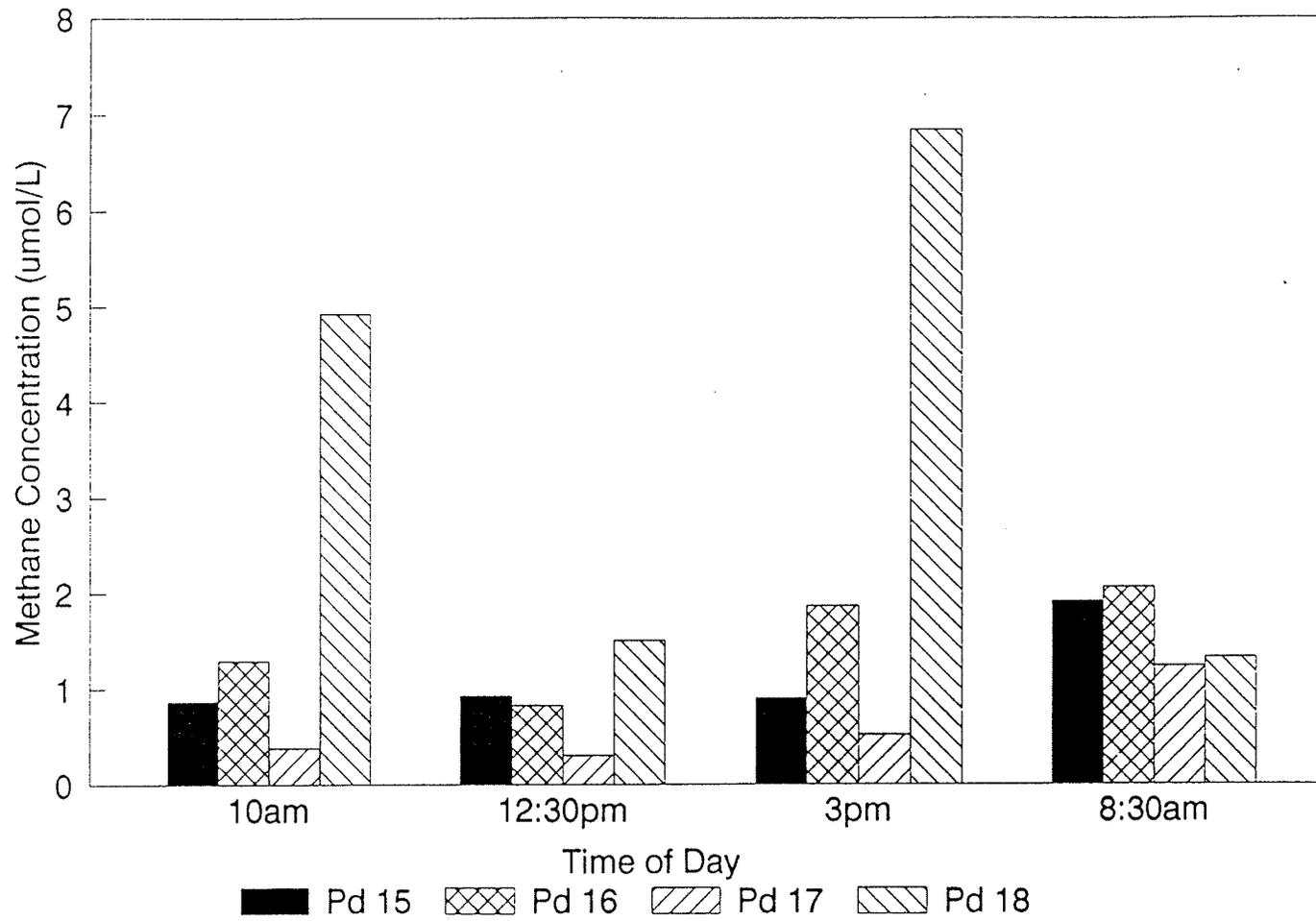


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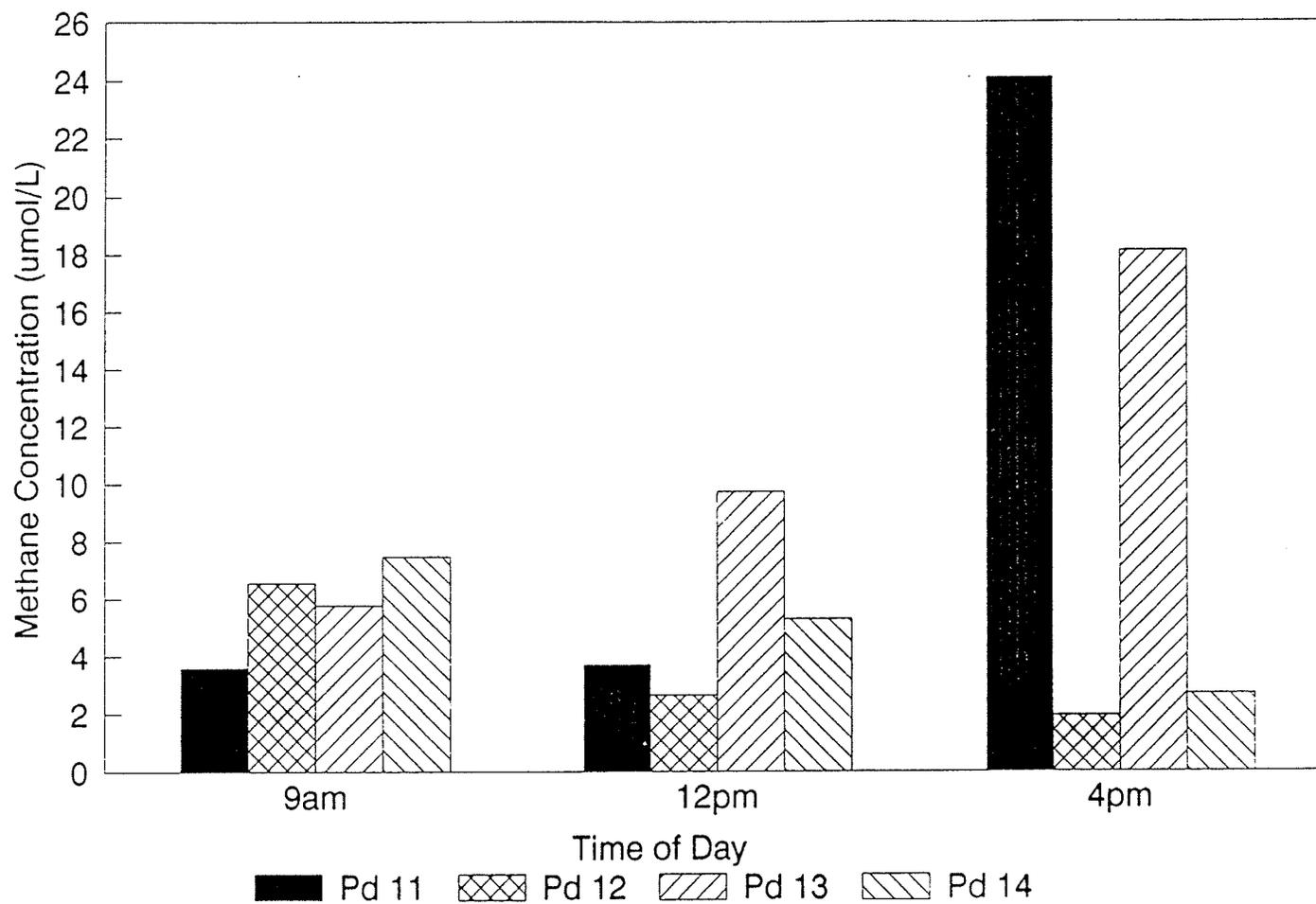


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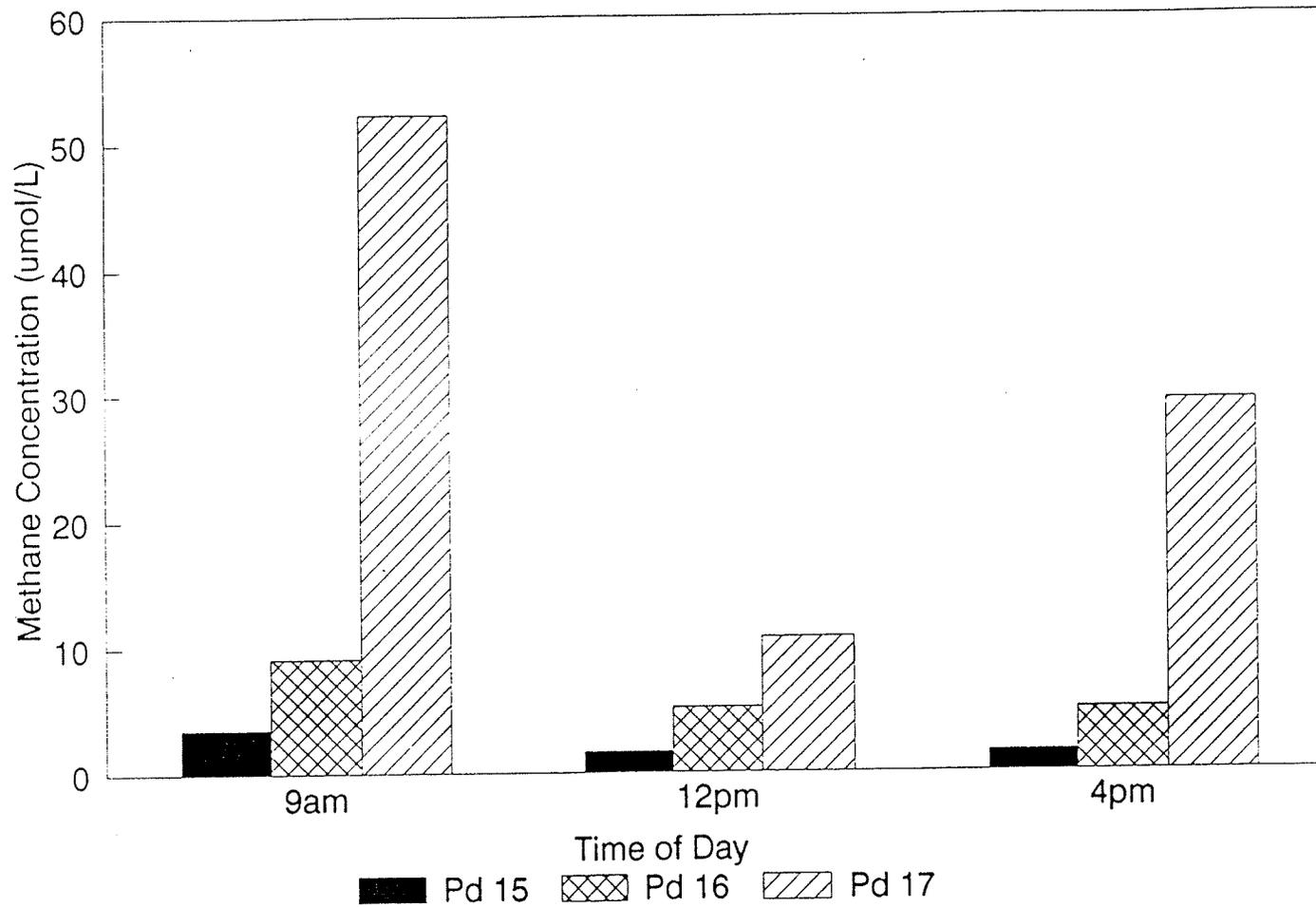


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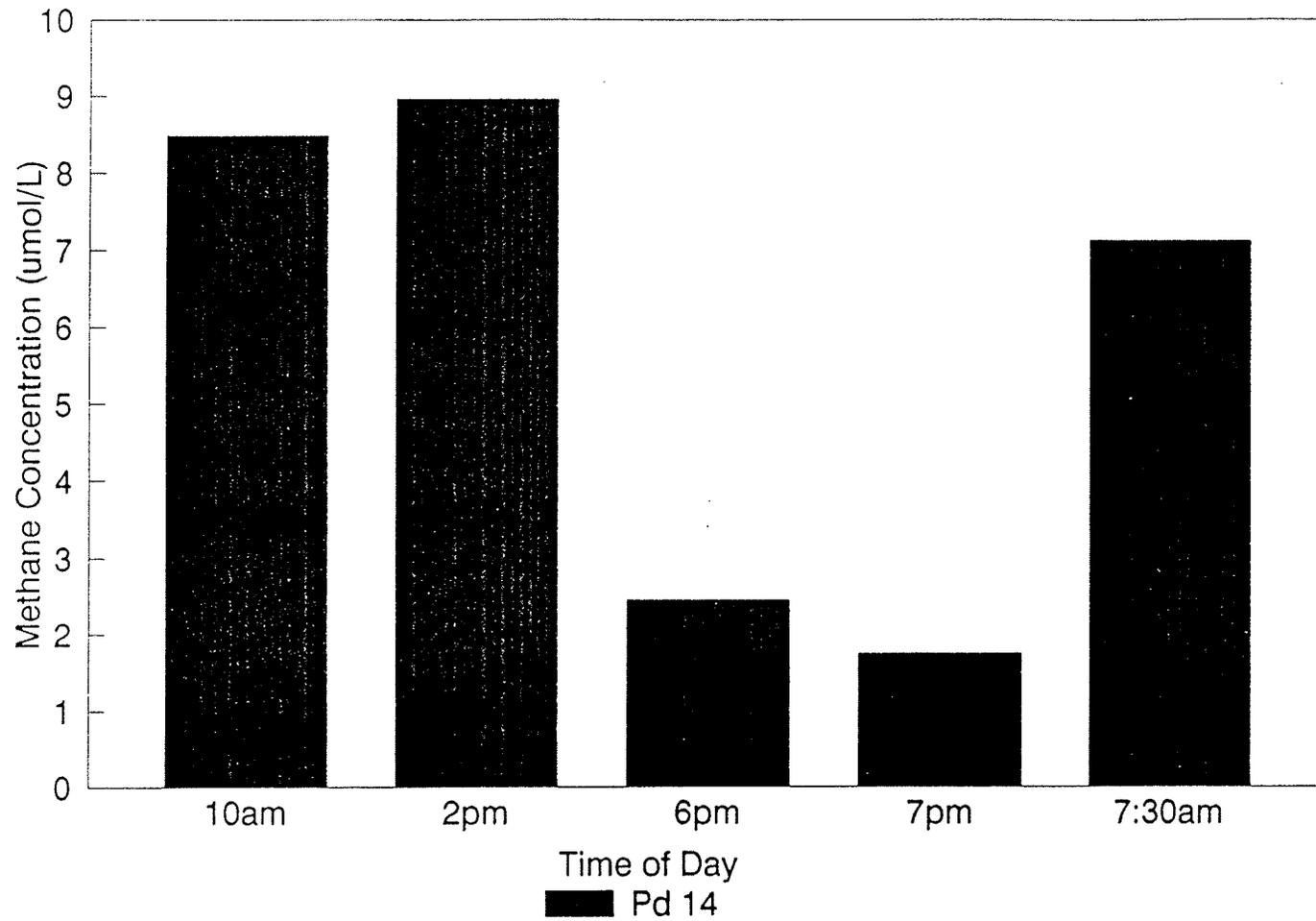


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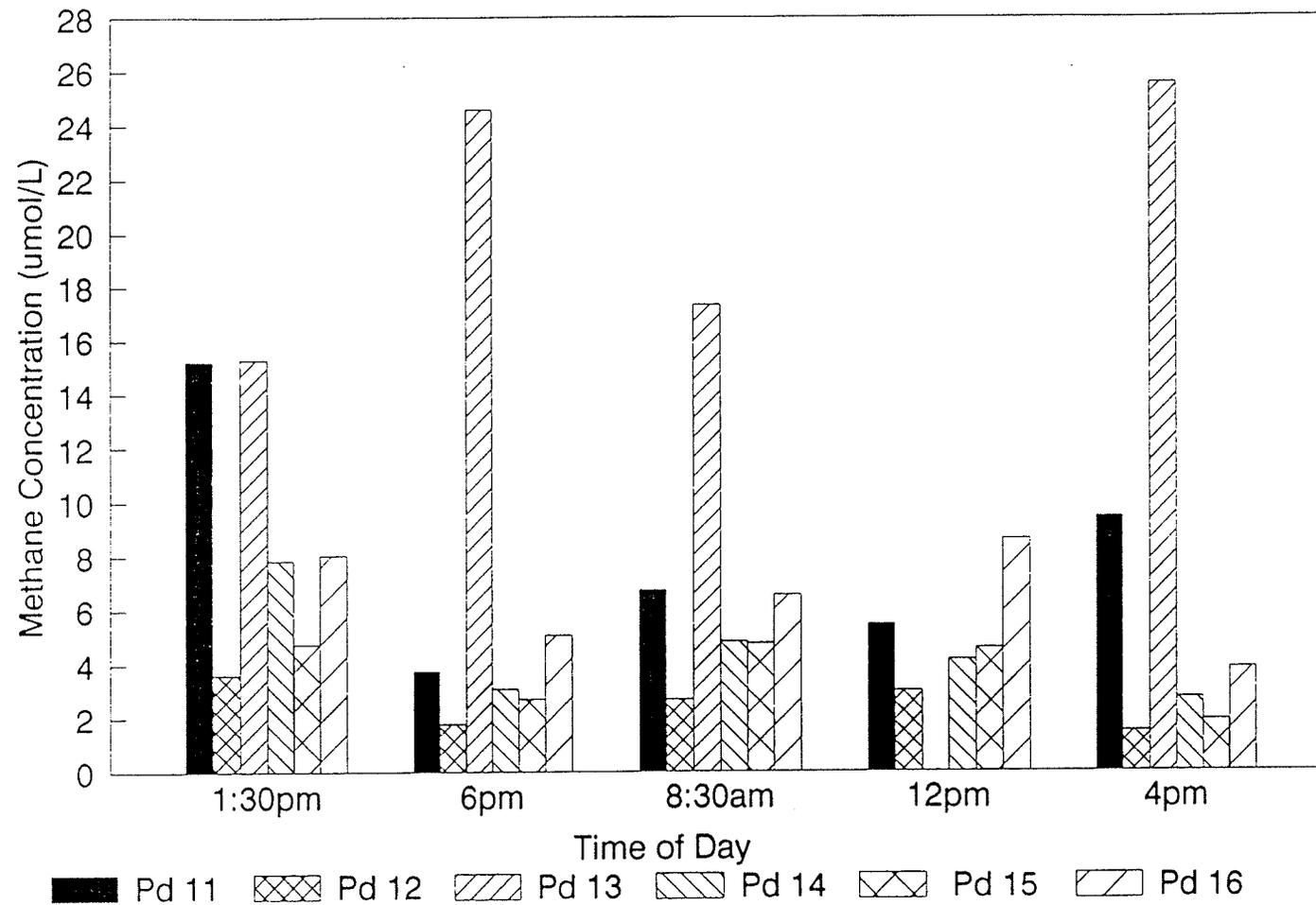


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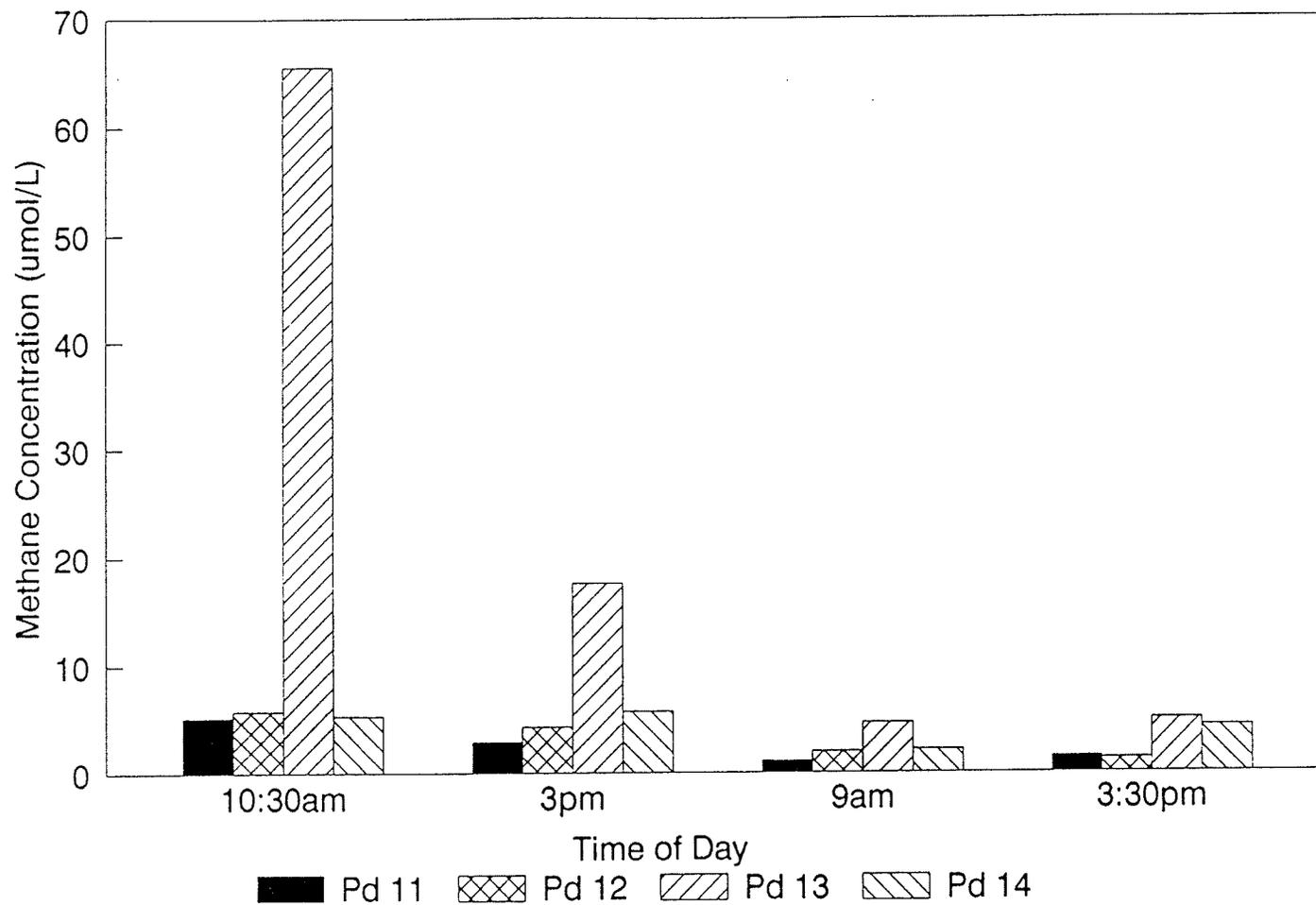


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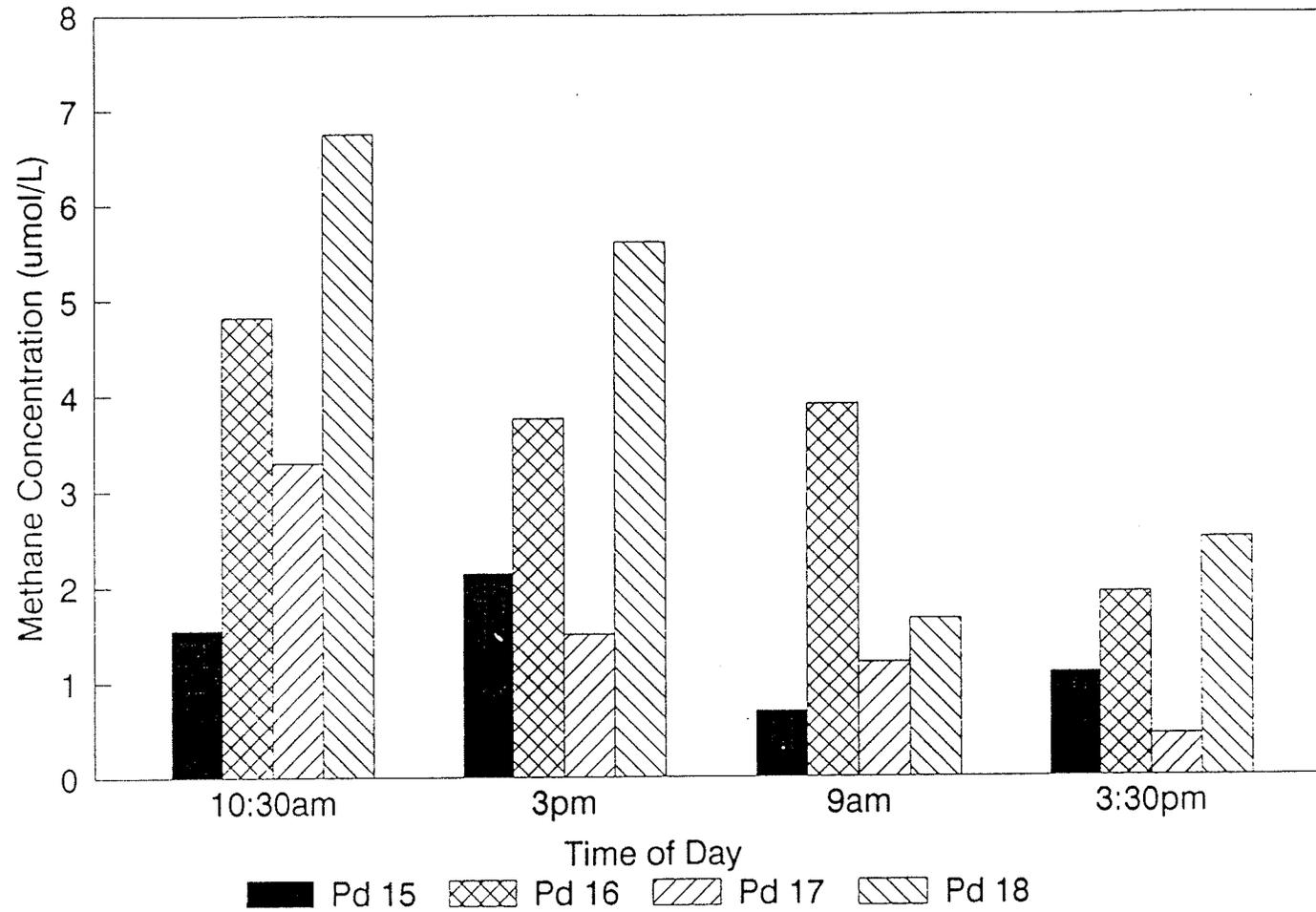


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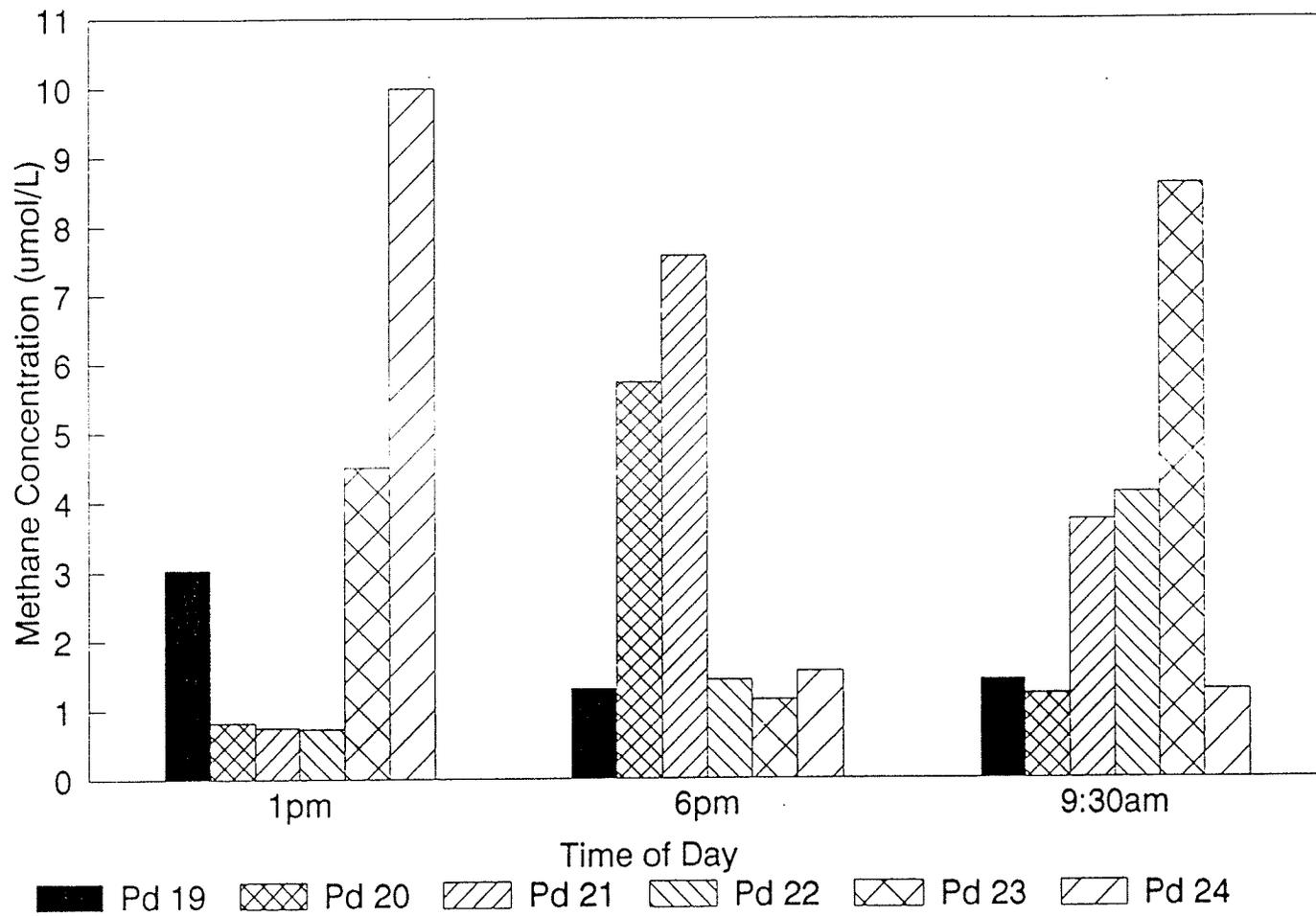


Figure A9. Methane concentration vs. time of day. Interior Fen, July 09-10, 1990.

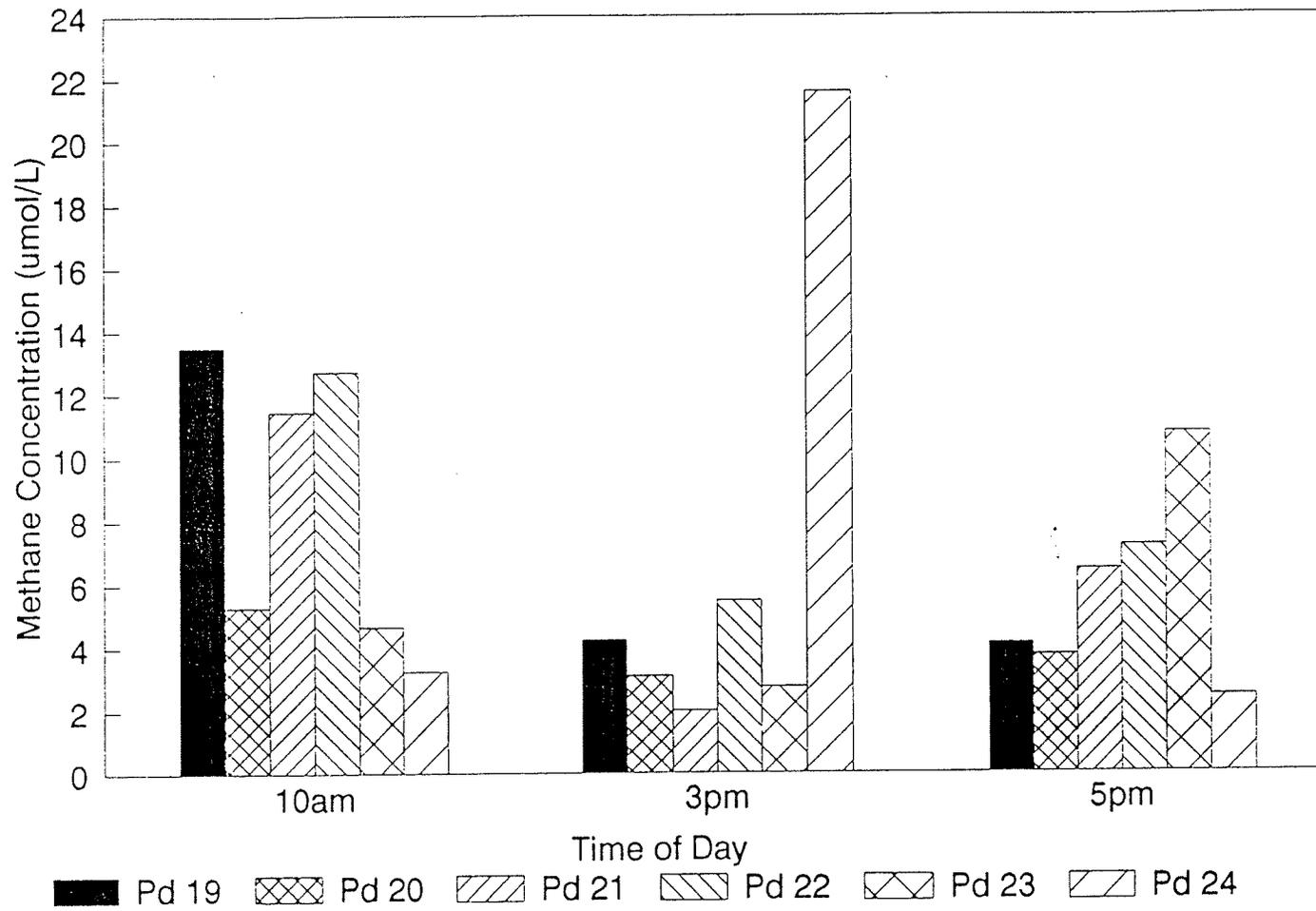


Figure A10. Methane concentration vs. time of day. Interior Fen, July 24, 1990.

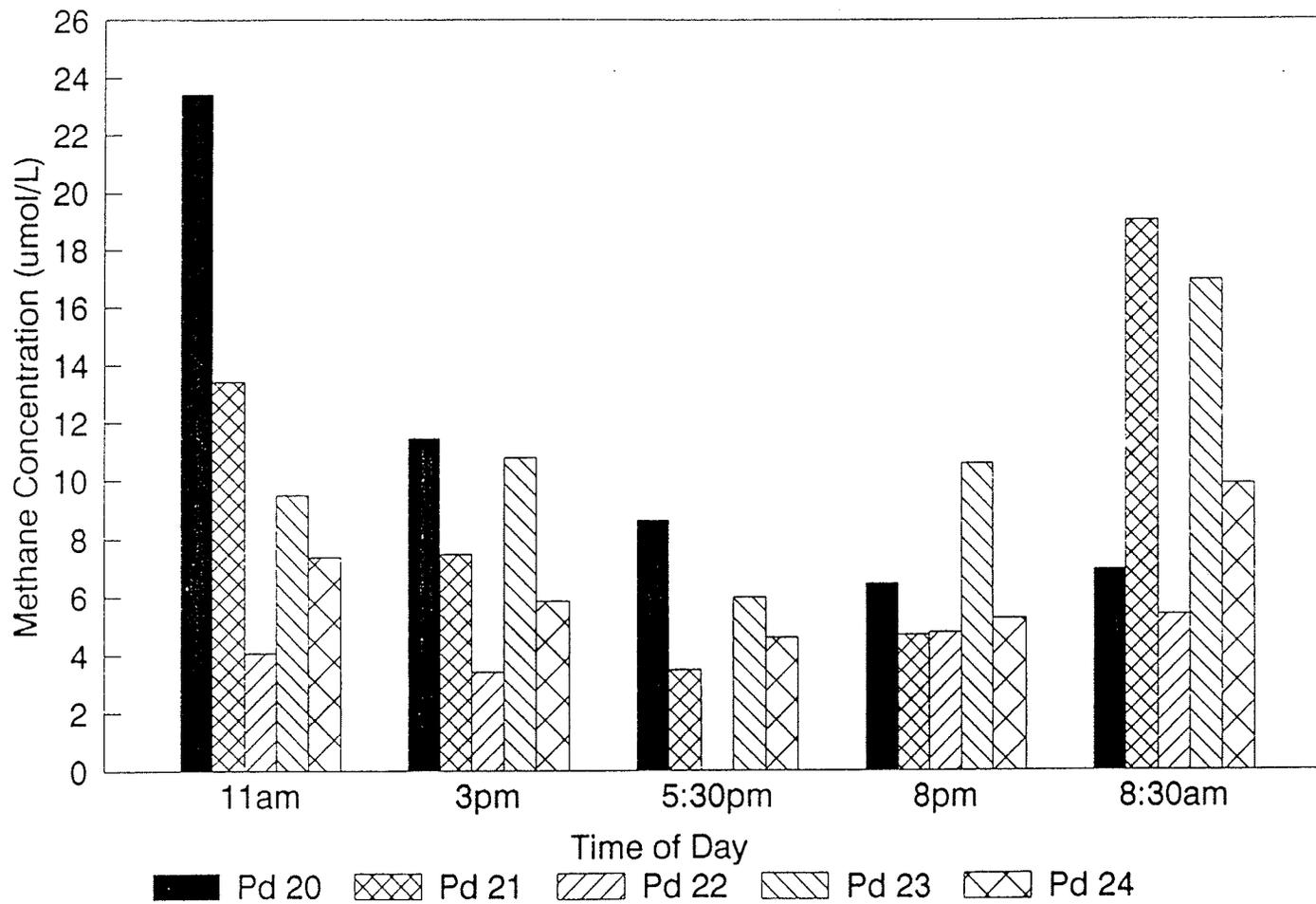


Figure A11. Methane concentration vs. time of day. Interior Fen, August 14-15, 1990.

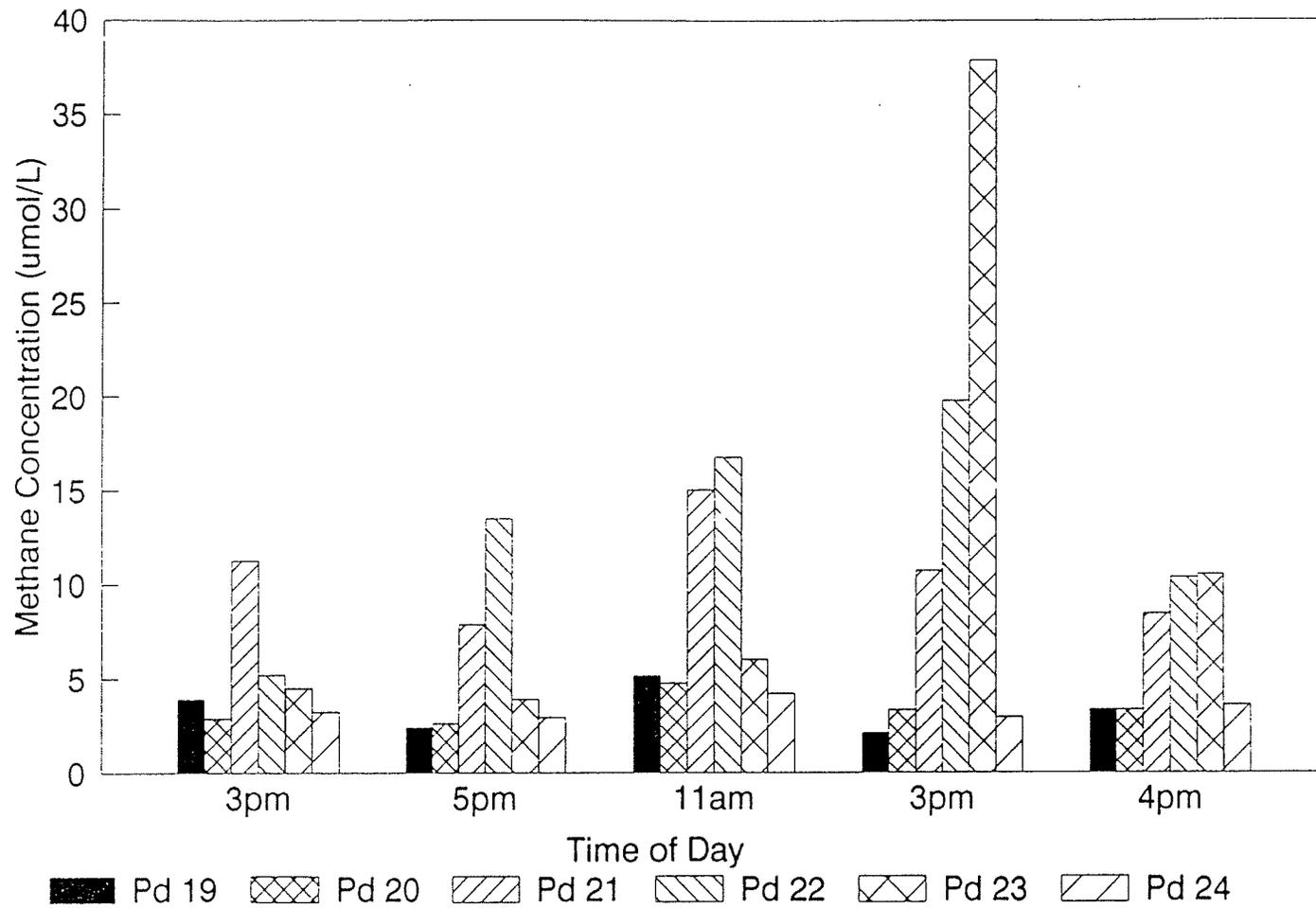


Figure A12. Methane concentration vs. time of day. Interior Fen, September 10-11, 1990.

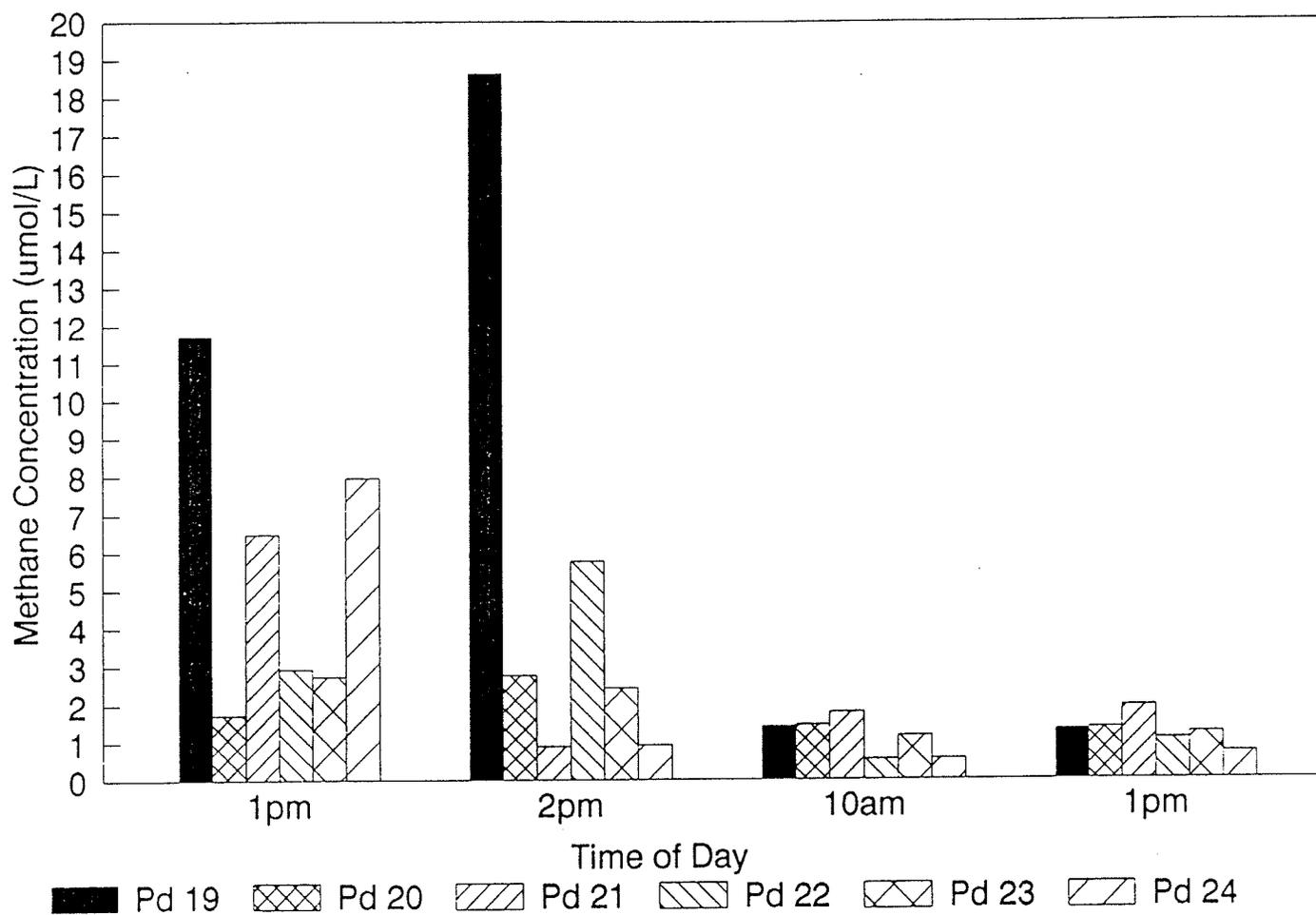


Figure A13. Methane concentration vs. time of day. Interior Fen, October 10-11, 1990.

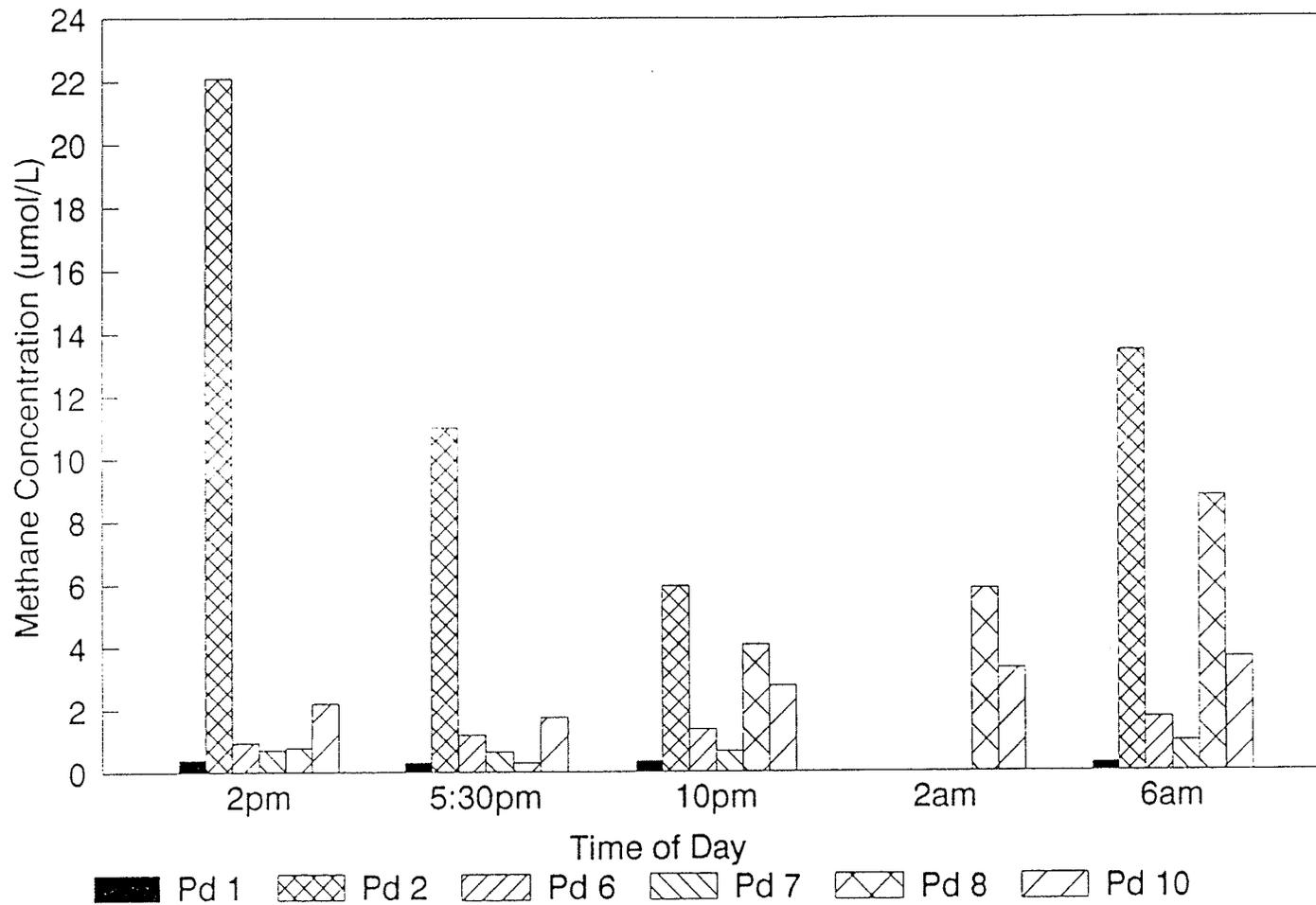


Figure A14. Methane concentration vs. time of day. Kinosheo Lake Bog, July 05-06, 1990.

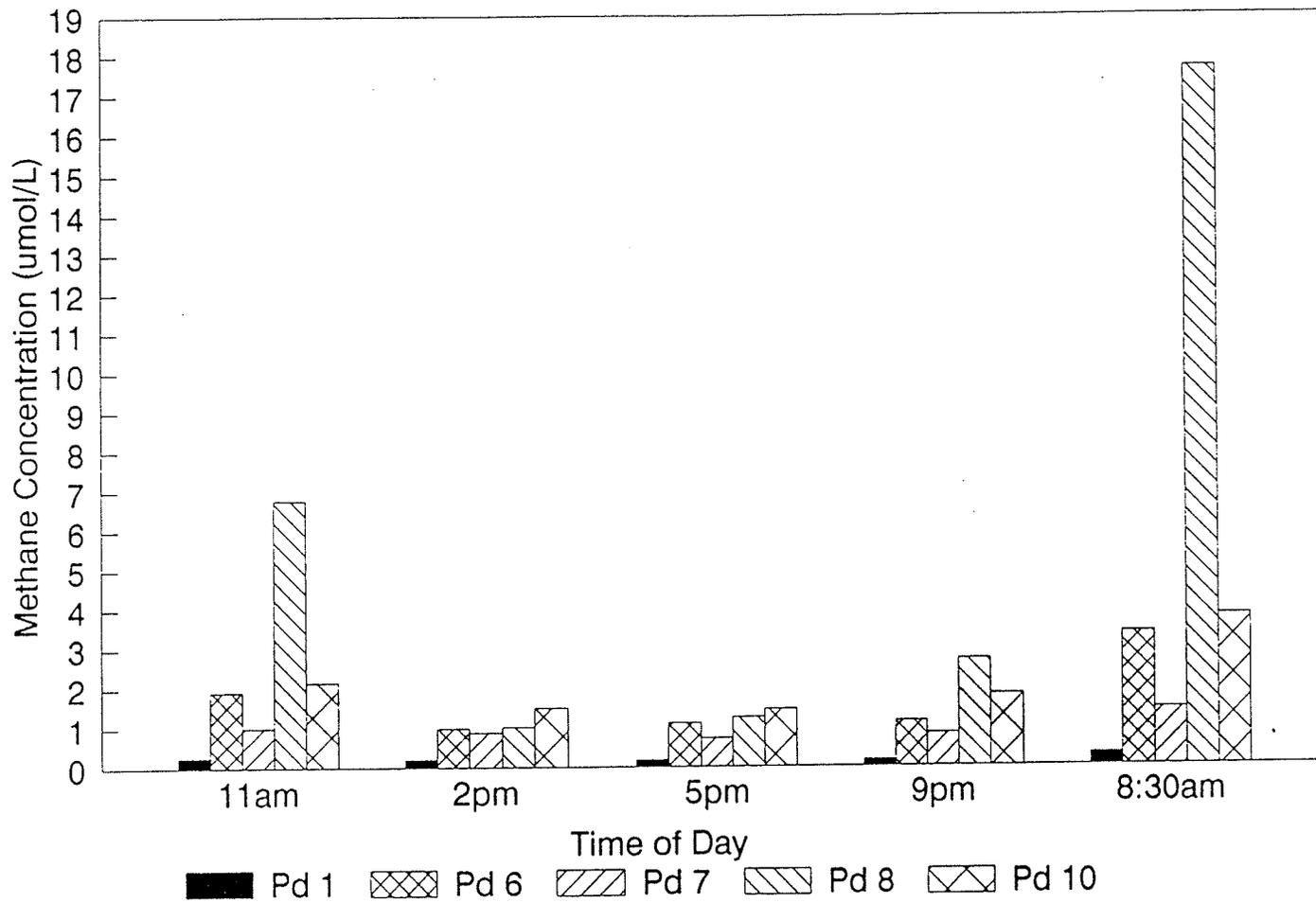


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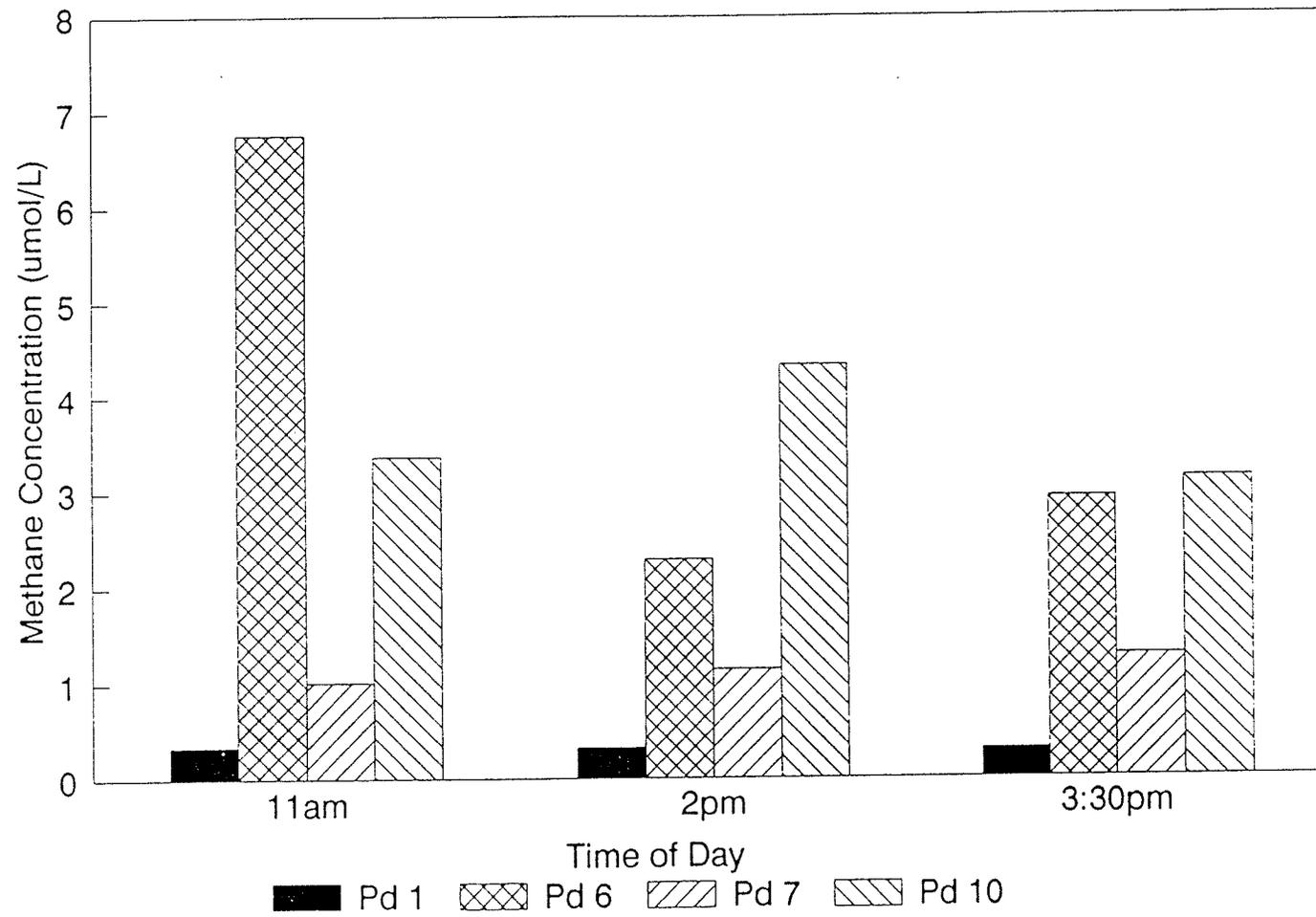


Figure A16. Methane concentration vs. time of day. Kinosheo Lake Bog, July 17, 1990.

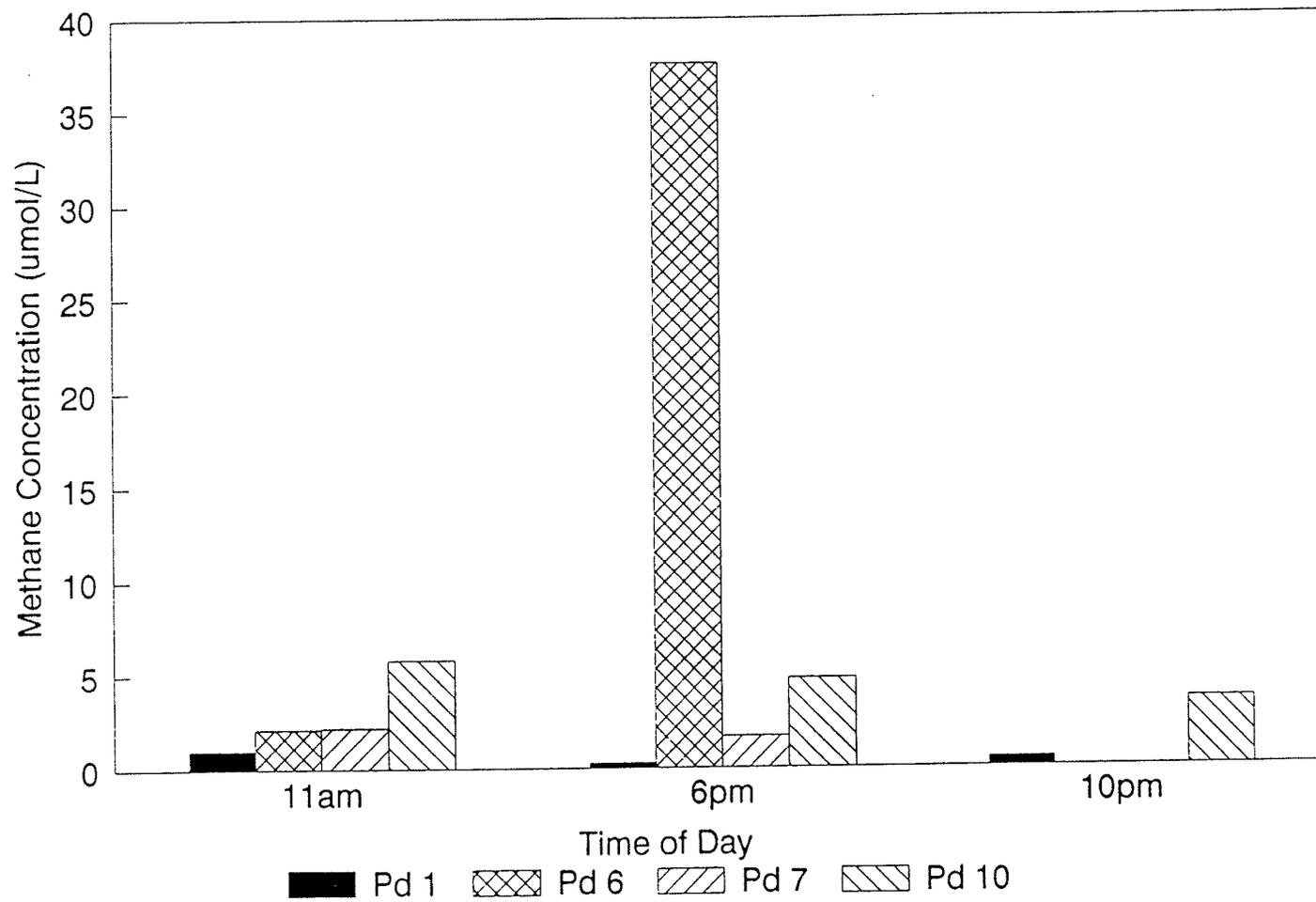


Figure A17. Methane concentration vs. time of day. Kinosheo Lake Bog, July 25, 1990.

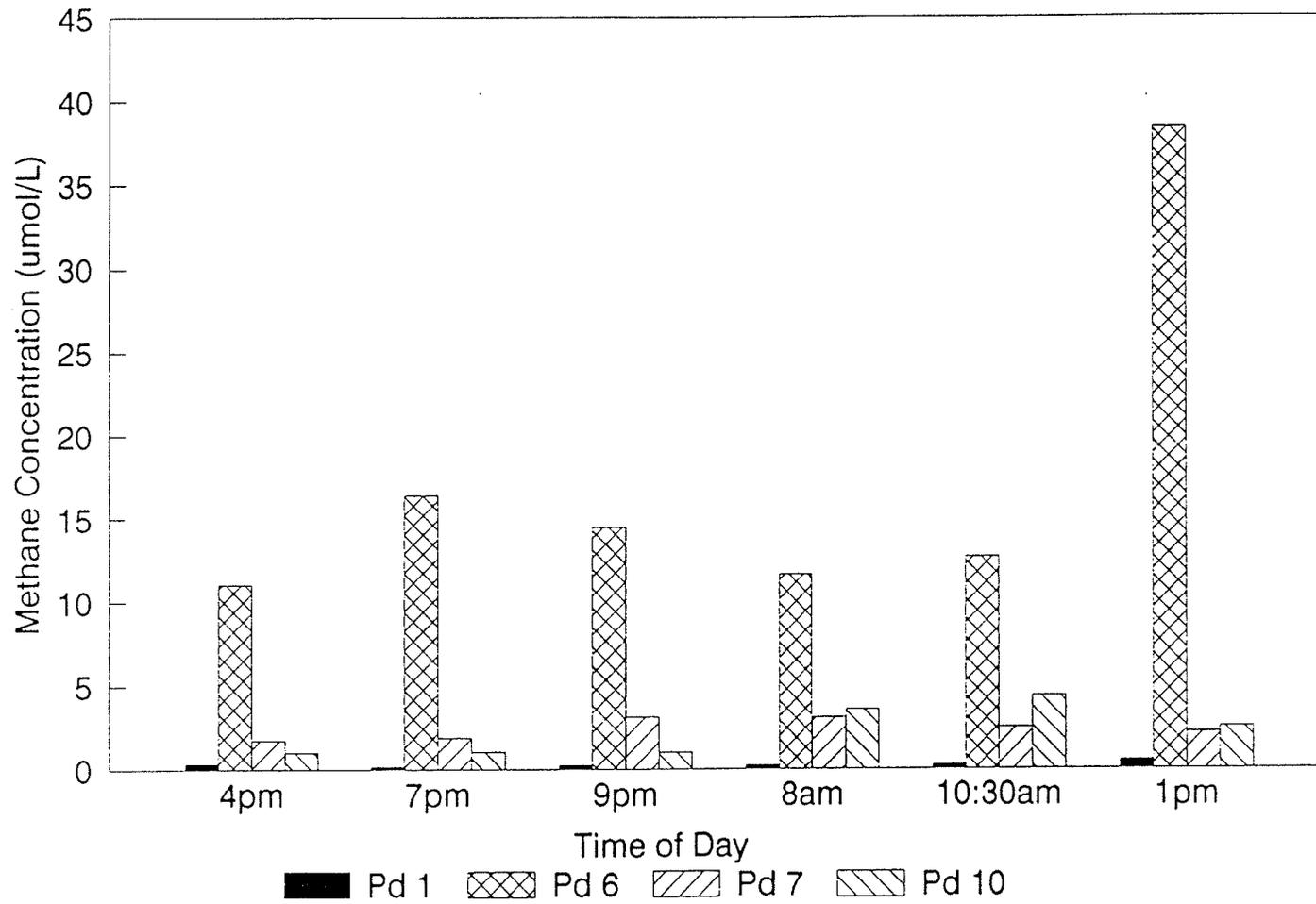


Figure A18. Methane concentration vs. time of day. Kinosheo Lake Bog, August 15-16, 1990.

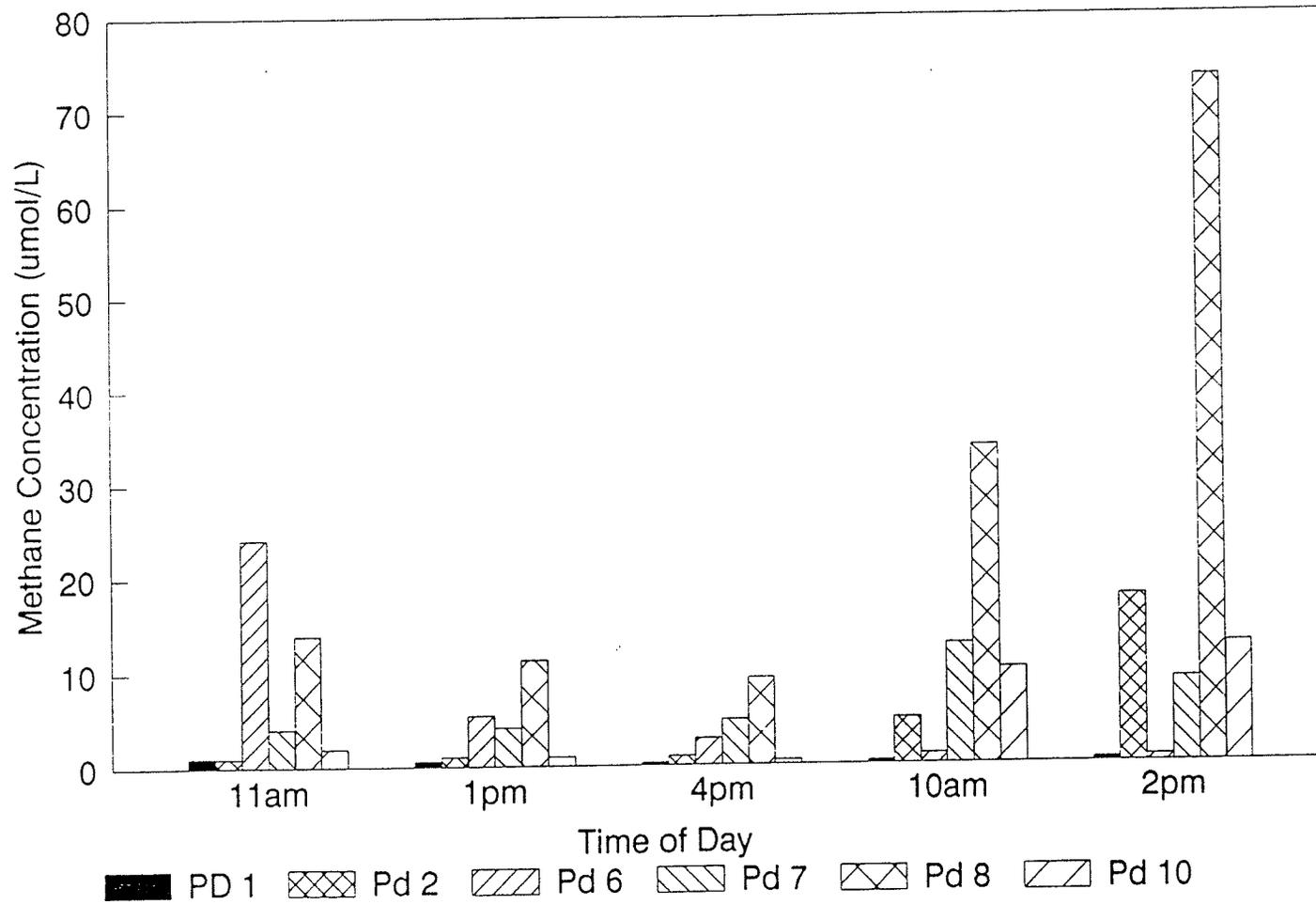


Figure A19. Methane concentration vs. time of day. Kinoshoe Lake Bog, September 12-13, 1990.

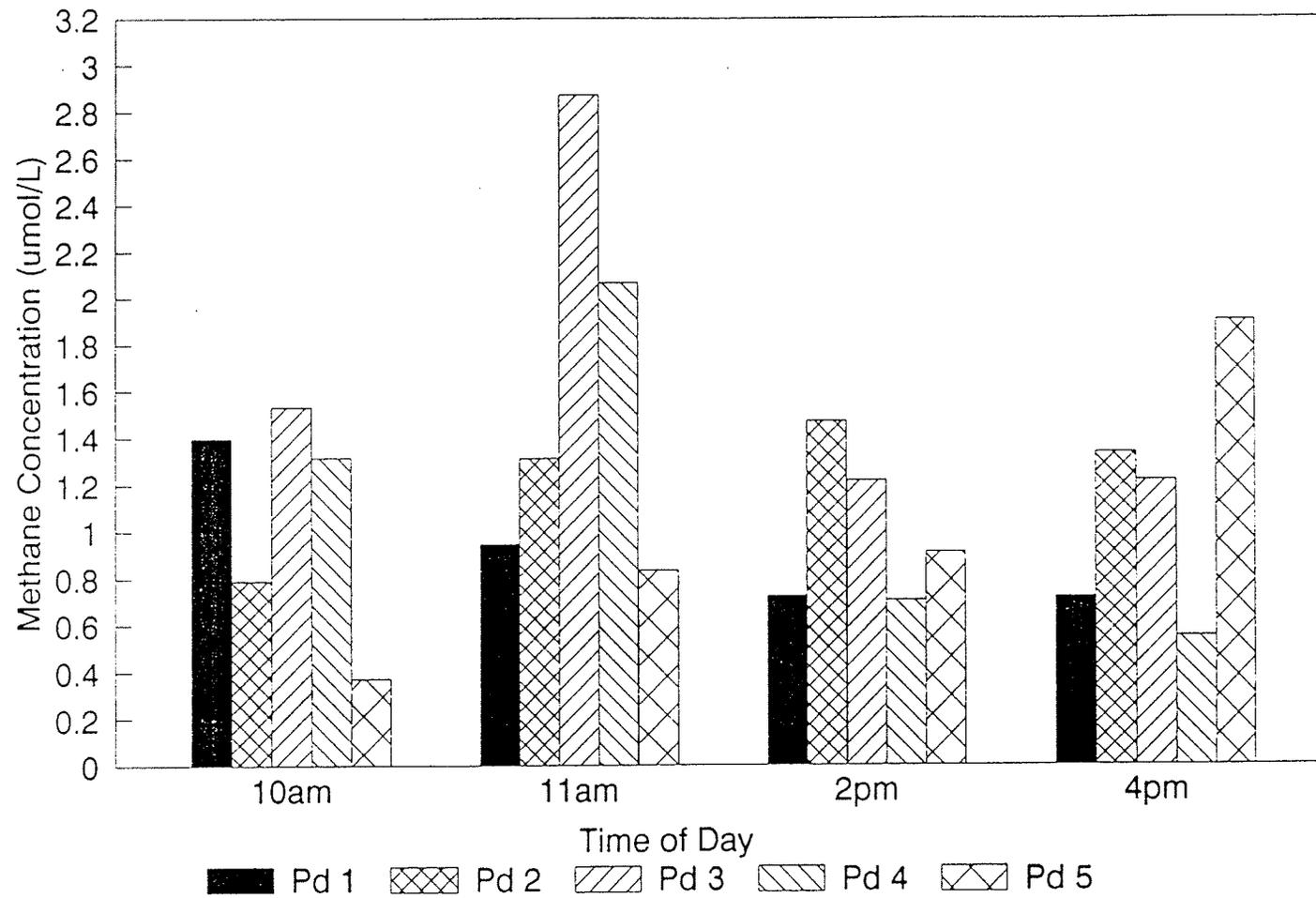


Figure A20. Methane concentration vs. time of day. Kinosheo Lake Bog (Ponds 1-5), October 12, 1990.

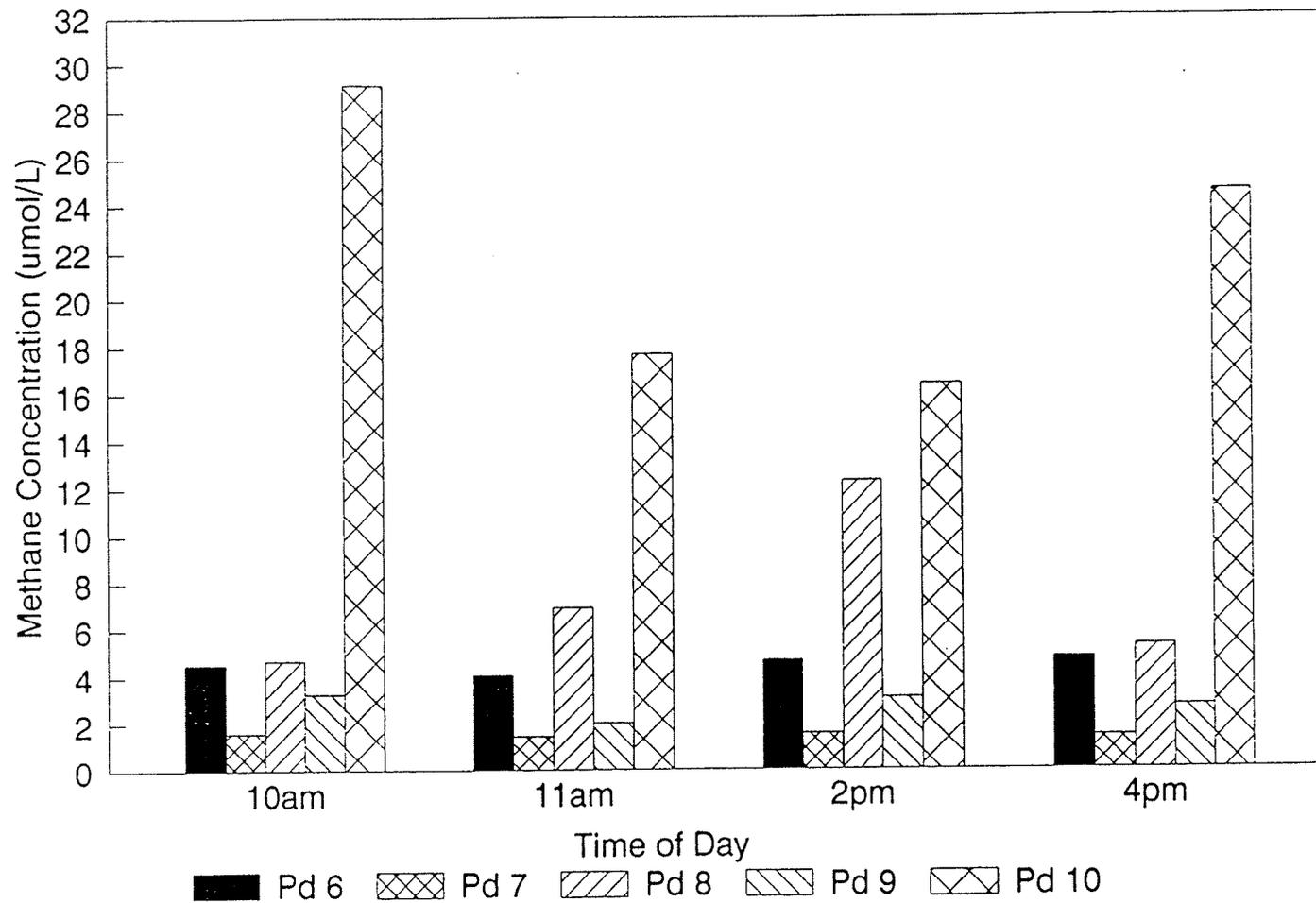


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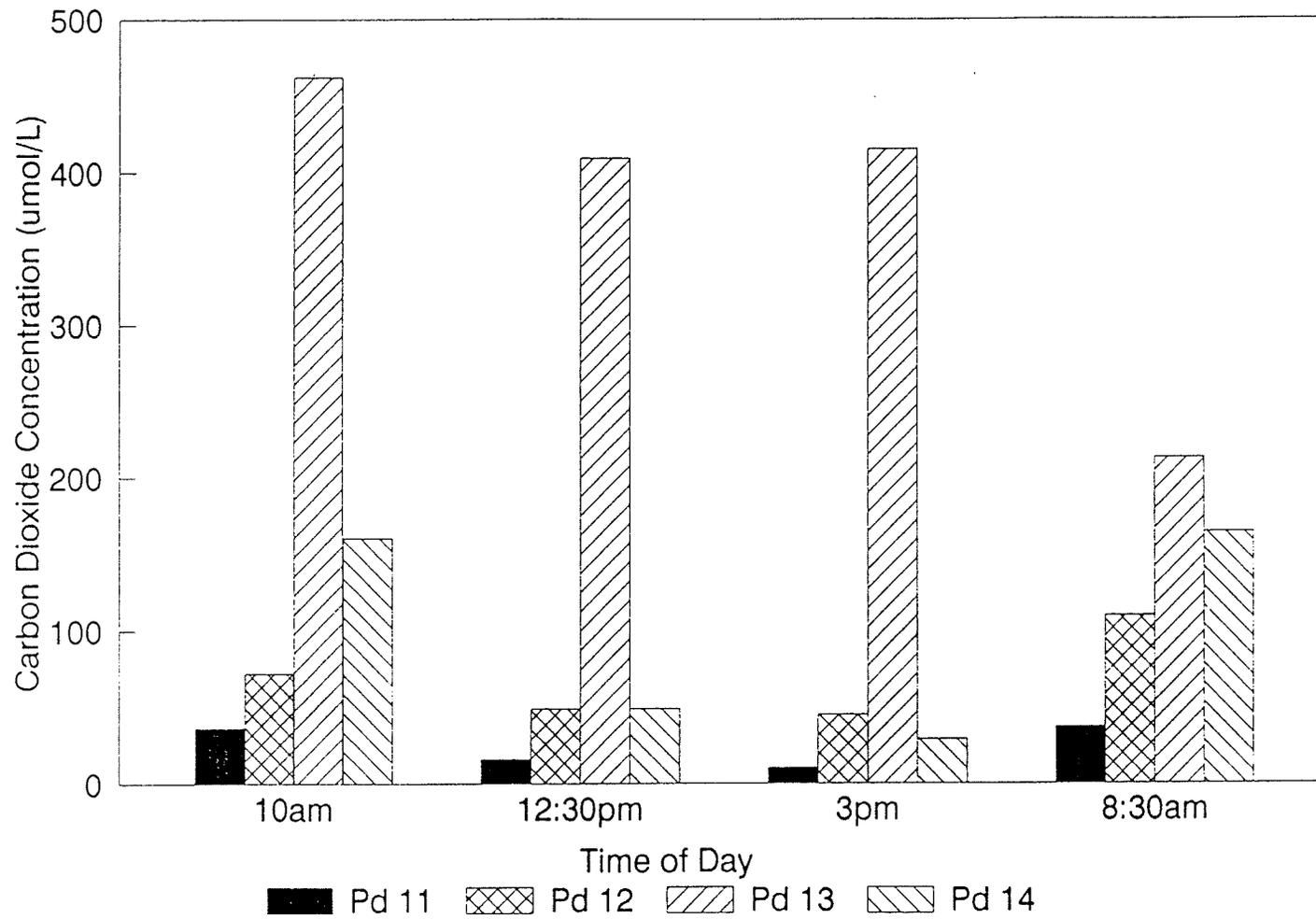


Figure A22. Carbon Dioxide concentration vs. time of day. Coastal Fen (Ponds 11-14), July 09-10, 1990.

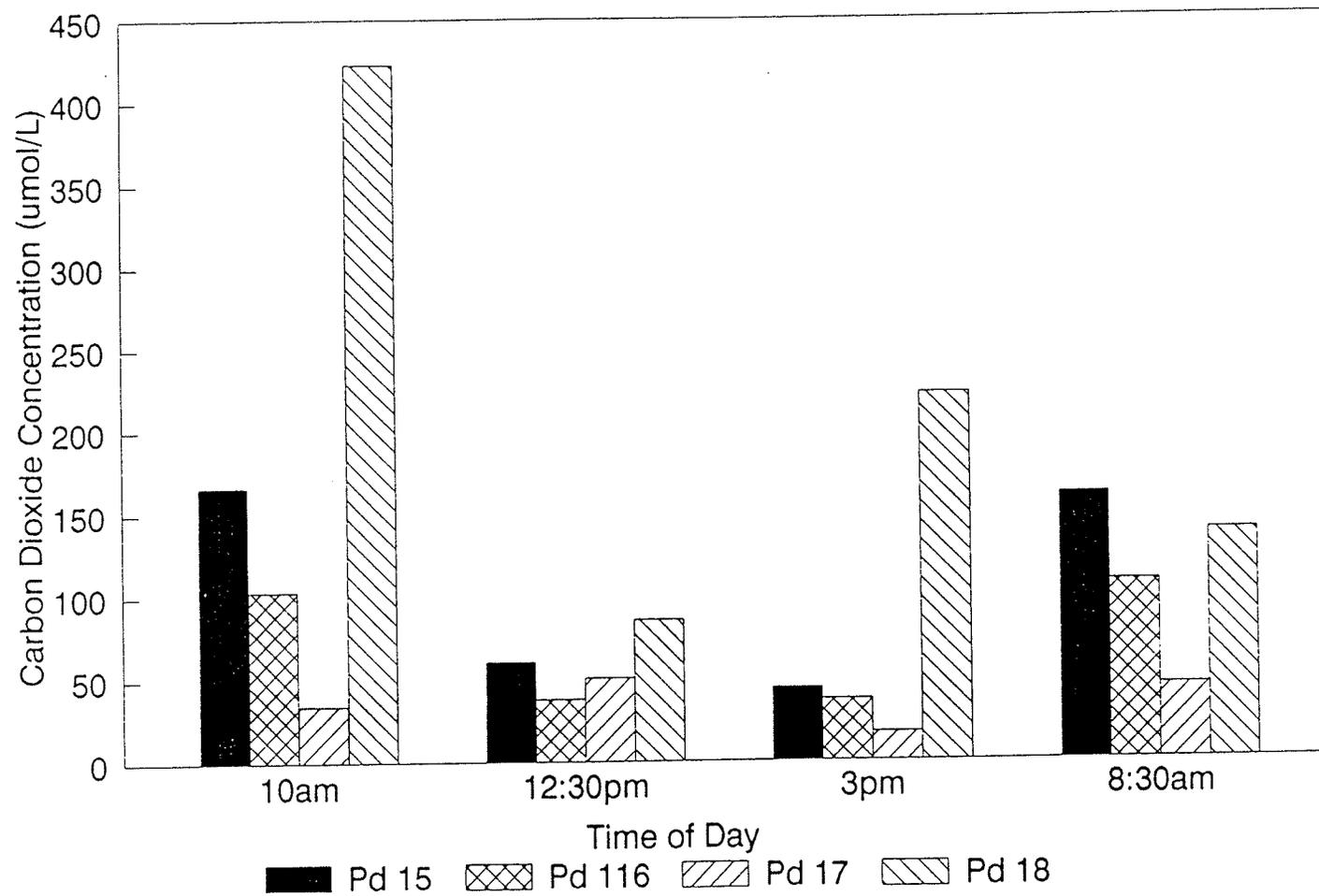


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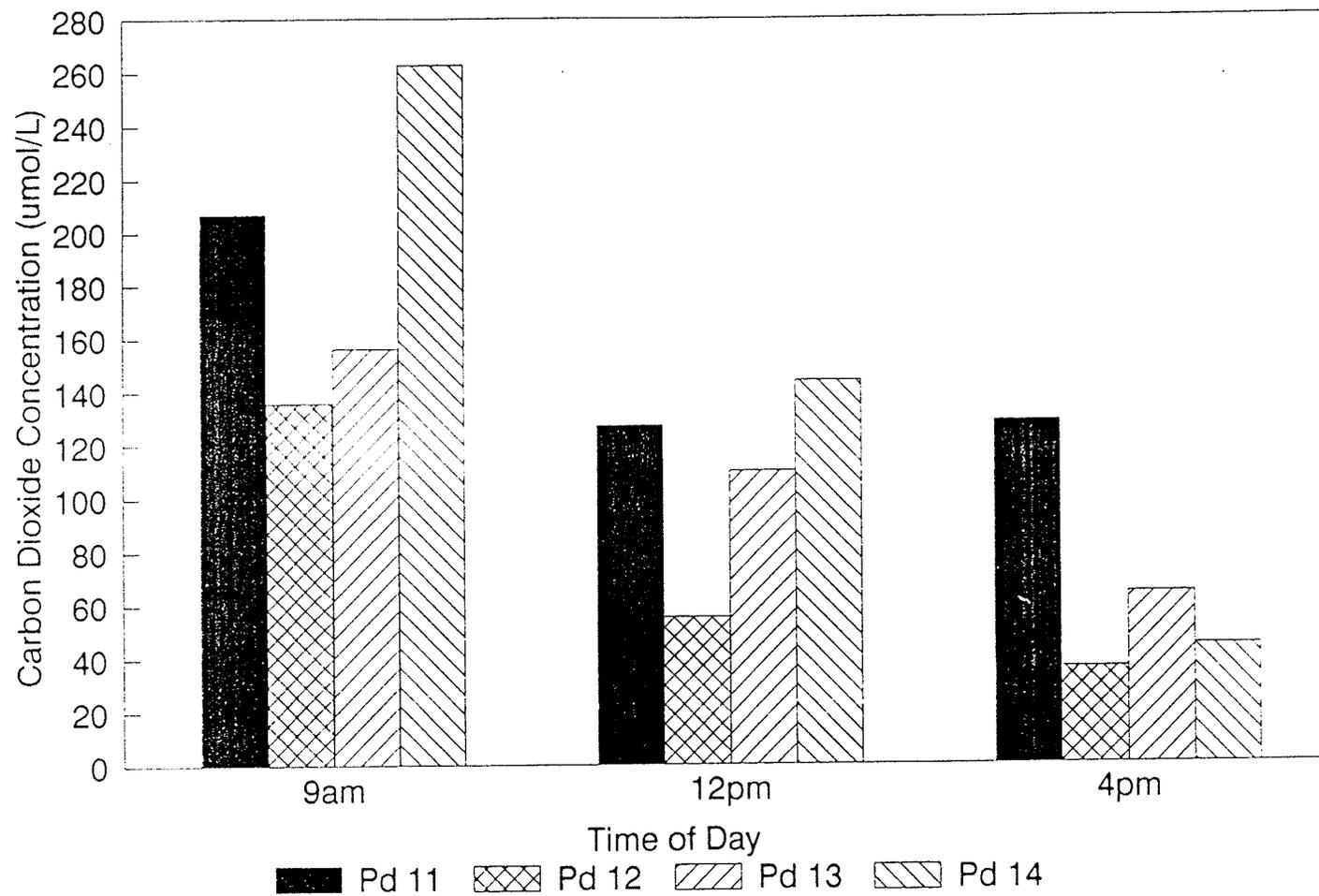


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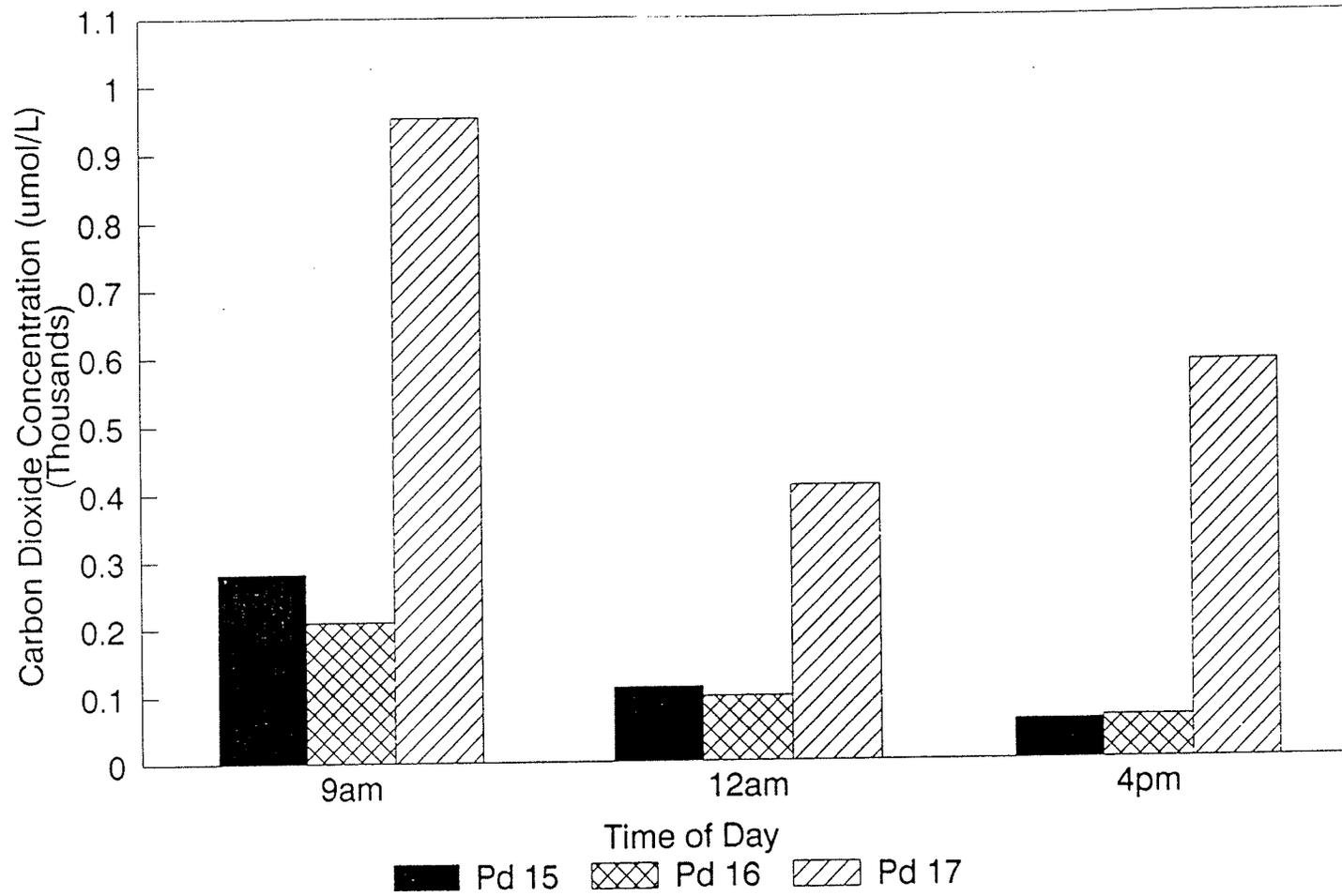


Figure A25. Carbon Dioxide concentration vs. time of day. Coastal Fen (Ponds 15-17), July 24, 1990.

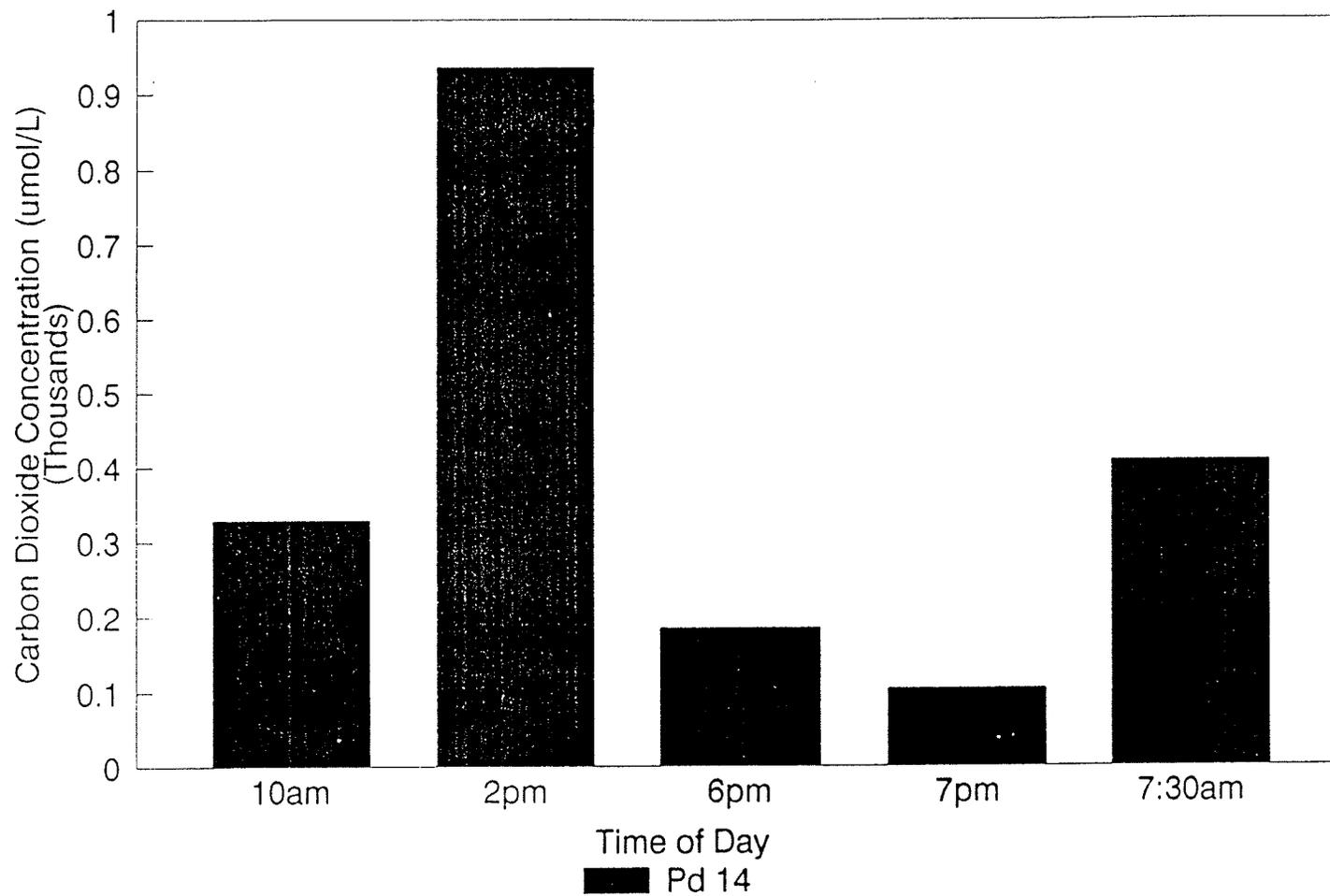


Figure A26. Carbon Dioxide concentration vs. time of day. Coastal Fen, August 14-15, 1990.

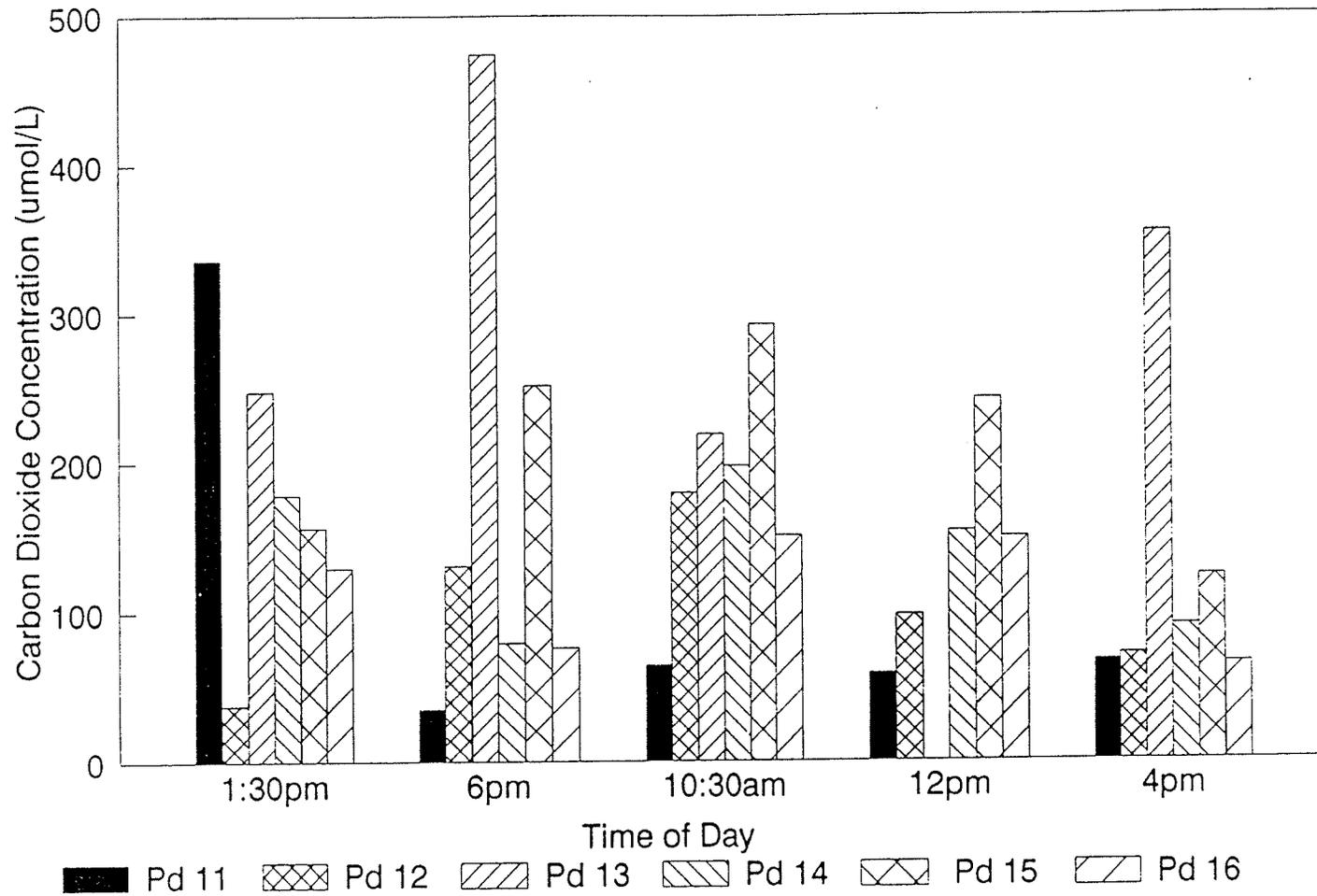


Figure A27. Carbon Dioxide concentration vs. time of day. Coastal Fen, September 10-11, 1990.

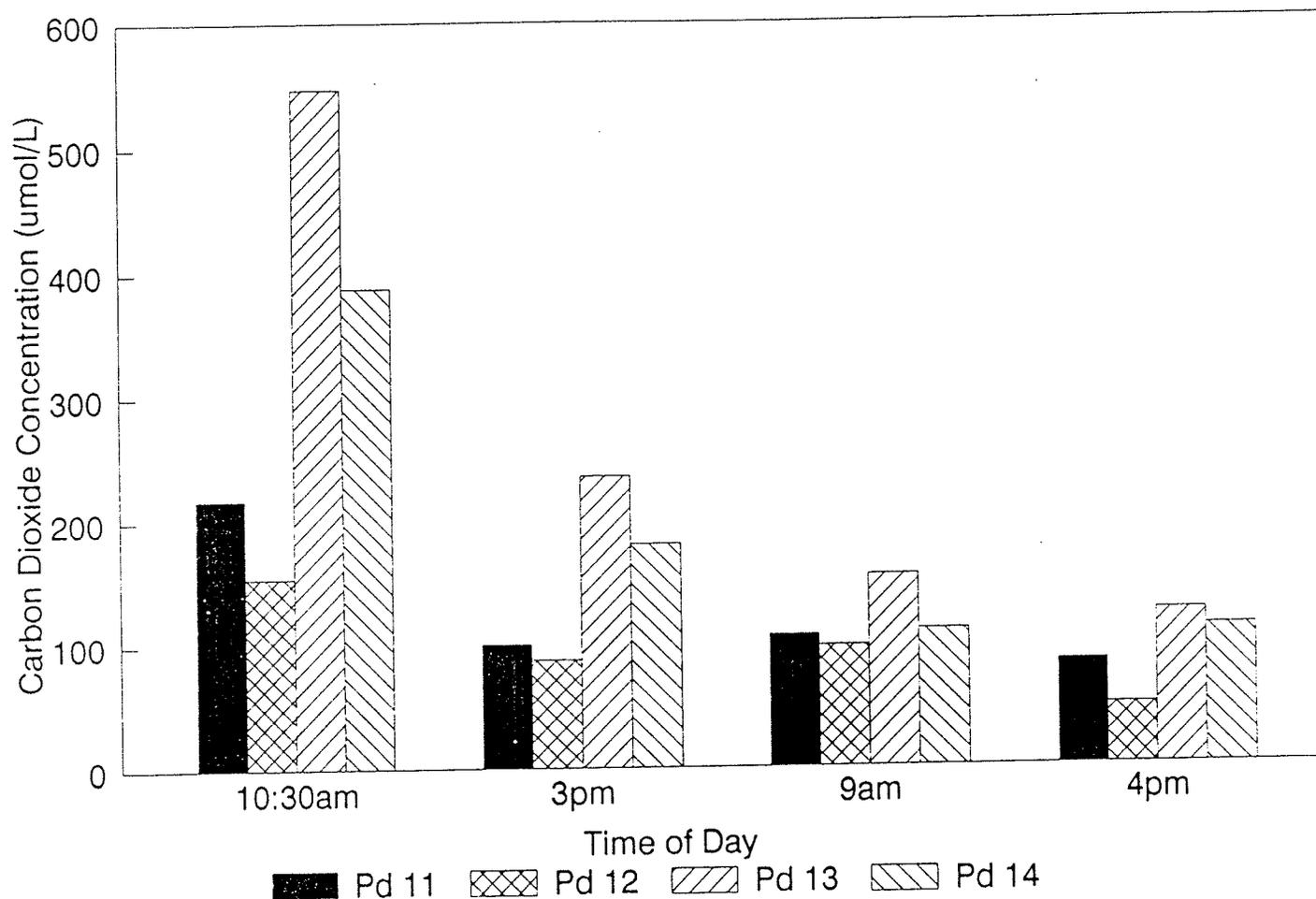


Figure A28. Carbon Dioxide concentration vs. time of day. Coastal Fen (Ponds 11-14), October 10-11, 1990.

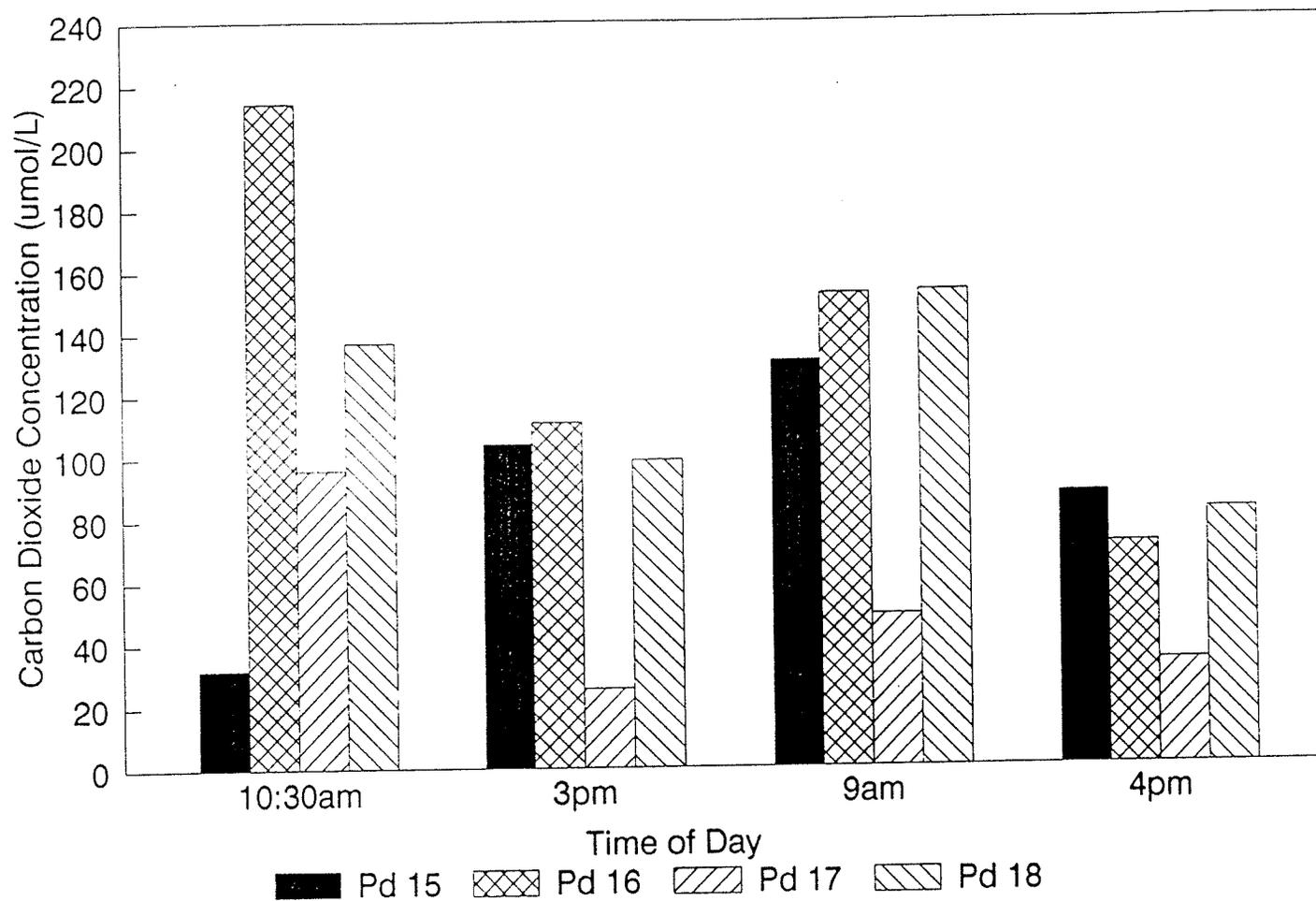


Figure A29. Carbon Dioxide concentration vs. time of day. Coastal Fen (Ponds 15-18), October 10-11, 1990.

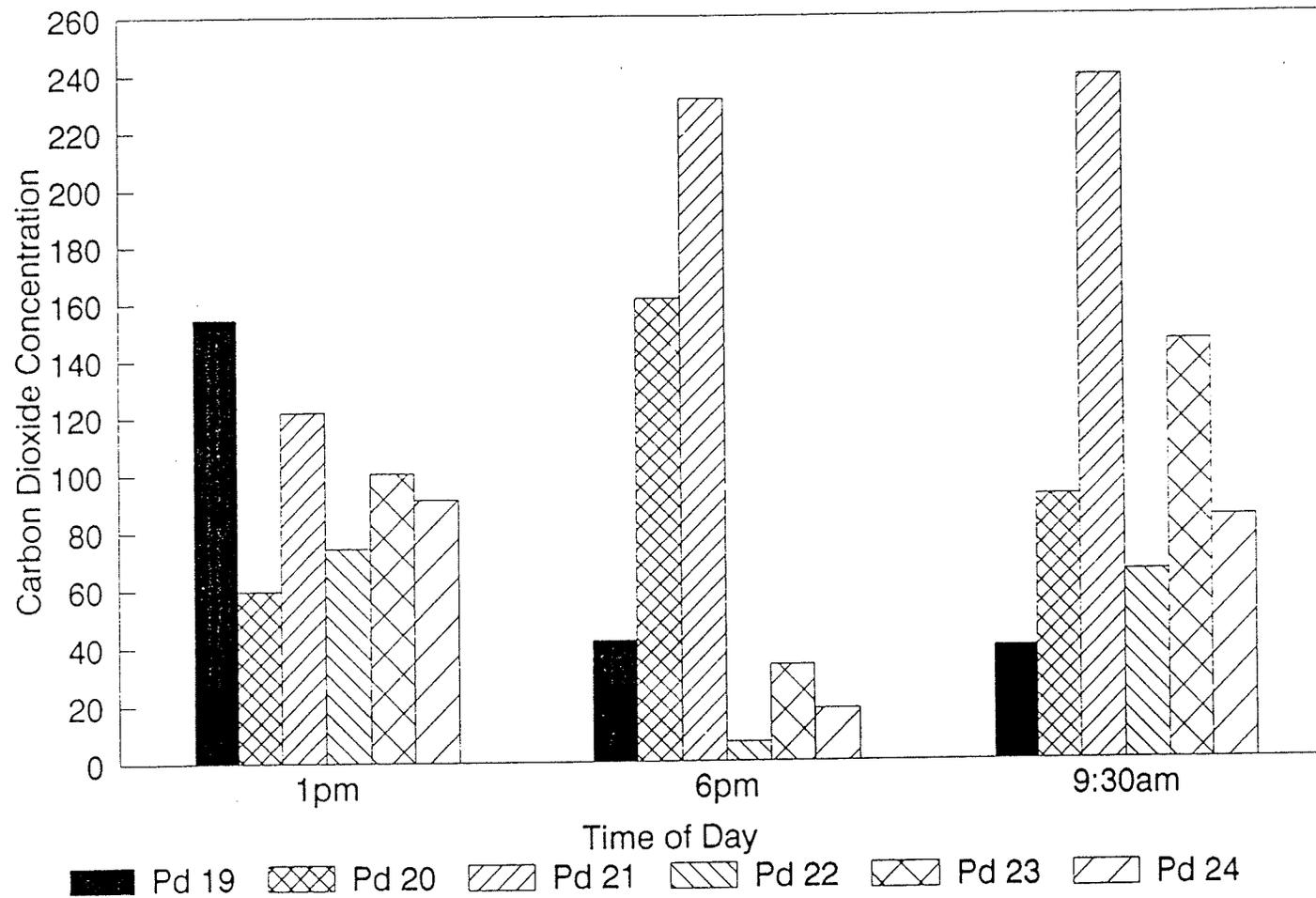


Figure A30. Carbon Dioxide concentration vs. time of day. Interior Fen, July 09-10, 1990.

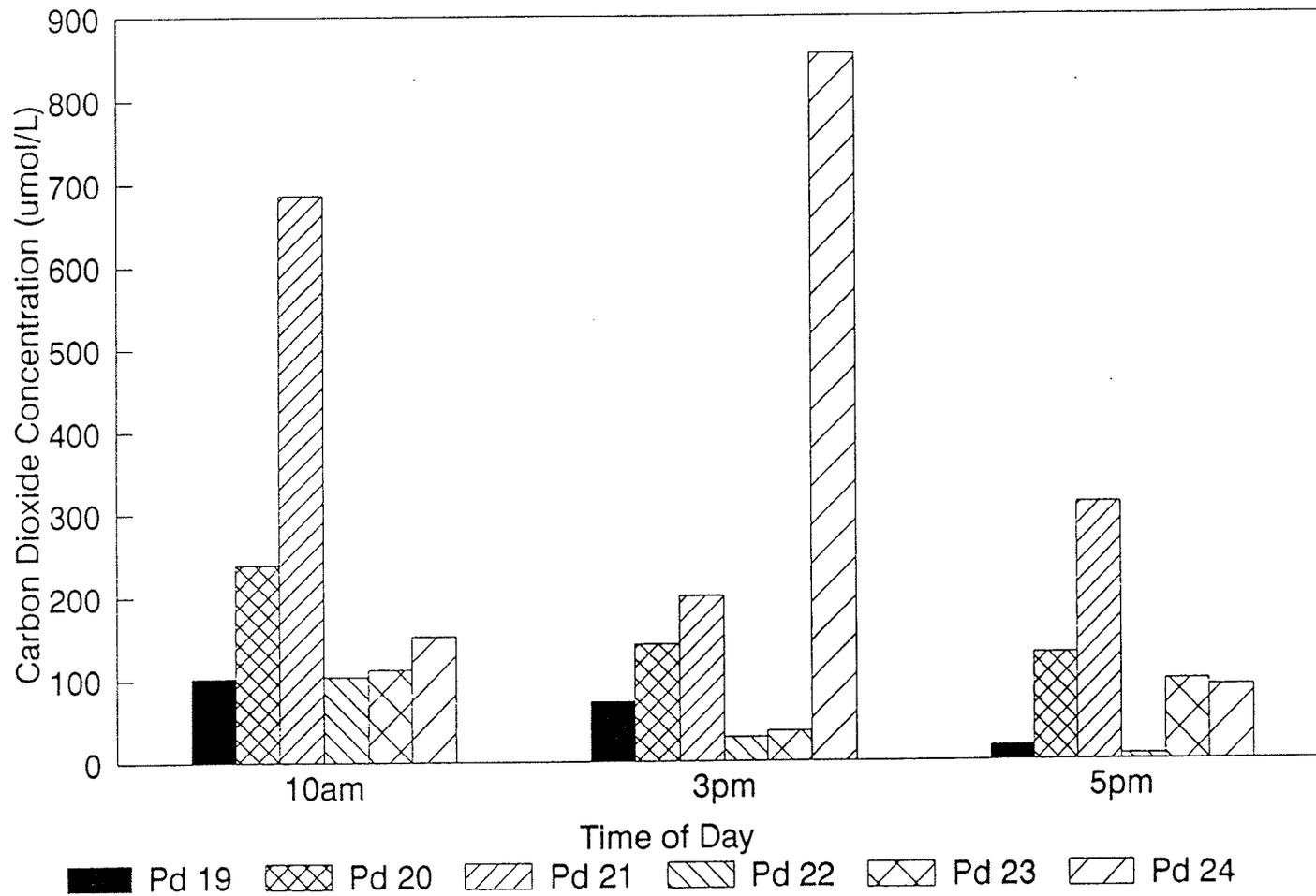


Figure A31. Carbon Dioxide concentration vs. time of day. Interior Fen, July 24, 1990.

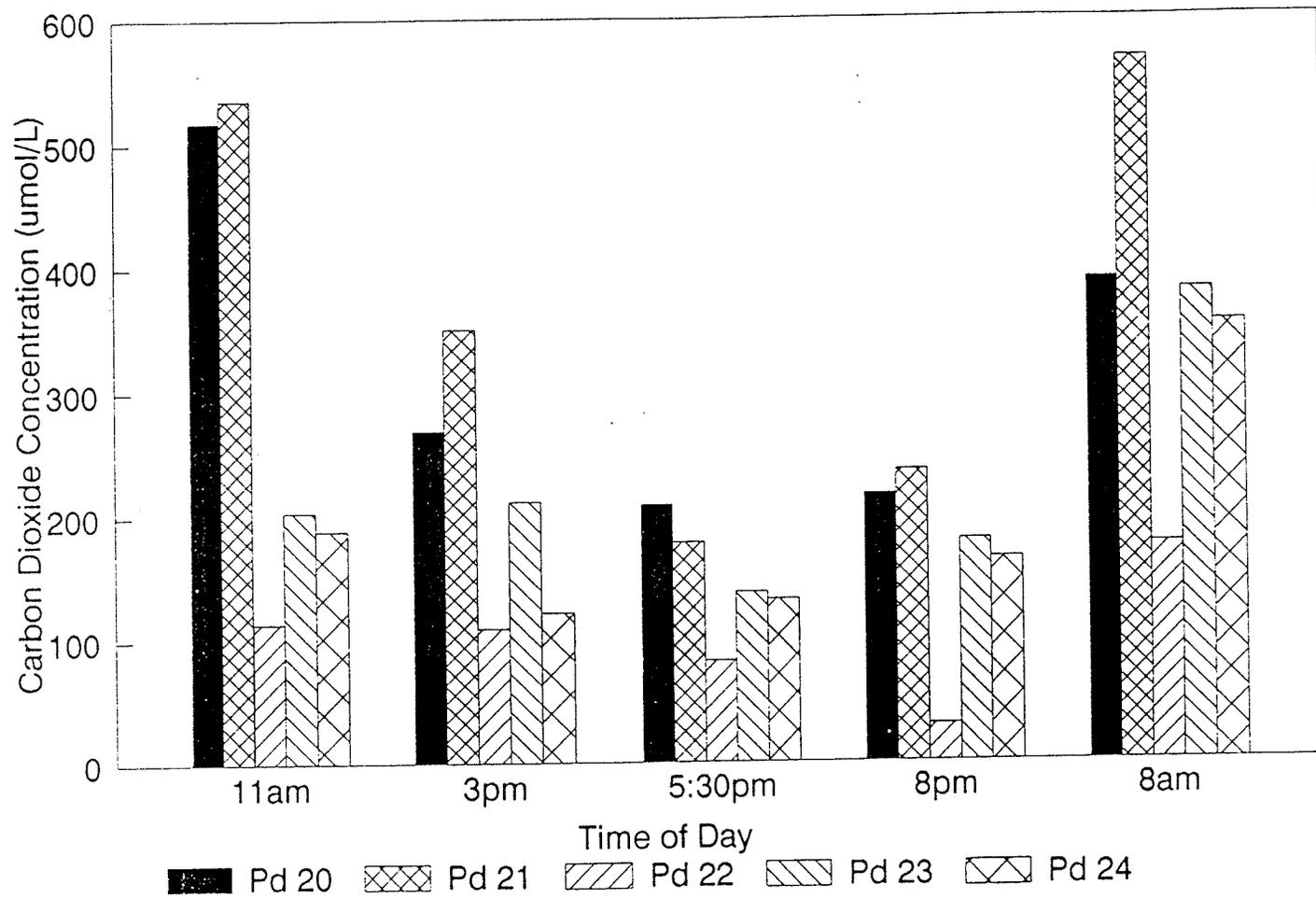


Figure A32. Carbon Dioxide concentration vs. time of day. Interior Fen, August 14-15, 1990.

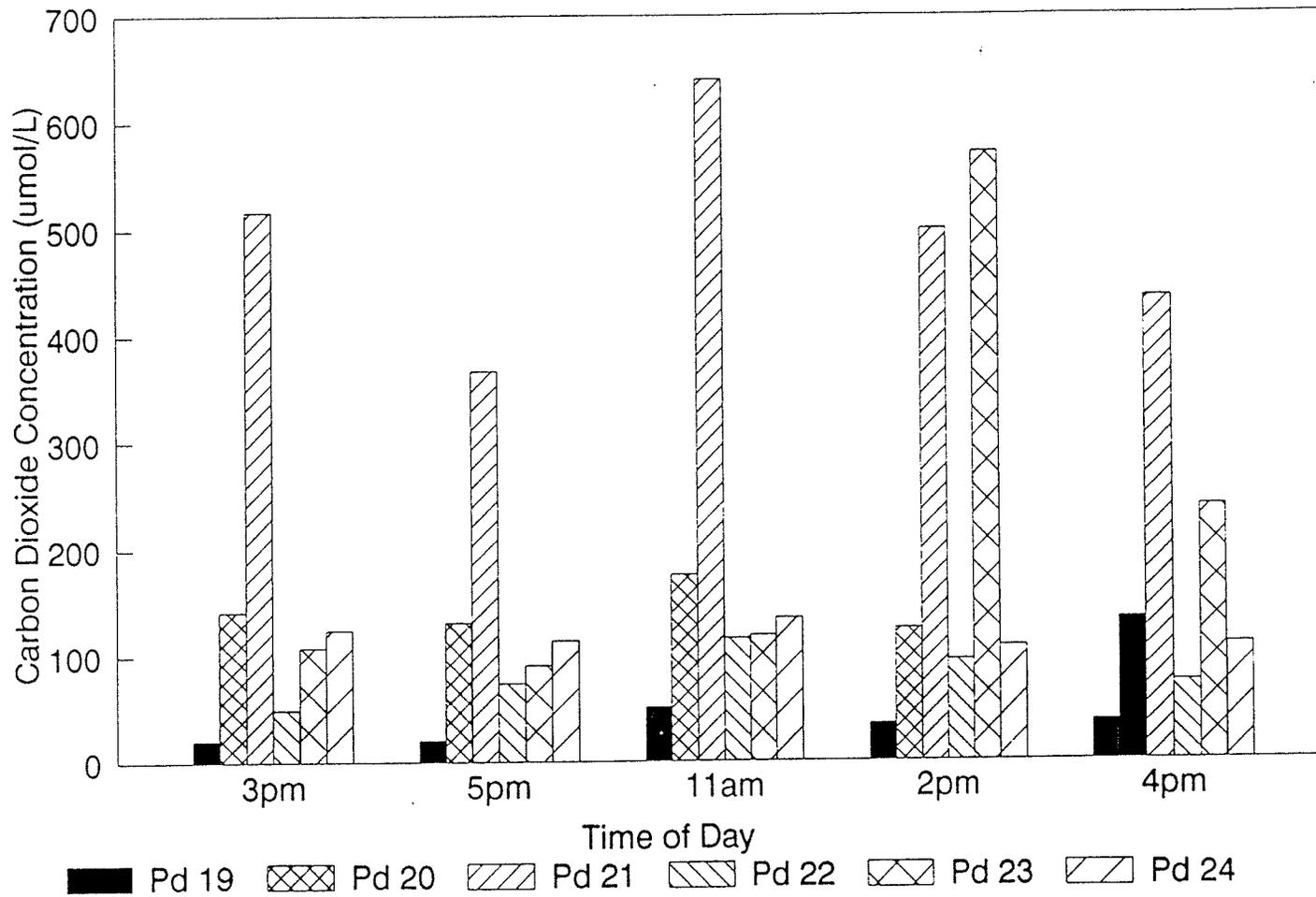


Figure A33. Carbon Dioxide concentration vs. time of day. Interior Fen, September 10-11, 1990.

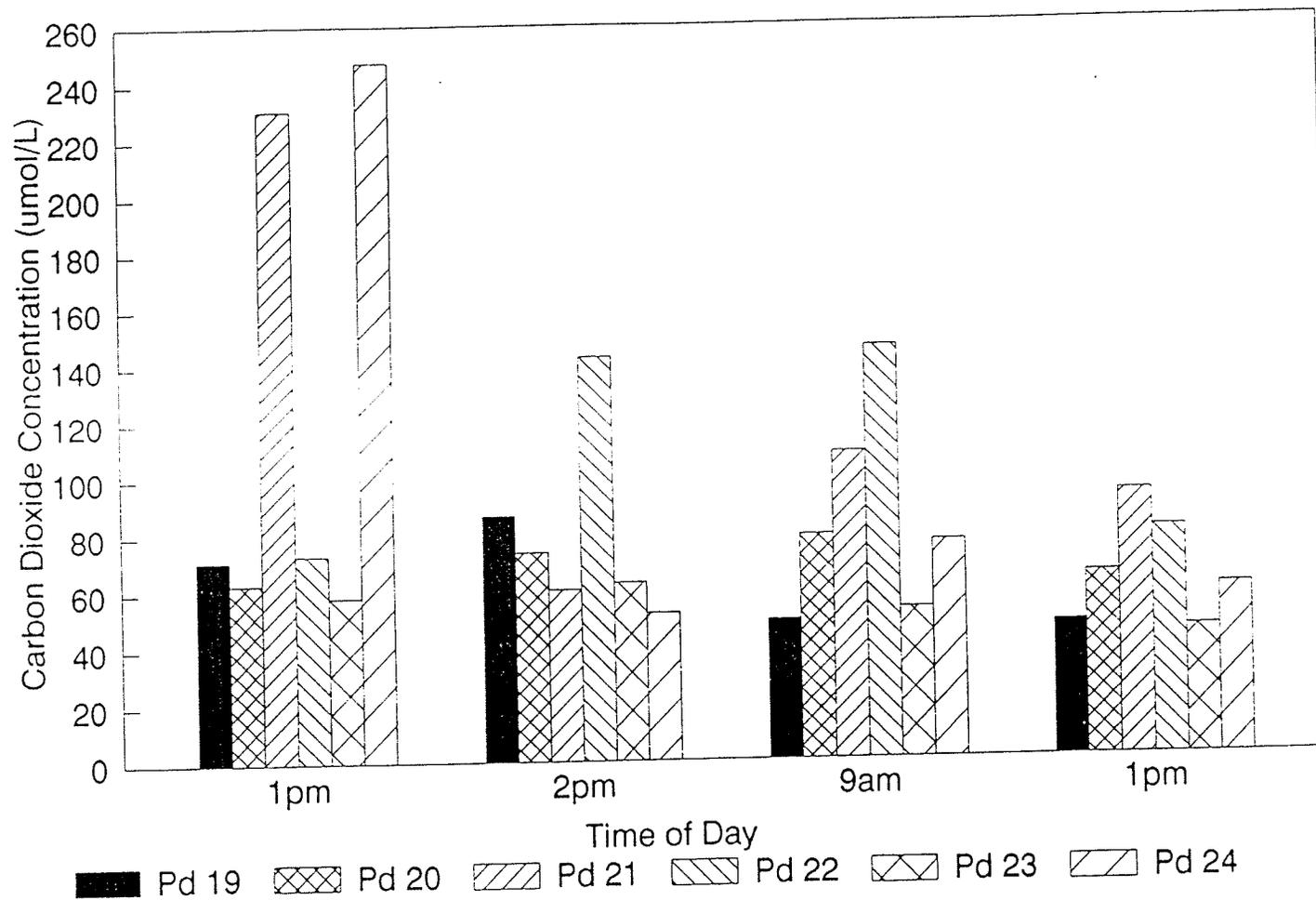


Figure A34. Carbon Dioxide concentration vs. time of day. Interior Fen, October 10-11, 1990.

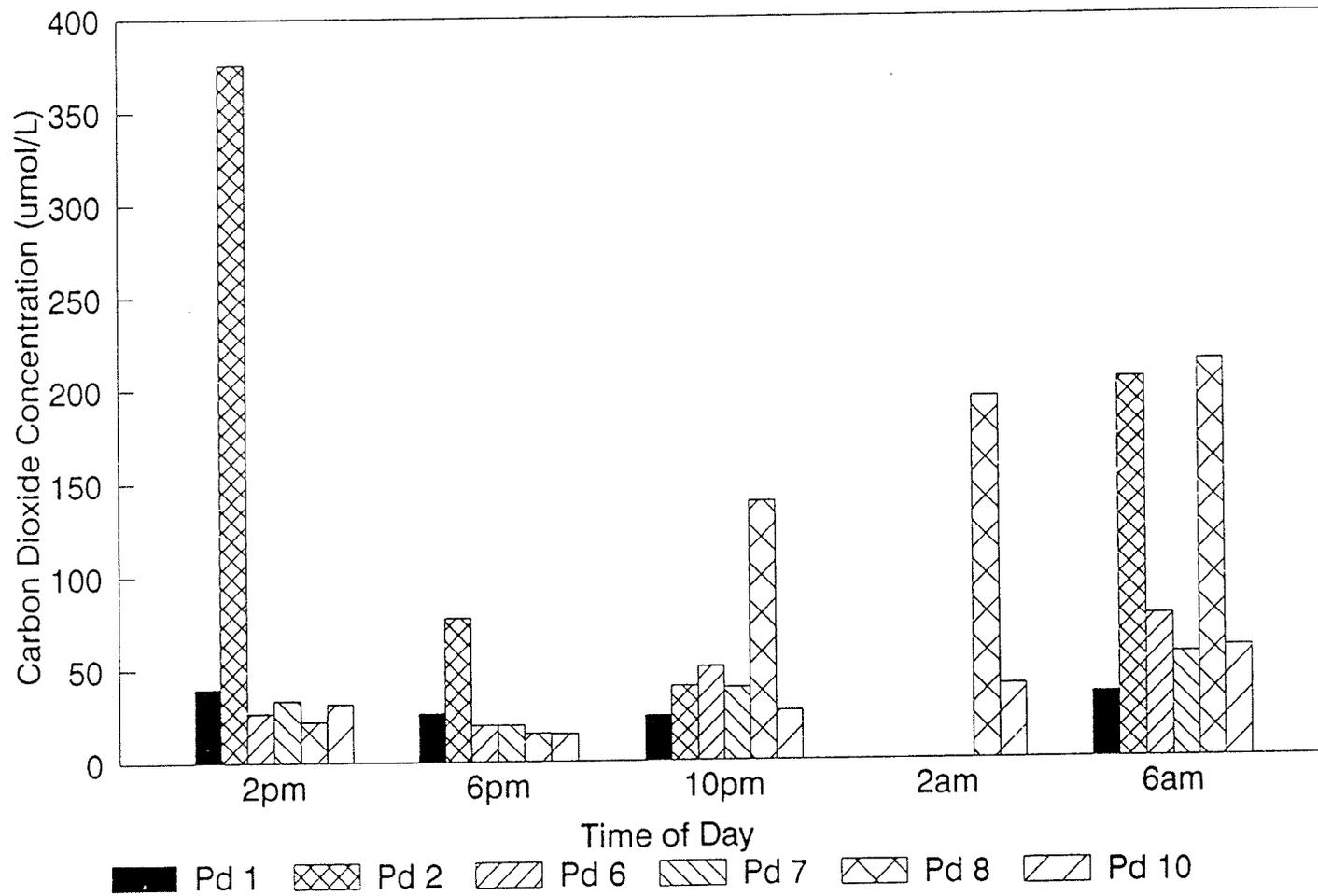


Figure A35. Carbon Dioxide concentration vs. time of day. Kinosheo Lake Bog, July 05-06, 1990.

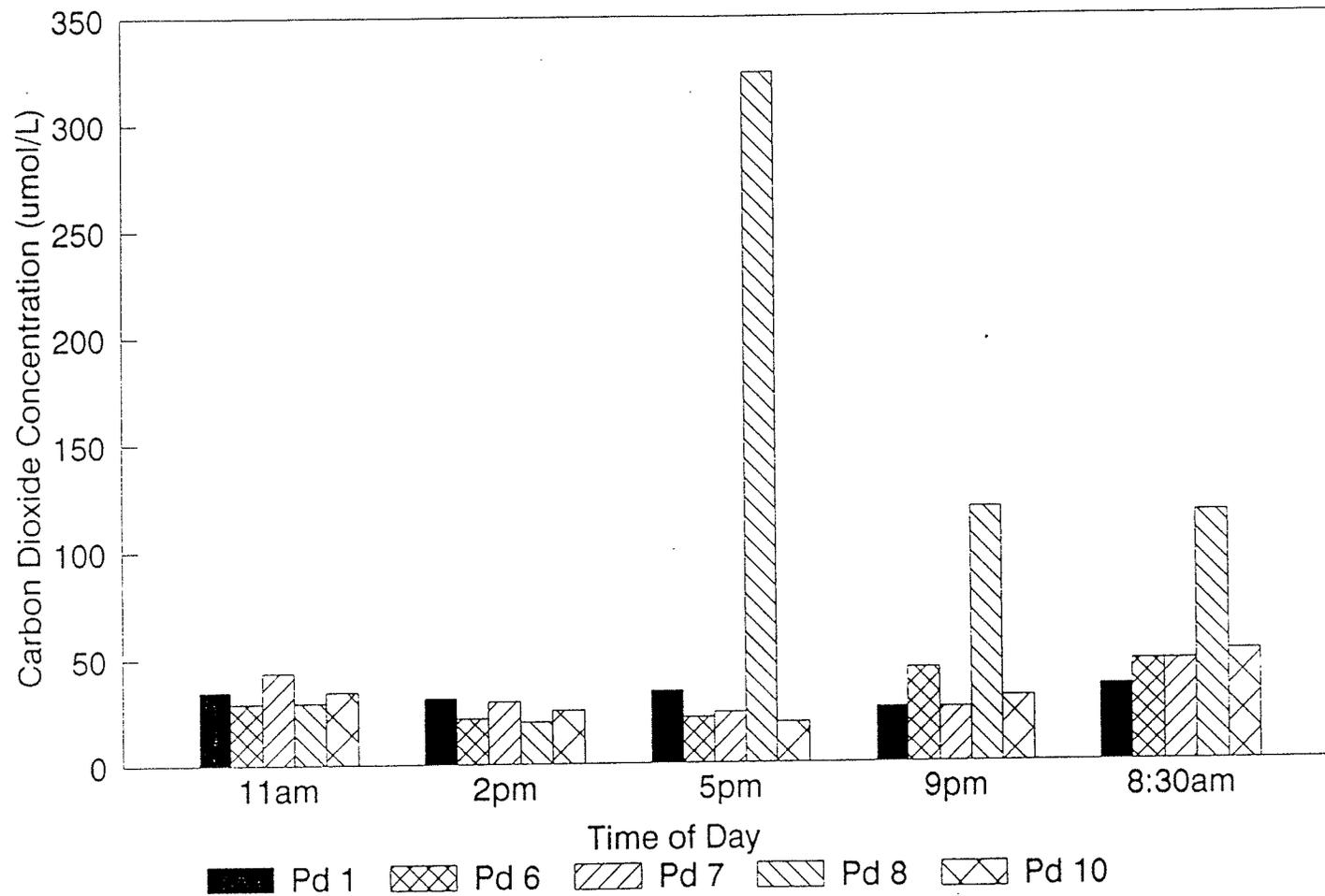


Figure A36. Carbon Dioxide concentration vs. time of day. Kinosheo Lake Bog, July 13-14, 1990.

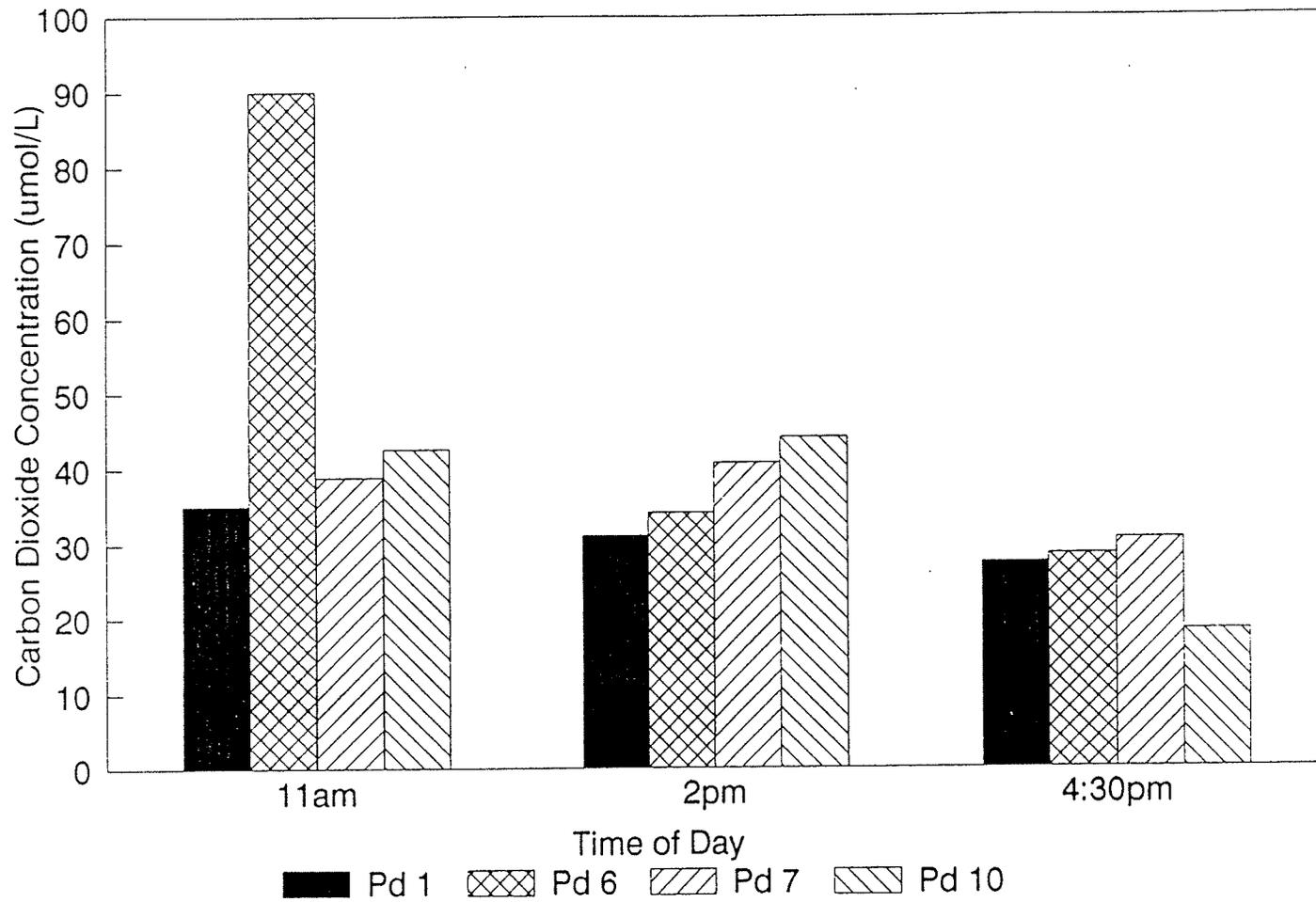


Figure A37. Carbon Dioxide concentration vs. time of day. Kinosheo Lake Bog, July 17, 1990.

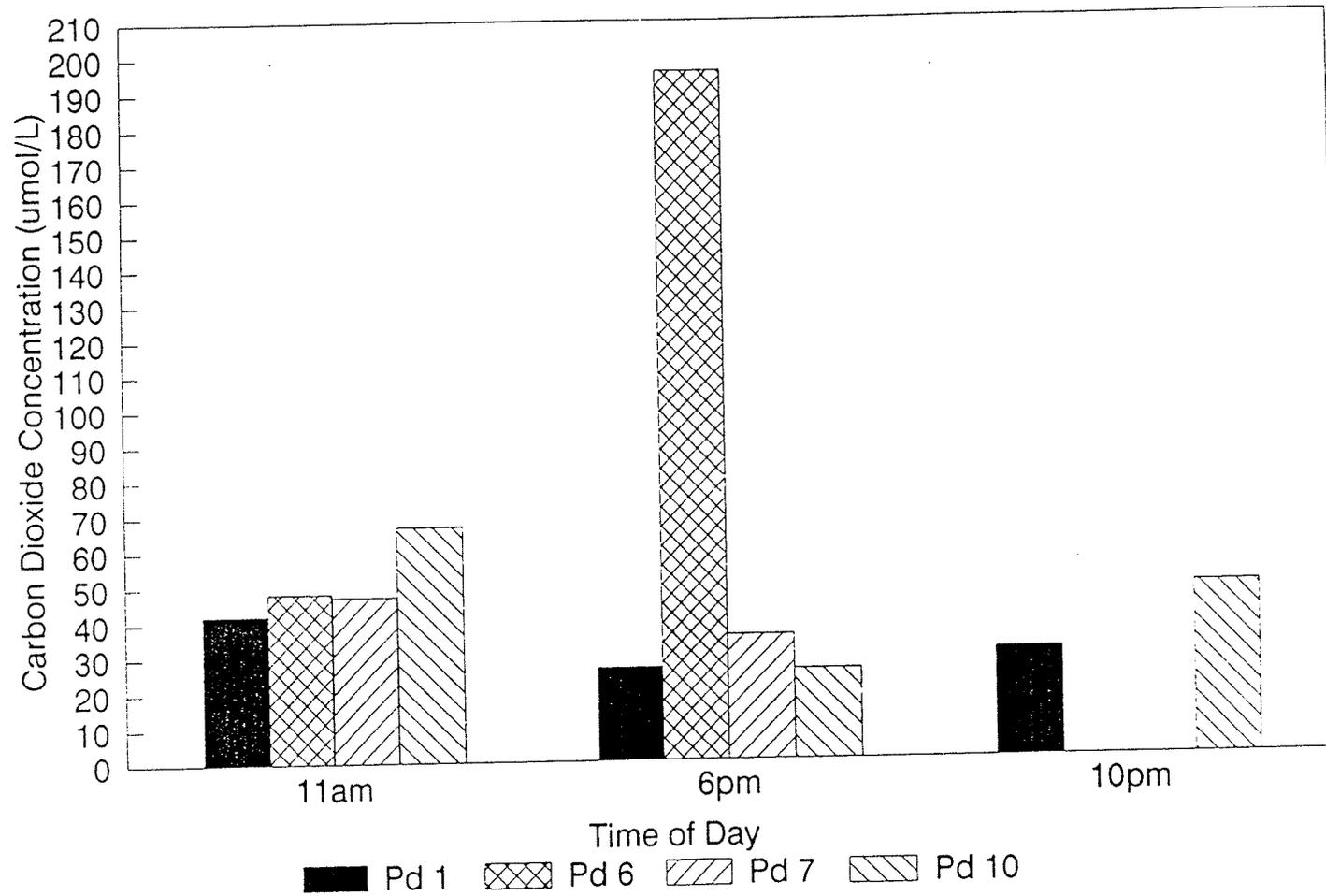


Figure A38. Carbon Dioxide concentration vs. time of day. Kinosheo Lake Bog, July 25, 1990.

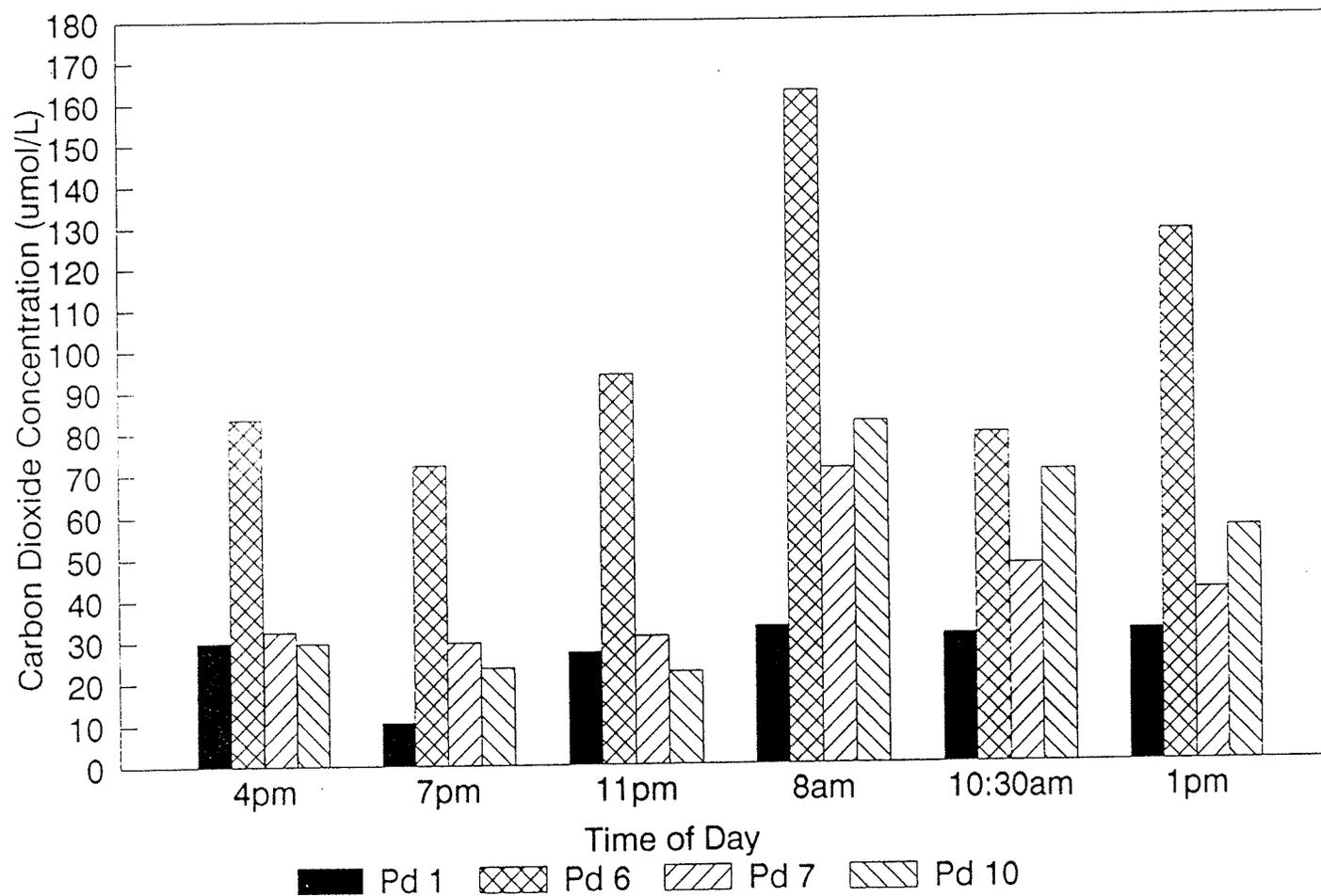


Figure A39. Carbon Dioxide concentration vs. time of day. Kinosheo Lake Bog, August 15-16, 1990.

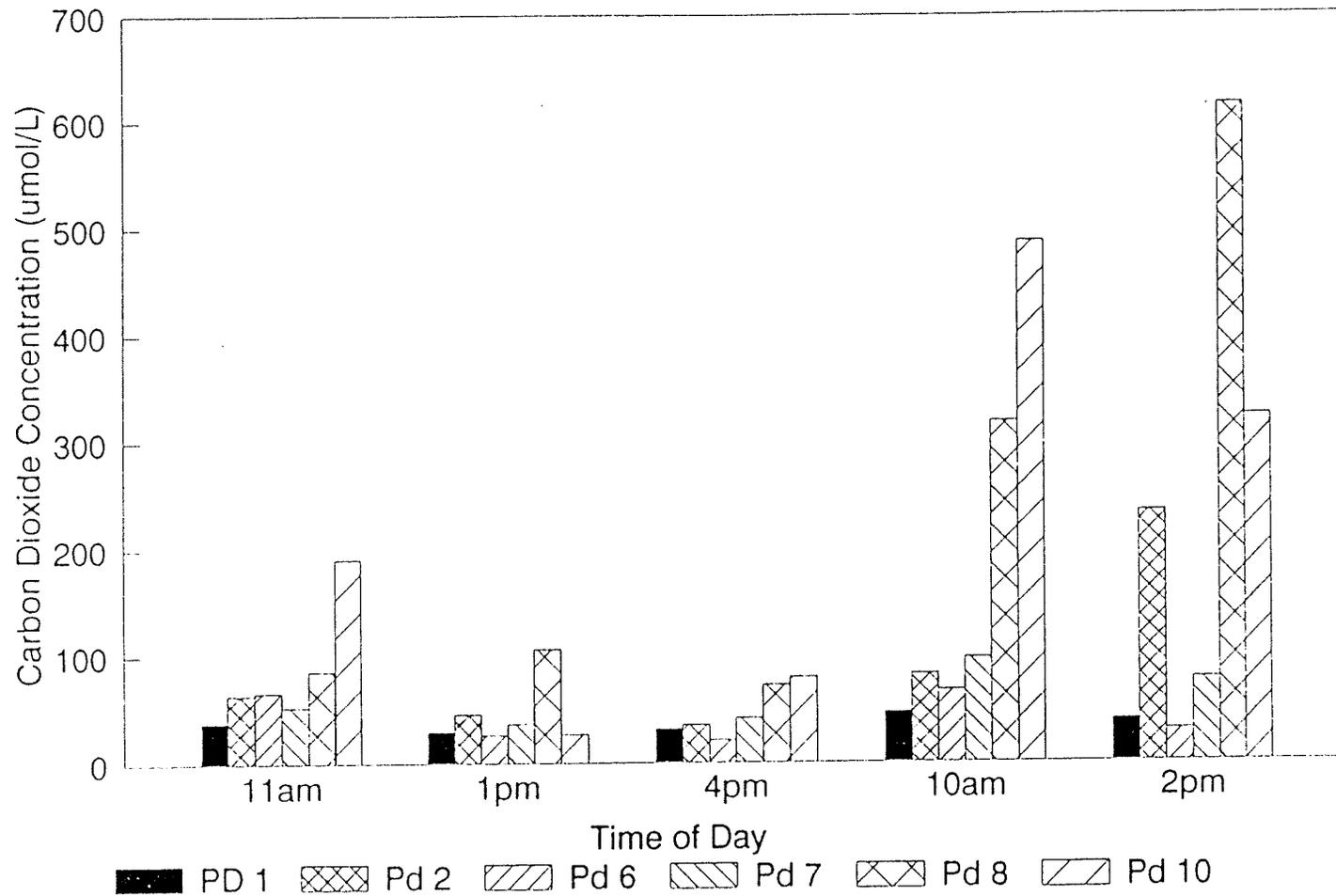


Figure A40. Carbon Dioxide concentration vs. time of day. Kinosheo Lake Bog, September 12-13, 1990.

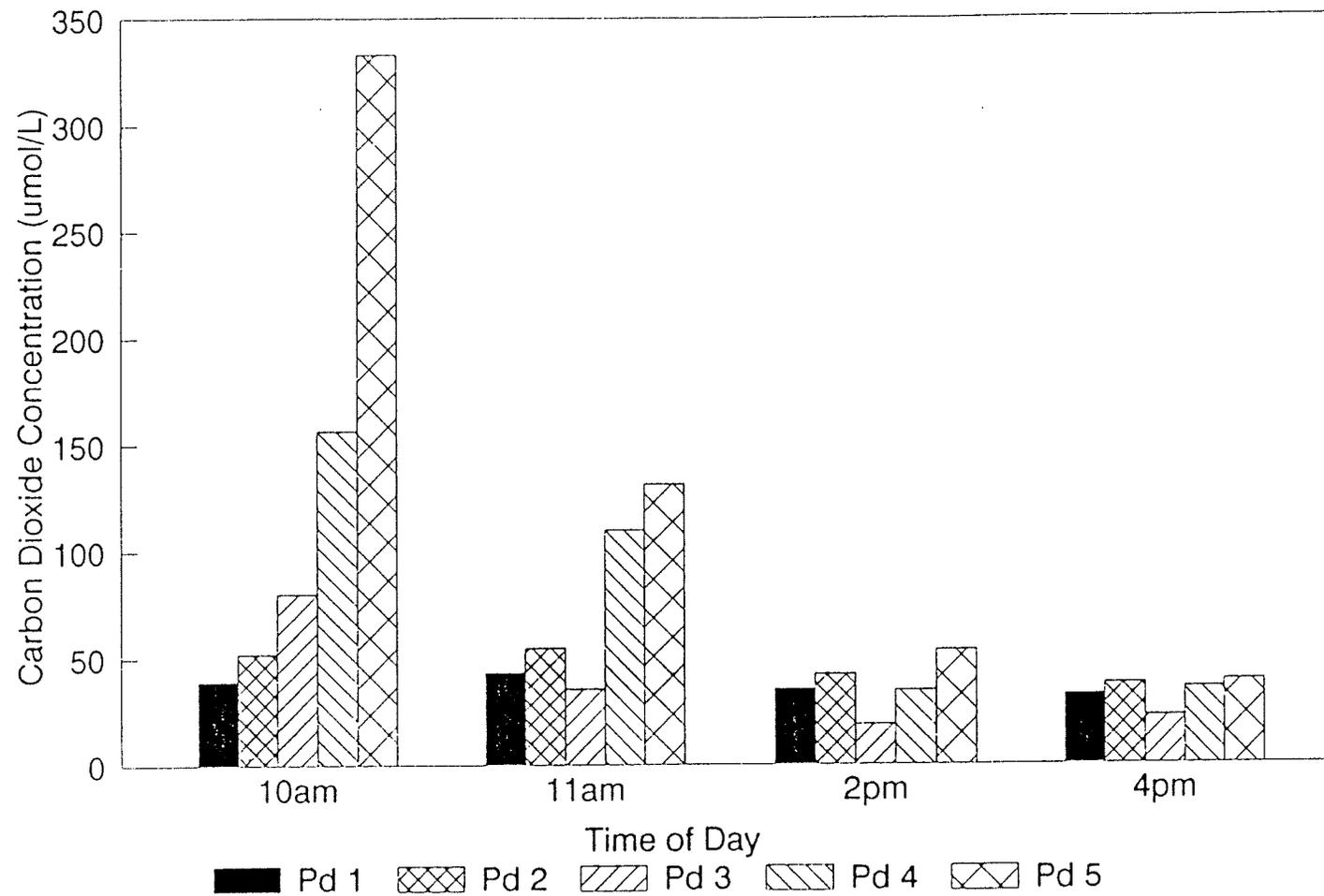


Figure A41. Carbon Dioxide concentration vs. time of day. Kinosheo Lake Bog (Ponds 1-5), October 12, 1990.

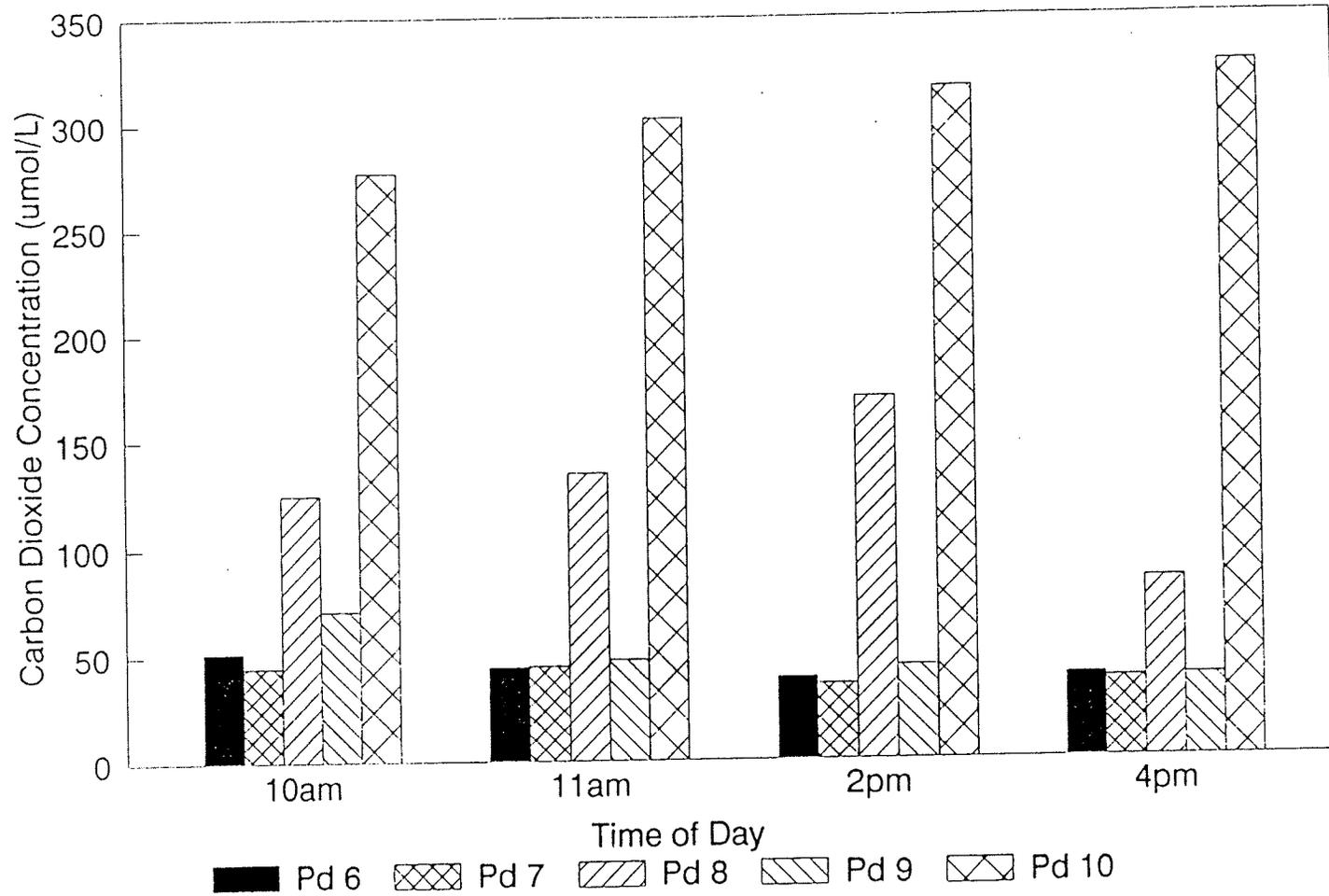


Figure A42. Carbon Dioxide concentration vs. time of day. Kinosheo Lake Bog (Ponds 6-10), October 12, 1990.

Table A1. Hudson Bay Lowland Water Chemistry Results

SAMPLE	Pond	SUSPN	TDN	SUSPP	TDP	DIC	DOC	SUSPC	C:N	C:P	CHLA	SRSI	CL	SO4	
06-Jun	1	75	440	5		5	50	2450	970	15.09	500.26	1.25	0.161	0.19	0.49
06-Jun	3	117	480	8		6	60	2210	1500	14.96	483.50	0.69	0.195	0.24	0.82
06-Jun	4	707	480	40		8	70	2480	13160	21.71	848.39	8.70	0.284	0.24	0.68
06-Jun	6	361	550	31		6	50	2390	4530	14.64	376.82	5.70	0.065	0.24	0.45
06-Jun	7	65	340	3		4	50	1730	820	14.72	704.84	1.92	0.056	0.40	0.66
06-Jun	8	87	400	6		6	60	2230	1010	13.54	434.08	0.83	0.333	0.27	0.75
06-Jun	9	148	500	11		5	60	2490	2050	16.16	480.57	2.30	0.096	0.25	0.61
06-Jun	10	105	350	6		4	50	1050	930	10.33	399.70	3.10	0.030	0.57	0.97
07-Jun	2	125	490	9		7	60	2260	1670	15.58	478.49	1.15	0.221	0.32	0.82
07-Jun	11	75	450	3		5	290	960	610	9.49	524.33	1.13	0.416	2.22	0.13
07-Jun	12	58	370	2		3	310	910	570	11.46	734.93	1.33	0.515	2.65	0.16
07-Jun	19	57	380	3		3	640	780	550	11.26	472.76	1.49	0.647	2.78	0.20
07-Jun	22	58	350	3		3	670	740	590	11.87	507.14	1.45	0.372	2.62	0.21
07-Jun	23	79	300	3		3	650	720	760	11.22	653.27	3.70	0.342	2.59	0.21
27-Jun	12	171	590	9		4	430	1070	2010	13.71	575.91	2.60	0.626	2.99	0.02
27-Jun	13	25	380	1		3	470	860	310	14.46	739.39	0.54	0.740	3.10	0.06
27-Jun	14	112	520	5		2	590	930	1210	12.60	624.04	2.80	0.928	3.28	0.06
27-Jun	15	184	560	9		3	520	930	2640	16.74	756.41	5.80	0.750	3.44	0.06
27-Jun	16	192	470	12		3	290	1150	2320	14.10	498.55	9.00	0.396	2.76	0.06
27-Jun	17	593	480	26		3	310	1160	9030	17.76	895.60	22.00	0.465	2.76	0.06
27-Jun	18	503	550	28		3	270	1130	6110	14.17	562.71	11.00	0.517	2.76	0.06
27-Jun	19	112	600	5		3	1180	1060	1170	12.19	603.41	3.90	1.630	4.81	0.06
27-Jun	20	64	350	4		2	1010	730	900	16.40	580.20	1.49	0.624	2.92	0.02
27-Jun	21	26	390	1		3	1050	790	300	13.46	773.61	0.38	0.775	2.85	0.02
27-Jun	22	39	420	2		3	970	790	440	13.16	567.31	0.64	0.452	2.85	0.06
27-Jun	23	27	350	1		2	1080	770	350	15.12	902.54	0.39	0.482	2.81	0.02
27-Jun	24	110	490	6		2	990	820	1230	13.04	528.63	3.60	0.525	2.88	0.02
28-Jun	1	127	300	8		4	150	1250	1220	11.21	393.25	3.20	0.181	0.54	0.80
28-Jun	2	144	740	10		8	80	2830	2100	17.01	541.52	3.10	0.122	0.11	0.23
28-Jun	6	144	860	7		8	70	2950	1650	13.37	607.83	3.80	0.020	0.34	0.35

Units $\mu\text{g/L}$, except for C:N and C:P are in units of $\mu\text{mol}/\mu\text{mol}$, Conductivity is $\mu\text{mho}/\text{cm}^2$ and Alkalinity is in $\mu\text{eq/L}$. * The pH and alkalinity are calculated from measured CO_2 and DIC concentrations.

Table A1 continued. Hudson Bay Lowland Water Chemistry Results

SAMPLED	Pond	COND	NA	K	MG	CA	FE	MN	PH	ALK	ACIDS	SPEC1	SPEC2	SPEC3
06-Jun	1	36	0.27	0.02	0.18	0.40	0.00	0.00	4.06	-114	96.0	0.00	0.00	0.00
06-Jun	3	35	0.29	0.06	0.13	0.24	0.00	0.00	4.07	-104	85.0	0.00	0.00	0.00
06-Jun	4	37	0.27	0.04	0.17	0.28	0.00	0.00	4.04	-128	91.0	0.00	0.00	0.00
06-Jun	6	30	0.28	0.05	0.22	0.47	0.00	0.00	4.16	-88	93.0	0.00	0.00	0.00
06-Jun	7	25	0.35	0.09	0.16	0.44	0.00	0.00	4.29	-70	67.0	0.00	0.00	0.00
06-Jun	8	38	0.43	0.05	0.15	0.25	0.00	0.00	4.09	-114	94.0	0.00	0.00	198.00
06-Jun	9	36	0.30	0.06	0.18	0.39	0.00	0.00	4.06	-114	92.0	0.00	0.00	0.00
06-Jun	10	13	0.35	0.13	0.21	1.19	0.00	0.00	5.19	-6	43.0	0.00	0.00	0.00
07-Jun	2	35	0.27	0.06	0.12	0.24	0.00	0.00	4.14	-108	77.0	0.00	0.00	110.00
07-Jun	11	38	2.28	0.86	0.65	4.40	0.00	0.00	7.55	220	56.0	0.00	0.00	0.00
07-Jun	12	42	2.53	0.82	0.72	4.65	0.00	0.00	7.62	256	53.0	0.00	0.00	0.00
07-Jun	19	70	2.42	0.25	1.73	10.10	0.00	0.00	7.95	550	42.0	0.00	0.00	0.00
07-Jun	22	71	2.31	0.30	1.74	10.70	0.00	0.00	7.98	582	39.0	0.00	0.00	0.00
07-Jun	23	70	2.30	0.28	1.70	10.10	0.00	0.00	7.98	560	40.0	0.00	0.00	0.00
27-Jun	12	53	2.89	0.75	0.94	5.96	0.00	0.00	7.75	334	76.0	0.00	0.00	0.00
27-Jun	13	56	3.04	0.63	1.01	6.88	0.00	0.00	7.85	384	53.0	0.00	0.00	0.00
27-Jun	14	68	3.37	0.65	1.34	9.10	0.00	0.00	7.98	494	59.0	0.00	0.00	0.00
27-Jun	15	62	3.37	0.63	1.12	7.14	0.00	0.00	7.91	440	54.0	0.00	0.00	0.00
27-Jun	16	44	2.17	0.49	0.81	5.33	0.00	0.00	7.66	252	68.0	0.00	0.00	0.00
27-Jun	17	45	2.21	0.50	0.88	5.69	0.00	0.00	7.69	276	68.0	0.00	0.00	0.00
27-Jun	18	41	2.14	0.54	0.75	4.96	0.00	0.00	7.61	228	73.0	0.00	0.00	0.00
27-Jun	19	123	3.67	0.17	3.40	17.20	0.00	0.00	8.30	1010	66.0	0.00	0.00	0.00
27-Jun	20	103	2.85	0.15	2.70	14.80	0.00	0.00	8.24	880	62.0	0.00	0.00	0.00
27-Jun	21	102	2.78	0.14	2.80	14.60	0.00	0.00	8.20	866	56.0	0.00	0.00	0.00
27-Jun	22	99	2.79	0.21	2.70	14.20	0.00	0.00	8.22	836	49.0	0.00	0.00	0.00
27-Jun	23	105	2.79	0.14	2.80	14.90	0.00	0.00	8.26	998	65.0	0.00	0.00	0.00
27-Jun	24	100	2.73	0.23	2.60	14.20	0.00	0.00	8.23	836	63.0	0.00	0.00	0.00
28-Jun	1	23	0.36	0.08	0.55	3.68	0.00	0.00	7.19	116	59.0	0.00	0.00	0.00
28-Jun	2	41	0.16	0.07	0.14	0.19	0.00	0.00	3.94	-130	109.0	0.00	0.00	0.00
28-Jun	6	36	0.30	0.04	0.28	0.57	0.00	0.00	4.08	-108	111.0	0.00	0.00	0.00

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Table A1 continued. Hudson Bay Lowland Water Chemistry Results

SAMPLE	Pond	SUSPN	TDN	SUSPP	TDP	DIC	DOC	SUSPC	C:N	C:P	CHLA	SRSI	CL	SO4
28-Jun	7	60	470	3	5	20	1880	710	13.80	610.29	0.90	0.034	0.41	0.71
28-Jun	8	85	630	4	5	40	3070	1190	16.33	767.16	1.42	0.060	0.14	0.16
28-Jun	9	358	730	17	6	50	3420	4620	15.05	700.80	4.90	0.025	0.08	0.30
28-Jun	10	106	390	7	5	60	1040	940	10.34	346.28	4.60	0.020	0.55	0.94
16-Aug	1	115	340	12	4	130	1260	1790	18.16	384.65	6.70	0.720	0.67	1.02
16-Aug	6	251	1500	19	18	100	5000	6240	29.00	846.89	10.00	0.224	0.96	0.57
16-Aug	7	75	600	6	9	50	2440	1370	21.31	588.80	3.90	0.026	0.60	0.94
16-Aug	10	69	470	7	6	40	1200	1030	17.41	379.43	6.50	0.027	0.67	1.00
16-Aug	14	42	580	3	4	1010	1240	680	18.89	584.50	0.87	2.150	4.74	0.03
16-Aug	20	21	450	2	3	1660	1000	450	25.00	580.20	0.59	3.760	4.62	0.03
16-Aug	21	47	570	4	5	2130	1090	790	19.61	509.29	1.67	3.150	4.60	0.03
16-Aug	22	62	720	4	3	1400	1050	920	17.31	593.10	2.20	2.190	4.14	0.03
16-Aug	23	36	510	3	3	1730	1050	650	21.06	558.71	0.70	3.850	4.15	0.03
16-Aug	24	19	490	2	3	1910	1050	410	25.17	528.63	0.62	3.810	4.14	0.03
11-Sep	14	57	640	3	4	1010	1010	860	17.60	739.22	1.37	1.940	5.23	-0.01
11-Sep	20	25	480	2	3	1720	840	460	21.46	593.10	0.50	3.530	4.55	0.02
11-Sep	21	31	710	2	4	1750	930	500	18.81	644.67	0.52	3.500	4.87	0.02
11-Sep	22	39	730	4	4	1310	940	630	18.84	406.14	0.69	1.270	4.05	0.07
12-Sep	1	134	470	13	5	150	1240	1940	16.89	384.82	5.20	0.838	0.71	1.09
12-Sep	7	87	760	6	5	40	2410	1680	22.53	722.03	3.30	0.049	0.70	0.87
12-Sep	10	121	680	9	5	30	1160	1550	14.94	444.11	7.10	0.050	0.71	1.03
11-Oct	11	128	350	6	3	360	970	2190	19.96	941.22	2.30	0.793	5.57	0.57
11-Oct	12	69	390	3	3	350	1080	1200	20.29	1031.47	1.34	0.711	5.45	0.55
11-Oct	14	29	390	2	3	510	910	1010	40.63	1302.24	0.72	0.960	5.72	0.46
11-Oct	19	39	510	2	3	1090	930	660	19.74	850.97	0.48	0.104	5.88	0.48
11-Oct	20	42	290	2	3	1150	1730	760	21.11	979.90	0.69	1.350	4.94	0.46
11-Oct	22	21	360	2	3	1020	960	480	26.66	618.88	0.33	0.973	5.01	0.48
12-Oct	6	99	680	8	7	90	3300	1860	21.92	599.54	2.40	0.296	1.56	0.95
12-Oct	7	80	600	4	5	70	3900	1190	17.35	767.16	2.30	0.094	1.01	0.97
12-Oct	10	137	560	15	6	130	1910	1560	13.28	268.18	5.50	0.246	0.98	0.95

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Table A1 continued. Hudson Bay Lowland Water Chemistry Results

SAMPLED	Pond	COND	NA	K	MG	CA	FE	MN	PH	ALK	ACIDS	SPEC1	SPEC2	SPEC3
28-Jun	7	23	0.38	0.06	0.19	0.49	0.00	0.00	4.23	-72	73.0	0.00	0.00	171.00
28-Jun	8	44	0.21	0.04	0.29	0.52	0.00	0.00	3.95	-142	134.0	0.00	0.00	0.00
28-Jun	9	48	0.13	0.06	0.28	0.45	0.00	0.00	3.89	-156	136.0	0.00	0.00	0.00
28-Jun	10	13	0.34	0.11	0.22	1.17	0.00	0.00	5.11	-8	43.0	0.00	0.00	0.00
16-Aug	1	26	0.49	0.11	0.74	4.32	0.00	0.00	7.27	116	63.0	0.00	0.00	0.00
16-Aug	6	50	0.75	0.11	0.60	1.25	0.00	0.00	4.01	-162	167.0	0.00	0.00	0.00
16-Aug	7	34	0.50	0.10	0.27	0.56	0.00	0.00	4.17	-128	90.0	0.00	0.00	220.00
16-Aug	10	14	0.40	0.12	0.26	1.43	0.00	0.00	5.29	-53	44.0	0.00	0.00	0.00
16-Aug	14	122	4.35	0.99	2.80	17.40	0.00	0.00	8.20	958	80.0	0.00	0.00	0.00
16-Aug	20	186	4.09	0.38	5.00	29.10	0.00	0.00	8.49	1650	72.0	0.00	0.00	0.00
16-Aug	21	228	4.14	0.60	6.80	35.20	0.00	0.00	8.55	2100	72.0	0.00	0.00	0.00
16-Aug	22	155	3.83	0.52	4.20	22.90	0.00	0.00	8.40	1375	74.0	0.00	0.00	0.00
16-Aug	23	186	3.76	0.41	5.20	29.20	0.00	0.00	8.49	1650	85.0	0.00	0.00	0.00
16-Aug	24	210	3.68	0.38	6.10	32.80	0.00	0.00	8.53	1950	80.0	0.00	0.00	0.00
11-Sep	14	106	5.00	1.63	2.50	15.50	0.16	0.01	8.20	922	60.0	0.00	0.00	0.00
11-Sep	20	172	4.05	0.67	4.70	26.30	0.16	0.01	8.44	1588	56.0	0.00	0.00	168.00
11-Sep	21	171	4.20	1.09	4.80	24.90	0.31	0.02	8.43	1568	65.0	0.00	0.00	0.00
11-Sep	22	141	3.60	0.47	3.90	20.60	0.05	-0.01	8.34	1252	59.0	0.00	0.00	0.00
12-Sep	1	26	0.51	0.16	0.75	3.99	0.05	-0.01	7.16	144	68.0	0.00	0.00	0.00
12-Sep	7	36	0.57	0.12	0.30	0.61	0.11	0.02	4.13	-96	94.0	0.00	0.00	0.00
12-Sep	10	15	0.50	0.21	0.27	1.35	0.09	0.02	5.30	12	56.0	0.00	0.00	0.00
11-Oct	11	61	3.43	1.50	1.04	6.40	0.00	0.00	7.65	328	70.0	0.00	0.00	0.00
11-Oct	12	57	3.16	1.14	0.96	6.06	0.00	0.00	7.62	299	62.0	0.00	0.00	0.00
11-Oct	14	72	3.91	1.70	1.34	7.56	0.00	0.00	7.81	451	56.0	0.00	0.00	0.00
11-Oct	19	122	3.59	0.82	3.30	17.20	0.00	0.00	8.19	958	64.0	0.00	0.00	0.00
11-Oct	20	100	3.36	0.66	2.60	13.60	0.00	0.00	8.12	804	43.0	0.00	0.00	0.00
11-Oct	22	105	3.39	0.82	2.70	14.70	0.00	0.00	8.15	836	45.0	0.00	0.00	0.00
12-Oct	6	47	0.56	0.11	0.48	1.22	0.00	0.00	4.04	-127	124.0	0.00	0.00	0.00
12-Oct	7	39	0.59	0.08	0.33	0.77	0.00	0.00	4.09	-96	101.0	0.00	0.00	0.00
12-Oct	10	24	0.46	0.20	0.33	1.69	0.00	0.00	4.53	-30	83.0	0.00	0.00	0.00

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Table A2. Coastal Fen June 07, 1990.

Pond #	Hours In situ		Wind		CO2 Flux		Total DIC umol/L	Total CH4		CH4 Flux	
	Temp oC	Speed m/sec	Total CO2 umol/L	Rate umol/m2/hr	Rate ugCO2/m2/sec	umol/L		Rate umol/m2/hr	Rate ugCH4/m2/sec		
Pond 11	9	9.00	3.39	111.28	3147.91	38.47	331.81	0.37	12.87	5.72E-02	
Pond 12	9	9.00	3.39	90.34	2430.09	29.70	342.14	1.33	46.71	2.08E-01	
Pond 14	9	9.00	3.39	89.89	2414.67	29.51	359.06	0.84	29.75	1.32E-01	
Pond 17	9	9.00	3.39	97.41	2672.39	32.66	259.53	0.30	10.71	4.76E-02	

Table A3. Coastal Fen June 15, 1990.

SUMMARY

Pond #	In situ		Wind Speed m/sec	CO ₂ Flux		CO ₂ Flux Rate ugCO ₂ /m ² /sec	Total DIC umol/L	Total CH ₄ umol/L	CH ₄ Flux	
	Hours	Temp oC		Total CO ₂ umol/L	Rate umol/m ² /hr				Rate umol/m ² /hr	Rate ugCH ₄ /m ² /sec
Pond 11	11	16.00	1.46	237.37	2136.09	26.11	0.00	47.35	473.46	2.10E+00
Pond 12	11	16.50	1.46	93.93	769.70	9.41	0.00	1.31	13.27	5.90E-02
Pond 13	11	14.50	1.46	163.47	1347.79	16.47	0.00	6.55	62.28	2.77E-01
Pond 14	11	14.50	1.46	99.35	760.65	9.30	0.00	4.48	42.58	1.89E-01
Pond 15	11	14.50	1.46	136.46	1100.45	13.45	0.00	1.37	13.02	5.79E-02
Pond 16	11	13.50	1.46	57.56	360.65	4.41	0.00	1.08	9.96	4.43E-02
Pond 17	11	15.50	1.46	101.00	807.07	9.86	0.00	0.84	8.26	3.67E-02
Pond 18	11	15.50	1.46	139.33	1170.08	14.30	0.00	1.81	17.82	7.92E-02

Table A4. Coastal Fen June 24, 1990.

SUMMARY

Pond #	Hours	In situ	Wind	umol/L	CO2 Flux	CO2 Flux	umol/L	umol/L	CH4 Flux	CH4 Flux
		Temp oC	Speed m/sec	Total CO2 umol/L	Rate umol/m2/hr	Rate ugCO2/m2/sec	Total DIC umol/L	Total CH4 umol/L	Rate umol/m2/hr	Rate ugCH4/m2/sec
Pond 11	11	23.00	3.72	45.82	2262.99	27.66	343.94	1.52	106.67	4.74E-01
Pond 12	11	23.00	3.72	96.96	5754.45	70.33	428.02	8.85	622.04	2.76E+00
Pond 13	11	19.00	3.72	176.90	10152.85	124.09	474.93	5.99	384.67	1.71E+00
Pond 14	11	20.00	3.72	44.77	1978.01	24.18	476.01	2.30	151.22	6.72E-01
Pond 15	11	20.00	3.72	117.06	6594.40	80.60	453.06	1.52	99.58	4.43E-01
Pond 16	11	18.00	3.72	32.96	1117.16	13.65	264.47	1.13	70.86	3.15E-01
Pond 17	11	21.00	3.72	50.59	2429.27	29.69	256.06	0.77	51.47	2.29E-01
Pond 18	11	21.00	3.72	93.16	5209.68	63.67	281.63	5.86	393.80	1.75E+00

Table A5. Coastal Fen June 30, 1990.

SUMMARY

Pond #	Hours	In situ	Wind	CO2 Flux		Total DIC	Total CH4	CH4 Flux		
		Temp oC	Speed m/sec	Total CO2 umol/L	CO2 Flux Rate umol/m2/hr			CO2 Flux Rate CO2/m2/s	Rate umol/L	CH4 Flux Rate umol/m2/hr
Pond 11	12.3	23.10	2.28	56.83	833.17	10.18	0.00	3.47	68.08	3.03E-01
Pond 11	12.3	23.10	2.28	112.46	1882.39	23.01	533.90	2.37	46.51	2.07E-01
Pond 12	12.2	23.90	2.28	49.68	719.90	8.80	504.88	4.40	88.25	3.92E-01
Pond 13	12.2	19.60	2.28	458.56	7550.35	92.28	929.37	3.96	69.91	3.11E-01
Pond 14	12.1	20.40	2.28	113.07	1730.41	21.15	0.00	3.89	70.38	3.13E-01
Pond 14	12.1	20.40	2.28	115.35	1770.08	21.63	663.81	3.66	66.13	2.94E-01
Pond 15	12	20.10	2.28	126.16	1938.36	23.69	0.00	1.85	33.10	1.47E-01
Pond 15	12	20.10	2.28	127.85	1967.52	24.05	573.00	1.64	29.41	1.31E-01
Pond 16	11.8	18.10	2.28	125.53	1797.64	21.97	0.00	2.88	48.55	2.16E-01
Pond 16	11.8	18.10	2.28	120.63	1718.24	21.00	456.65	2.55	42.85	1.90E-01
Pond 17	11.7	21.60	2.28	102.13	1605.03	19.62	0.00	2.24	41.94	1.86E-01
Pond 17	11.7	21.60	2.28	120.28	1932.50	23.62	455.84	2.67	50.00	2.22E-01
Pond 18	11.7	21.20	2.28	136.42	2194.58	26.82	0.00	1.77	32.72	1.45E-01
Pond 18	11.7	21.20	2.28	154.05	2508.97	30.67	444.77	1.81	33.51	1.49E-01

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Table A6. Coastal Fen July 09-10, 1990

SUMMARY														
Pond #	In situ Hours	Temp oC	Wind Speed m/sec	Total CO2 umol/L	CO2 Flux Rate umol/m2/hr	CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec	CO2 Flux /Period mg/m2	CO2 Flux /Day mg/m2/d	CH4 Flux /Period mg/m2	CH4 Flux /Day mg/m2/d
Pond 11	10	17.50	5.50	36.60	3330.92	40.71	609.49	1.79	281.63	1.25E+00				
Pond 11	12.5	22.90	5.83	16.33	697.88	8.53	ERR	0.73	144.73	6.43E-01	221.583665		8.527138	
Pond 11	15	24.50	5.39	10.28	-326.04	-3.98	ERR	0.65	115.16	5.12E-01	20.4510153		5.197743	
Pond 11	32.5	12.30	4.74	37.15	1958.53	23.94	ERR	2.09	213.59	9.49E-01	628.509413	928.5803	46.02405	63.73220
Pond 12	10	16.50	5.50	72.08	8486.07	103.72	576.55	1.28	196.47	8.73E-01				
Pond 12	12.5	20.80	5.83	49.26	6588.26	80.52	ERR	1.40	265.75	1.18E+00	829.088273		9.244248	
Pond 12	15	22.10	5.39	45.12	5253.33	64.21	ERR	1.17	197.34	8.77E-01	651.287708		9.261776	
Pond 12	32.5	11.90	4.74	109.43	9029.23	110.36	ERR	1.77	178.90	7.95E-01	5498.78796	7444.441	52.67406	75.92542
240 Pond 13	10	17.50	5.50	462.55	68551.07	837.85	965.68	22.59	3558.13	1.58E+01				
Pond 13	12.5	20.20	5.83	409.46	71883.34	878.57	ERR	15.92	2975.88	1.32E+01	7723.89234		130.6801	
Pond 13	15	19.30	5.39	415.44	61621.81	753.16	ERR	17.30	2732.00	1.21E+01	7342.78335		114.1576	
Pond 13	32.5	14.20	4.74	213.12	20559.62	251.28	ERR	6.32	679.23	3.02E+00	31639.8541	49820.29	477.5725	770.5710
Pond 14	10	16.10	5.50	160.37	21442.30	262.07	907.82	3.10	471.90	2.10E+00				
Pond 14	12.5	20.50	5.83	49.19	6509.72	79.56	ERR	1.69	317.68	1.41E+00	1537.36076		15.79155	
Pond 14	15	22.00	5.39	29.34	2660.72	32.52	ERR	1.45	243.02	1.08E+00	504.373996		11.21395	
Pond 14	32.5	13.00	4.74	164.22	14911.32	182.25	ERR	4.35	453.26	2.01E+00	6765.23284	9394.098	97.47949	132.7840
Pond 15	10	17.50	5.50	166.38	23202.32	283.58	738.12	0.86	136.10	6.05E-01				
Pond 15	12.5	21.30	5.83	60.30	8752.79	106.98	ERR	0.92	176.79	7.86E-01	1757.53118		6.257857	
Pond 15	15	22.20	5.39	44.26	5130.72	62.71	ERR	0.90	151.44	6.73E-01	763.593430		6.564589	
Pond 15	32.5	13.60	4.74	160.65	14811.07	181.02	ERR	1.91	202.23	8.99E-01	7677.58969	10878.62	49.51399	66.49220

Table A6 continued. Coastal Fen July 09-10, 1990

SUMMARY

Pond #	Hours	In situ	Wind	CO2 Flux		Total DIC	Total CH4	CH4 Flux		CO2	CO2	CH4	CH4
		Temp oC	Speed m/sec	Total CO2 umol/L	Rate umol/m2/hr			Rate CO2/m2/s	Rate umol/L	Rate umol/m2/hr	Rate ugCH4/m2/sec	Flux /Period mg/m2	Flux /Day mg/m2/d
Pond 16	10	17.70	5.50	103.27	13617.06	166.43	511.67	1.29	203.95	9.06E-01			
Pond 16	12.5	21.30	5.83	37.78	4560.43	55.74	ERR	0.83	158.69	7.05E-01	999.762062		7.252911
Pond 16	15	22.00	5.39	36.99	3909.91	47.79	ERR	1.87	313.41	1.39E+00	465.868589		9.442090
Pond 16	32.5	12.20	4.74	107.70	8947.21	109.35	ERR	2.06	209.84	9.33E-01	4949.99212	6843.330	73.25529 95.94698
Pond 17	10	19.80	5.50	34.20	3284.31	40.14	451.55	0.38	63.45	2.82E-01			
Pond 17	12.5	23.20	5.83	50.58	7372.26	90.11	ERR	0.30	60.79	2.70E-01	586.111486		2.484920
Pond 17	15	23.30	5.39	17.38	807.54	9.87	ERR	0.51	88.37	3.93E-01	449.889342		2.983265
Pond 17	32.5	13.30	4.74	44.93	2861.48	34.97	ERR	1.23	129.09	5.74E-01	1412.57272	2611.811	30.44444 38.30680
Pond 18	10	19.30	5.50	423.19	65357.37	798.81	1008.36	4.93	809.59	3.60E+00			
Pond 18	12.5	22.90	5.83	85.46	14032.39	171.51	ERR	1.50	298.62	1.33E+00	4366.43702		22.16406
Pond 18	15	21.60	5.39	222.04	33784.83	412.93	ERR	6.85	1139.68	5.07E+00			Contaminated do not u
Pond 18	32.5	12.70	4.74	138.12	12153.54	148.54	ERR	1.32	136.85	6.08E-01	11521.8107	16947.46	69.67511 97.96178
											Avg.	13108.58	167.7150
											Count	8	8
											STD.DEV.	15634.79	245.2118

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Table A7. Coastal Fen July 24, 1990

Pond #	In situ Temp oC	Wind Speed m/sec	SUMMARY				CO2 Flux Rate umol/m2/hr	CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec	CO2	CO2	CH4	CH4
			Flux /Period mg/m2	Flux /Day mg/m2/d	Flux /Period mg/m2	Flux /Day mg/m2/d										
Pond 11	9	19.20	1.95	206.91	2755.43	33.68	1158.21	3.59	53.26	2.37E-01						
Pond 11	12	30.10	2.25	127.08	2615.24	31.96	907.17	3.70	86.21	3.83E-01	354.464108			3.347249		
Pond 11	16	29.30	1.68	128.47	1924.35	23.52	788.39	24.09	409.43	1.82E+00	768.877060			30.17933		
Pond 11	16	29.30	1.68	322.07	5089.18	62.20	1026.59		contaminated			3851.455			114.9482	
Pond 12	9	19.60	1.95	135.81	1763.28	21.55	1097.21	6.56	98.62	4.38E-01						
Pond 12	12	28.60	2.25	55.18	954.62	11.67	850.31	2.64	59.26	2.63E-01	179.381060			3.789129		
Pond 12	16	30.10	1.68	35.74	420.61	5.14	736.40	1.92	33.38	1.48E-01	214.593384			5.302550		
Pond 12	16	30.10	1.68	48.76	638.04	7.80	763.84	3.51	60.97	2.71E-01		1350.769			31.17147	
Pond 13	9	19.40	1.95	156.20	2044.49	24.99	1354.64	5.77	86.18	3.83E-01						
Pond 13	12	27.30	2.25	109.99	2056.60	25.14	1127.69	9.74	211.00	9.38E-01	270.671865			7.132513		
Pond 13	16	27.00	1.68	64.12	810.65	9.91	970.69	18.13	289.68	1.29E+00	399.462435			18.60177		
Pond 13	16	26.40	1.68	14.33	41.64	0.51	922.91	1.84	28.92	1.29E-01		2297.603			88.23184	
Pond 14	9	19.50	1.95	262.66	3587.17	43.84	1241.31	7.49	112.20	4.99E-01						
Pond 14	12	23.70	2.25	143.72	2474.96	30.25	1096.36	5.30	103.75	4.61E-01	400.100860			5.182869		
Pond 14	16	28.20	1.68	44.31	528.11	6.45	927.42	2.68	44.19	1.96E-01	485.811384			8.054765		
Pond 14	16	28.20	1.68	49.67	613.22	7.49	952.36	2.68	44.22	1.97E-01		3037.413			45.38617	
Pond 15	9	19.90	1.95	281.51	3909.28	47.78	1332.00	3.52	53.41	2.37E-01						
Pond 15	12	27.00	1.68	110.57	2050.19	25.06	1006.90	1.65	35.44	1.57E-01	393.325643			2.132274		
Pond 15	16	28.60	1.68	58.15	757.72	9.26	971.98	1.59	26.56	1.18E-01	439.852900			3.183318		
Pond 15	16	28.60	1.68	75.62	1038.15	12.69	1008.65	1.84	30.65	1.36E-01		2856.612			18.22489	

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Table A7 continued. Coastal Fen July 24, 1990

SUMMARY

Pond #	In situ Temp oC	Wind Speed m/sec	CO2 Flux		Total DIC umol/L	CH4 Flux		CO2	CO2	CH4	CH4		
			Total CO2 umol/L	Rate umol/m2/hr		Rate CO2/m2/s	Total CH4 umol/L	Rate umol/m2/hr	Rate ugCH4/m2/sec	Flux /Period mg/m2	Flux /Day mg/m2/d	Flux /Period mg/m2	Flux /Day mg/m2/d
Pond 16	9	21.80	1.95	208.70	3025.26	36.98	1076.75	9.11	146.35	6.50E-01			
Pond 16	12	28.20	2.25	96.16	1817.06	22.21	824.53	5.17	114.74	5.10E-01	319.593247	6.266132	
Pond 16	16	28.80	1.68	62.30	829.51	10.14	696.08	4.98	83.59	3.72E-01	392.092003	10.06579	
Pond 16	16	28.80	1.68	61.30	813.44	9.94	698.17	5.16	86.57	3.85E-01	2440.063	55.99516	
Pond 17	9	21.60	1.95	952.56	14443.25	176.53	1656.63	52.26	834.80	3.71E+00			
Pond 17	12	28.30	2.25	408.86	8516.29	104.09	1166.53	10.73	238.77	1.06E+00	1515.32940	25.76554	
Pond 17	16	28.10	1.68	587.19	9123.95	111.52	1299.13	29.40	484.00	2.15E+00	2202.30124	25.82945	
Pond 17	16	28.10	1.68	444.44	6863.18	83.88	1196.26	10.65	175.27	7.79E-01	12746.16	176.8971	
									Ave.		4082.868		75.83642
									Count		7		7
									Std.Dev.		3895.579		55.57515

Table A8. Coastal Fen July 31, August 4 and 12, 1990
SUMMARY

July 31										
Pond #	Hours	In situ Temp oC	Wind Speed m/sec	Total CO2 umol/L	CO2 Flux Rate umol/m2/hr	CO2 Flux Rate ugCO2/m2/sec	Total DIC umol/L	Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec
Pond 14	15.3	18.70	3.42	1118.10	50222.72	613.83	2394.48	49.54	2319.17	1.03E+01
Pond 14	18	23.10	2.22	514.35	9168.02	112.05	1647.02	17.76	337.14	1.50E+00
August 4										
Pond 14	11.5	17.90	2.07	947.58	13591.44	290.05	166.12	35.78	541.44	2.41E+00
Pond 14	18	23.10	2.22	514.35	9168.02	195.45	112.05	17.76	337.14	1.50E+00
August 12										
Pond 14	10.5	14.50	1.48	1169.76	10714.19	130.95	2349.45	53.61	517.06	2.30E+00
Pond 14	16	23.50	1.71	967.06	13562.20	165.76	2136.64	32.36	477.82	2.12E+00

Table A9. Coastal Fen Aug SUMMARY

August 14-15														
Pond#	In situ	Wind	CO2 Flux			CO2 Flux			CH4 Flux		CO2	CO2	CH4	CH4
Hours	Temp	Speed	Total CO2	Rate	Rate	Total DIC	Total CH4	Rate	Rate	Flux	Flux	Flux	Flux	
	oC	m/sec	umol/L	umol/m2/hr	CO2/m2/s	umol/L	umol/L	umol/m2/hr	ugCH4/m2/sec	mg/m2	/Day	/Period	/Day	
Pond 14	10	15.50	5.01	467.39	54897.50	670.97	1568.33	289.87	36242.69	1.61E+02				
Pond 14	10	15.50	5.01	328.74	38043.87	464.98	1436.20	8.47	1059.60	4.71E+00	0		0	
Pond 14	14	15.50	4.19	936.28	74070.92	905.31	2000.39	8.96	741.63	3.30E+00				
Pond 14	18	18.50	1.49	184.65	1820.90	22.26	1137.99	2.45	27.20	1.21E-01	8499.31792		69.55517	
Pond 14	19	18.80	2.24	103.62	1448.78	17.71	1052.10	1.75	29.40	1.31E-01	71.9328783		0.452818	
Pond 14	31.5	12.40	1.38	408.25	3146.60	38.46	1496.06	7.13	59.55	2.65E-01	1263.72941	13487.97	8.895487	108.2104
Pond 14 missing														
24														
Pond 25	10	15.50	5.01	596.13	70547.62	862.25	1759.27	11.92	1490.39	6.62E+00				
Pond 25	18	18.60	1.49	188.24	1865.60	22.80	1280.25	2.13	23.79	1.06E-01	12744.7275		96.90748	
Pond 25	19	18.30	2.24	114.71	1599.84	19.55	1138.67	1.17	19.47	8.65E-02	76.2396188		0.346018	
Pond 25	31.5	12.40	1.38	668.53	5242.00	64.07	1835.51	7.11	59.38	2.64E-01	1881.50485	16412.06	7.884995	117.3639
											14950.01		112.7871	
											Count	2	2	
											Std.Dev.	2067.643	6.472448	
August 16														
SAMPLE LOCATION:	In situ	Wind	CO2 Flux			CO2 Flux			CH4 Flux		CH4 Flux			
Hours	Temp	Speed	Total CO2	Rate	Rate	Total DIC	Total CH4	Rate	Rate	Flux	Flux			
	oC	m/sec	umol/L	umol/m2/hr	CO2/m2/s	umol/L	umol/L	umol/m2/hr	gCH4/m2/sec					
Pond 14 1800	18	23.10	2.22	514.35	9168.02	112.05	1647.02	17.76	337.14	1.50E+00				
Pond 14 1900	19	16.40	3.54	69.25	2664.15	32.56	1030.99	1.49	75.72	3.37E-01				

Table A10. Coastal Fen September 10-11, 1990.

Pond #	SUMMARY													
	In situ hours	Temp oC	Wind Speed m/sec	CO2 Flux Total CO2 umol/L	CO2 Flux Rate umol/m2/hr	CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec	CO2 Flux /Period mg/m2	CO2 Flux /Day mg/m2/d	CH4 Flux /Period mg/m2	CH4 Flux /Day mg/m2/d
Pond 11	13.5	18.00	1.39	336.01	3145.76	38.45	992.76	15.21	154.65	6.87E-01				
Pond 11	18	14.00	4.17	35.14	1423.35	17.40	717.04	3.74	294.31	1.31E+00	452.342282		16.16269	
Pond 11	34.5	9.00	5.56	63.66	5523.61	67.51	856.87	6.74	866.63	3.85E+00	2521.74644		153.2449	
Pond 11	36	12.00	6.00	58.18	6327.26	77.33	771.66	5.44	872.91	3.88E+00	391.078690		20.87449	
Pond 11	40	12.00	6.00	66.28	7590.67	92.77	781.38	9.45	1515.34	6.73E+00	1224.77802	4156.931	76.42394	241.5451
Pond 12	13.5	16.50	1.39	37.61	208.06	2.54	858.37	3.60	34.90	1.55E-01				
Pond 12	18	14.00	4.17	131.31	8782.29	107.34	936.07	1.77	139.54	6.20E-01	890.044318		6.279882	
Pond 12	34.5	8.00	5.56	179.44	19348.27	236.48	951.38	2.69	335.65	1.49E+00	10211.3925		62.72469	
Pond 12	36	10.50	6.00	97.78	11872.38	145.11	935.78	2.99	460.23	2.05E+00	1030.28151		9.550555	
Pond 12	40	12.00	6.00	70.70	8281.04	101.21	886.46	1.47	236.39	1.05E+00	1773.50113	12593.40	22.29205	91.33330
Pond 13	14	17.00	1.39	247.89	2206.83	26.97	768.91	15.27	150.32	6.68E-01				
Pond 13	17.3	15.00	4.17	474.36	35971.91	439.66	984.56	24.59	1984.59	8.82E+00	2771.77655		56.36162	
Pond 13	34.6	11.00	5.56	218.42	26466.65	323.48	813.02	17.33	2355.96	1.05E+01	23860.2709		603.1632	
Pond 13	40.5	11.50	6.00	354.21	51768.85	632.73	1004.09	25.58	4048.21	1.80E+01	10034.4855	21728.31	298.6906	567.8314
Pond 14	13.6	13.50	1.39	178.56	1363.42	16.66	1078.57	7.85	68.65	3.05E-01				
Pond 14	17.6	13.00	4.17	79.25	4636.21	56.66	913.05	3.08	236.39	1.05E+00	527.967752		9.761342	
Pond 14	35	8.00	5.56	197.06	21489.33	262.65	1127.78	4.84	603.82	2.68E+00	9960.62499		116.4871	
Pond 14	36.5	9.00	6.00	153.49	19247.23	235.24	1062.58	4.16	614.62	2.73E+00	1344.30664		14.62125	
Pond 14	40.6	11.50	6.00	90.25	11134.74	136.09	1036.83	2.73	432.07	1.92E+00	2787.24242	12995.68	34.91758	156.2554

Table A10 continued. Coastal Fen September 10-11, 1990.

SUMMARY														
Pond #	In situ hours	Temp oC	Wind Speed m/sec	CO2 Flux		CO2 Flux Rate CO2/m2/s	Total DIC umol/L	CH4 Flux		CH4 Flux Rate ugCH4/m2/sec	CO2	CO2	CH4	CH4
				Total CO2 umol/L	Rate umol/m2/hr			Flux /Period mg/m2	Flux /Day mg/m2/d		Flux /Period mg/m2	Flux /Day mg/m2/d		
Pond 15	13.8	16.00	1.39	156.43	1292.48	15.80	1726.47	4.73	45.02	2.00E-01				
Pond 15	17.5	15.00	4.17	251.60	18489.10	225.98	1497.59	2.71	218.73	9.72E-01	1610.22096		7.806748	
Pond 15	35.8	9.00	5.56	292.21	34098.09	416.75	1515.86	4.75	610.98	2.72E+00	21171.6017		121.4691	
Pond 15	36.3	10.00	6.00	242.43	33032.72	403.73	1185.99	4.56	692.88	3.08E+00	738.438847		5.215465	
Pond 15	40.5	11.00	6.00	123.31	15959.53	195.06	1080.62	1.89	295.36	1.31E+00	4526.88322	25210.91	33.20511	150.7384
Pond 16	14	17.00	1.39	129.44	1084.09	13.25	1325.87	8.05	79.27	3.52E-01				
Pond 16	17.5	15.00	4.17	75.81	4692.16	57.35	991.74	5.07	409.36	1.82E+00	444.771465		13.68176	
Pond 16	34.7	10.00	5.56	150.85	16978.29	207.51	1210.22	6.55	865.89	3.85E+00	8223.93692		175.9846	
247 Pond 16	36.2	11.00	6.00	149.46	19932.27	243.62	1276.87	8.64	1348.29	5.99E+00	1218.04840		26.57009	
Pond 16	40.5	12.00	6.00	64.86	7369.00	90.07	1035.36	3.82	613.48	2.73E+00	2552.66878	11265.89	66.69998	256.2443
											Avg.	14658.52	243.9913	
											Count	6	6	
											Std.Dev.	7617.848	170.1332	

Table A11. Coastal Fen October 10-11, 1990.

SUMMARY

Pond #	In situ		Wind Speed m/sec	CO2 Flux		Total DIC umol/L	CH4 Flux		CO2	CO2	CH4	CH4		
	Hours	Temp oC		Total CO2 umol/L	Rate umol/m2/hr		Rate CO2/m2/s	Rate umol/L	Rate umol/m2/hr	Flux /Period mg/m2	Flux /Day mg/m2/d	Flux /Period mg/m2	Flux /Day mg/m2/d	
Pond 11	10.5	5.00	5.56	217.59	21656.63	264.69	638.39	5.11	582.01	2.59E+00				
Pond 11	15	8.50	5.56	99.87	9867.31	120.60	437.19	2.89	366.07	1.63E+00	3120.86945	34.13064		
Pond 11	33.2	3.50	2.22	106.33	756.29	9.24	423.85	1.05	9.94	4.42E-02	4253.68627	54.74609		
Pond 11	39.5	6.00	6.00	84.08	8212.35	100.37	385.93	1.51	203.57	9.05E-01	1243.05344	7131.814	10.76077	82.45863
Pond 12	10.5	2.50	5.56	154.51	13301.92	162.58	537.89	5.76	605.18	2.69E+00				
Pond 12	15	8.00	5.56	87.63	8196.43	100.18	409.07	4.29	535.38	2.38E+00	2128.33686	41.06031		
Pond 12	33.2	3.00	2.22	97.77	659.37	8.06	394.23	1.99	18.43	8.19E-02	3545.86329	80.63456		
Pond 12	39.5	5.00	6.00	48.32	3304.38	40.39	313.69	1.29	168.29	7.48E-01	549.376204	5150.545	9.410638	108.5011
Pond 13	10.5	4.00	5.56	547.55	56360.90	688.86	1202.68	65.61	7244.72	3.22E+01				
Pond 13	15.5	7.00	5.56	236.05	25378.54	310.18	615.64	17.59	2131.99	9.48E+00	8991.33855	375.0683		
Pond 13	33.3	3.50	2.22	154.63	1198.13	14.64	487.61	4.66	44.21	1.96E-01	10407.4237	309.8903		
Pond 13	39.5	5.00	6.00	124.20	12975.37	158.59	429.87	4.95	647.97	2.88E+00	1933.26443	17654.09	34.33179	595.2748
Pond 14	10.7	2.50	5.56	387.95	37194.69	454.60	1003.00	5.33	560.49	2.49E+00				
Pond 14	15.5	6.50	5.56	180.79	18538.31	226.58	674.71	5.69	679.20	3.02E+00	5824.09791	47.10834		
Pond 14	33.8	3.00	2.22	110.04	769.16	9.40	549.43	2.17	20.09	8.93E-02	7773.18591	102.3756		
Pond 14	40	5.00	6.00	111.02	11295.50	138.06	550.45	4.30	563.34	2.50E+00	1645.61968	12506.99	28.93790	146.3974
Pond 15	11	2.50	5.56	31.76	739.15	9.03	588.28	1.55	163.01	7.24E-01				
Pond 15	15.3	8.50	5.56	104.03	10379.33	126.86	498.52	2.14	271.34	1.21E+00	1051.80815	14.94170		
Pond 15	33.7	4.00	2.22	130.65	1004.14	12.27	521.43	0.69	6.71	2.98E-02	4608.02798	40.92904		
Pond 15	39.7	5.50	6.00	87.74	8510.14	104.01	429.33	1.09	145.23	6.45E-01	1266.35158	5781.861	7.353549	52.77854

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Table A11 continued. Coastal Fen October 10-11, 1990.

Pond #	In situ Hours Temp oC	Wind Speed m/sec	SUMMARY			CO2 Flux Rate CO2/m2/s	CO2 Flux Rate CO2/m2/s	Total DIC umol/L	CH4 Flux		CO2	CO2	CH4	CH4
			Total CO2 umol/L	CO2 Flux Rate umol/m2/hr	Total CH4 umol/L				CH4 Flux Rate umol/m2/hr	CH4 Flux Rate umol/m2/hr	Flux /Period mg/m2	Flux /Day mg/m2/d	Flux /Period mg/m2	Flux /Day mg/m2/d
Pond 16	11	2.00	5.56	214.01	19022.36	232.50	479.40	4.83	498.73	2.22E+00				
Pond 16	15.2	9.00	5.56	110.97	11439.56	139.82	325.03	3.75	482.54	2.14E+00	2814.68170		32.97052	
Pond 16	33.6	3.00	2.22	152.10	1145.58	14.00	387.60	3.91	36.28	1.61E-01	5094.46531		76.36990	
Pond 16	39.7	5.50	6.00	71.27	6378.21	77.96	258.56	1.93	256.33	1.14E+00	1017.96892	7452.201	14.39611	103.2931
Pond 17	11	3.00	5.56	95.96	7478.88	91.41	487.47	3.30	352.55	1.57E+00				
Pond 17	15.2	10.50	5.56	25.42	899.43	10.99	297.20	1.50	201.74	8.97E-01	783.371671		18.84596	
Pond 17	33.6	3.00	2.22	48.51	218.51	2.67	294.60	1.20	11.10	4.93E-02	451.312571		31.24536	
Pond 17	39.8	6.00	6.00	33.33	1539.97	18.82	260.00	0.44	58.79	2.61E-01	239.857091	1228.784	3.466742	44.63173
Pond 18	11.2	2.00	5.56	136.98	11270.03	137.74	496.73	6.75	697.83	3.10E+00				
Pond 18	15	9.50	5.56	98.87	10109.09	123.56	279.00	5.61	731.14	3.25E+00	1787.29371		43.44072	
Pond 18	33.4	3.00	2.22	152.93	1153.03	14.09	341.50	1.66	15.38	6.84E-02	4558.90266		109.8876	
Pond 18	39.7	5.00	6.00	81.82	7573.91	92.57	254.17	2.49	326.59	1.45E+00	1209.55339	6362.736	17.23530	143.6325
											Avg.	7908.629		159.6210
											Count	8		8
											Std.dev.	5015.277		179.9217

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Table A12. Interior Fen June 07,1990.

SUMMARY										
Pond #	In situ		Wind Speed m/sec	CO2 Flux		Total DIC umol/L	Total CH4 umol/L	CH4 Flux		CH4 Flux Rate
	Hours	Temp oC		Total CO2 umol/L	CO2 Flux Rate umol/m2/hr			CO2 Flux Rate CO2/m2/s	CH4 Flux Rate umol/m2/hr	
Pond 19	12.5	9.50	3.41	72.84	1910.66	23.35	642.61	0.81	29.54	1.31E-01
Pond 21	12.5	10.00	3.41	84.15	2357.43	28.81	645.98	1.23	45.73	2.03E-01
Pond 22	12.5	10.50	3.41	49.07	1117.79	13.66	620.46	1.51	56.67	2.52E-01
Pond 23	12.5	10.00	3.41	61.52	1540.72	18.83	626.36	1.01	37.50	1.67E-01

Table A13. Interior Fen June 16, 1990.

Pond #	In situ Hours Temp oC	Wind Speed m/sec	CO2 Flux		CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux		
			Total CO2 umol/L	Rate umol/m2/hr				Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec	
Pond 19	11	15.00	3.81	32.19	984.27	12.03	0.00	1.72	107.67	4.79E-01
Pond 20	11	14.00	3.81	52.33	2124.23	25.96	0.00	0.37	22.44	9.98E-02
Pond 21	11	13.50	3.81	191.15	10214.90	124.85	0.00	15.38	926.83	4.12E+00
Pond 22	11	13.00	3.81	13.17	-225.46	-2.76	0.00	0.87	51.77	2.30E-01
Pond 23	11	14.00	3.81	58.72	2503.23	30.60	0.00	9.81	598.62	2.66E+00
Pond 24	11	13.50	3.81	43.63	1571.73	19.21	0.00	0.44	26.39	1.17E-01

Table A14. Interior Fen June 30, 1990.

SUMMARY										
Pond #	In situ Hours	Temp oC	Wind Speed m/sec	CO2 Flux Total CO2 Rate umol/L	CO2 Flux Rate umol/m2/hr	CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec
Pond 19	9.5	19.00	1.03	73.63	442.99	5.41	0.00	1.18	9.17	4.07E-02
Pond 19	9.5	19.00	1.03	67.39	396.45	4.85	1083.52	1.13	8.79	3.90E-02
Pond 20	9.5	17.60	1.03	116.72	726.79	8.88	0.00	1.17	8.66	3.85E-02
Pond 20	9.5	17.60	1.03	119.36	745.64	9.11	1014.93	1.05	7.75	3.44E-02
Pond 21	9.5	17.00	1.03	331.83	2215.61	27.08	0.00	9.82	71.35	3.17E-01
Pond 21	9.5	17.00	1.03	274.50	1814.60	22.18	1293.55	7.95	57.77	2.57E-01
252 Pond 22	9.5	15.40	1.03	47.46	209.91	2.57	0.00	2.56	17.62	7.83E-02
252 Pond 22	9.5	15.40	1.03	46.05	200.57	2.45	942.75	2.45	16.87	7.50E-02
Pond 23	9.5	17.40	1.03	140.08	887.07	10.84	0.00	15.18	111.74	4.97E-01
Pond 23	9.5	17.40	1.03	133.42	839.88	10.27	1051.31	9.68	71.21	3.16E-01
Pond 24	9.5	17.00	1.03	103.11	615.81	7.53	0.00	0.84	6.12	2.72E-02
Pond 24	9.5	17.00	1.03	109.24	658.68	8.05	1020.58	0.94	6.83	3.04E-02

Table A15. Interior Fen July 03-04, 1990.

SUMMARY														
Pond #	In situ Hours	Temp oC	Wind Speed m/sec	CO2 Flux		Total DIC umol/L	CH4 Flux		CO2	CO2	CH4	CH4		
				Total CO2 umol/L	Rate umol/m2/hr		Rate CO2/m2/s	Total CH4 umol/L	Rate umol/m2/hr	Rate ugCH4/m2/sec	Flux /Period mg/m2	Flux /Day mg/m2/d	Flux /Period mg/m2	Flux /Day mg/m2/d
Pond 21	11	17.30	3.66	312.42	16855.90	206.02	1506.44	4.71	274.34	1.22E+00				
Pond 21	13	23.10	4.22	562.64	53873.63	658.46	1806.07	36.82	3711.71	1.65E+01	3112.09946		63.77683	
Pond 21	15	25.00	3.56	26.39	876.20	10.71	1060.31	6.03	377.89	1.68E+00	2408.99282		65.43355	
Pond 21	16	23.00	2.69	703.00	15251.01	186.40	1797.96	57.71	1324.81	5.89E+00	354.798698		13.62152	
Pond 21	32.5	12.00	2.44	458.99	6197.95	75.75	1825.51	12.12	176.61	7.85E-01	7785.97147	15250.45	198.1873	380.6727
Pond 22	11	19.30	3.66	140.51	7510.01	91.79	1208.67	8.37	511.74	2.27E+00				
Pond 22	13	22.80	4.22	21.66	867.71	10.61	948.70	3.01	301.78	1.34E+00	368.619793		13.01623	
Pond 22	15	27.30	3.56	12.01	45.10	0.55	859.93	1.34	87.91	3.91E-01	40.1634642		6.235026	
Pond 22	16	26.60	2.69	7.95	-87.17	-1.07	885.14	1.70	43.10	1.92E-01	-0.9255140		1.048110	
Pond 22	32.5	13.60	2.44	179.65	2420.36	29.58	1255.50	24.71	381.14	1.69E+00	846.948874	1400.714	55.99973	85.17109
										Avg. Flux	8325.582		232.9219	
										Count	2		2	
										Std.Dev.	9793.242		208.9511	

Table A16. Interior Fen July 9-10, 1990.

Pond #	In situ Hours Temp oC	Wind Speed m/sec	SUMMARY			CO2 Flux Rate CO2/m2/s	CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec	CO2	CO2	CH4	CH4
			Flux /Period mg/m2	Flux /Day mg/m2/d	Flux /Period mg/m2							Flux /Day mg/m2/d			
Pond 19	13	17.30	6.54	154.55	28818.33	352.22	ERR	3.03	644.09	2.86E+00					
Pond 19	18.2	24.00	5.05	42.10	4472.48	54.66	ERR	1.30	201.33	8.95E-01	3845.08868			35.50753	
Pond 19	33.5	17.30	5.38	39.47	3586.83	43.84	1354.26	1.42	214.03	9.51E-01	2703.89944	7667.108	50.67438	100.8958	
Pond 20	13	17.30	6.54	59.60	9218.74	112.67	ERR	0.82	173.64	7.72E-01					
Pond 20	18.2	24.00	5.05	161.35	22391.04	273.67	ERR	5.74	886.91	3.94E+00	3650.92921			44.54321	
Pond 20	33.5	17.00	5.38	91.97	11159.88	136.40	1091.40	1.22	182.06	8.09E-01	11256.3317	17452.40	130.4144	204.8284	
Pond 21	13	17.30	6.54	121.95	22089.07	269.98	ERR	0.75	158.95	7.06E-01					
Pond 21	18.2	24.00	5.05	231.17	32883.39	401.91	ERR	7.57	1169.86	5.20E+00	6349.31837			55.81002	
Pond 21	33.5	14.90	5.38	238.75	30685.55	375.05	1425.20	3.74	529.52	2.35E+00	21327.3769	32401.98	207.3242	308.0596	
Pond 22	13	14.70	6.54	74.40	11270.87	137.76	ERR	0.73	144.61	6.43E-01					
Pond 22	18.2	24.00	5.05	6.82	-828.17	-10.12	ERR	1.43	220.84	9.82E-01	1206.13192			15.34870	
Pond 22	33.5	14.70	5.38	65.30	6734.87	82.32	1061.09	4.13	582.28	2.59E+00	1981.69781	3732.093	97.98115	132.6788	
Pond 23	13	17.10	6.54	100.59	17575.26	214.81	ERR	4.50	950.95	4.23E+00					
Pond 23	18.2	24.00	5.05	33.21	3136.83	38.34	ERR	1.14	175.57	7.80E-01	2392.24745			47.31407	
Pond 23	33.5	17.10	5.38	145.95	19047.37	232.80	1159.82	8.61	1287.90	5.72E+00	7442.80133	11514.20	178.5435	264.4186	
Pond 24	13	15.20	6.54	91.11	14738.37	180.14	ERR	9.99	2015.21	8.96E+00					
Pond 24	18.2	24.00	5.05	18.23	885.66	10.82	ERR	1.55	239.34	1.06E+00	1804.57538			94.69108	
Pond 24	33.5	15.20	5.38	84.11	9467.52	115.71	1087.42	1.27	181.43	8.06E-01	3473.49354	6179.202	51.33388	170.9560	
												13157.83			196.9729
											Count	6			6
											Std.Dev.	10575.21			78.73028

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Table A17. Interior Fen July 19, 1990.

SUMMARY

Pond #	In situ Hours	Temp oC	Wind Speed m/sec	CO2 Flux		Total DIC umol/L	CH4 Flux		CH4 Flux Rate ugCH4/m2/sec	
				Total CO2 umol/L	Rate umol/m2/hr		Total CH4 umol/L	Rate umol/m2/hr		
Pond 19	10	17.10	4.26	34.52	1705.23	20.84	1610.40	1.49	134.45	5.98E-01
Pond 20	10	17.10	4.26	206.24	16725.23	204.42	1500.15	4.25	382.35	1.70E+00
Pond 21	10	16.30	4.26	505.31	42026.79	513.66	2182.12	14.21	1254.16	5.57E+00
Pond 22	10	17.50	4.26	192.74	15711.05	192.02	1436.18	27.02	2454.81	1.09E+01
Pond 23	10	16.40	4.26	161.91	12603.30	154.04	1520.12	10.55	932.82	4.15E+00
Pond 24	10	16.60	4.26	172.83	13616.86	166.43	1516.33	3.77	335.38	1.49E+00
Tent Pd	10	17.40	4.26	111.08	8474.75	103.58	2322.69	13.34	1208.65	5.37E+00

Table A18. Interior Fen July 24, 1990.

Pond #	Hours In situ	Temp oC	Wind Speed m/sec	CO2 Flux		CO2 Flux Rate CO2/m2/s	Total DIC umol/L	CH4 Flux		CH4 Flux Rate ugCH4/m2/sec	CO2	CO2	CH4	CH4
				Total CO2 umol/L	Rate umol/m2/hr			Flux /period mg/m2	Flux /Day mg/m2/d		Flux /period mg/m2	Flux /Day mg/m2/d		
Pond 19	10	19.00	2.26	237.00	3666.80	44.82	1901.22	11.78	201.48	8.95E-01				
Pond 19	10	19.00	2.26	101.99	1444.85	17.66	1661.17	13.50	230.81	1.03E+00	0			0
Pond 19	15	29.00	2.27	73.23	1368.57	16.73	1638.75	4.25	96.88	4.31E-01	309.475455			13.10743
Pond 19	17	29.20	2.76	17.81	188.79	2.31	1057.79	4.09	114.07	5.07E-01	68.5235853	1295.996	3.375087	56.51149
Pond 20	10	18.00	2.26	232.56	3475.43	42.48	1570.55	4.13	68.34	3.04E-01				
Pond 20	10	18.00	2.26	239.07	3579.14	43.75	1536.93	5.29	87.59	3.89E-01	0			0
Pond 20	15	28.00	2.27	142.02	2796.05	34.17	1336.99	3.09	68.65	3.05E-01	701.270816			6.249933
Pond 20	17	28.80	2.76	129.58	3152.16	38.53	1398.89	3.72	102.77	4.57E-01	261.720989	3301.686	2.742844	30.83238
25 Pond 21	10	19.00	2.26	1087.77	17668.55	215.95	2527.56	46.99	803.31	3.57E+00				
Pond 21	10	19.00	2.26	686.16	11058.89	135.16	2489.61	11.45	195.69	8.70E-01	0			0
Pond 21	15	29.00	2.27	200.20	4153.31	50.76	1540.04	1.99	45.30	2.01E-01	1673.34174			9.639654
Pond 21	17	29.20	2.76	311.32	8065.45	98.58	2010.30	6.44	179.74	7.99E-01	537.625302	7580.458	3.600723	45.39558
Pond 22	10	19.00	2.26	116.47	1683.15	20.57	1396.84	14.72	251.60	1.12E+00				
Pond 22	10	19.00	2.26	103.50	1469.62	17.96	1365.84	12.73	217.65	9.67E-01	0			0
Pond 22	15	29.00	2.27	29.08	400.23	4.89	1063.41	5.48	124.90	5.55E-01	205.683176			13.70200
Pond 22	17	29.50	2.76	6.83	-104.43	-1.28	1000.11	7.21	202.61	9.00E-01	13.0152333	749.8231	5.240173	64.94462
Pond 23	10	19.00	2.26	117.99	1708.07	20.88	1448.49	4.82	82.35	3.66E-01				
Pond 23	10	19.00	2.26	111.79	1606.10	19.63	1466.46	4.66	79.60	3.54E-01	0			0
Pond 23	15	30.00	2.27	36.65	587.37	7.18	1355.75	2.74	64.06	2.85E-01	241.281947			5.746167
Pond 23	17	30.60	2.76	96.23	2388.13	29.19	1372.13	10.75	311.11	1.38E+00	130.922078	1276.128	6.002617	40.28155

Table A18 continued. Interior Fen July 24, 1990.

SUMMARY

Pond #	Hours In situ	Temp oC	Wind Speed m/sec	CO2 Flux		Total DIC umol/L	Total CH4 umol/L	CH4 Flux		CO2	CO2	CH4	CH4	
				Total CO2 umol/L	Rate umol/m2/hr			Rate CO2/m2/s	Flux /period mg/m2	Flux /Day mg/m2/d	Flux /period mg/m2	Flux /Day mg/m2/d		
Pond 24	10	19.00	2.26	222.54	3428.70	41.91	1592.48	2.05	35.12	1.56E-01				
Pond 24	10	19.00	2.26	151.98	2267.53	27.71	1461.90	3.25	55.63	2.47E-01	0		0	
Pond 24	15	29.00	2.27	855.48	18524.60	226.41	2429.21	21.58	491.94	2.19E+00	2287.13380		21.90259	
Pond 24	17	29.30	2.76	89.17	2110.18	25.79	1421.80	2.43	67.93	3.02E-01	907.930260	10954.50	8.957869	105.8073
										Avg.	4193.099		57.29549	
										Count	6		6	
										Std.Dev.	4165.177		26.62292	

Table A19. Interior Fen July 31 and August 06,1990

SUMMARY										
Pond #	In situ		Wind Speed m/sec	CO2 Flux		Total DIC umol/L	Total CH4 umol/L	CH4 Flux		CH4 Flux ugCH4/m2/sec
	Hours	Temp oC		Total CO2 umol/L	CO2 Flux Rate umol/m2/hr			CO2 Flux Rate CO2/m2/s	Rate umol/m2/hr	
July 31										
Pond 23	16.2	18.10	2.52	441.72	7603.24	92.93	1867.33	40.49	748.68	3.33E+00
Pond 24	16.2	18.80	2.52	278.62	4810.40	58.79	1891.75	6.94	131.12	5.83E-01
August 6										
Pond 21	11	16.60	1.79	471.88	5490.25	67.10	2343.78	12.56	156.87	6.97E-01
Pond 22	11	17.10	1.79	116.48	1239.87	15.15	1411.98	8.72	110.71	4.92E-01
Pond 24	11	17.10	1.79	295.92	3432.73	41.96	2125.08	26.77	339.75	1.51E+00

Table A20. Interior Fen August 14-15, 1990.

Pond #	In situ Hours Temp oC	Wind Speed m/sec	SUMMARY				CO2 Flux /Period mg/m2	CO2 Flux /Day mg/m2/d	CH4 Flux /Period mg/m2	CH4 Flux /Day mg/m2/d				
			Total CO2 umol/L	CO2 Flux Rate umol/m2/hr	CO2 Flux Rate CO2/m2/s	Total DIC umol/L					Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec	
Pond 20	11	14.20	4.54	517.15	47414.42	579.51	2450.54	23.43	2282.10	1.01E+01				
Pond 20	15	16.40	3.47	268.86	11627.04	142.11	2094.70	11.46	540.45	2.40E+00	5195.64872		90.32174	
Pond 20	17.5	19.90	2.04	209.24	2973.65	36.34	1899.76	8.64	136.66	6.07E-01	803.038373		13.54234	
Pond 20	20	18.20	2.09	217.05	3001.57	36.69	1925.33	6.45	99.27	4.41E-01	328.637062		4.718712	
Pond 20	32.5	12.00	2.30	388.91	4904.00	59.94	2191.29	6.94	95.11	4.23E-01	2174.03199	9489.885	19.43793	142.9068
Pond 21	10.5	14.70	4.95	535.46	60246.62	736.35	2777.04	13.42	1601.40	7.12E+00				
Pond 21	15	16.40	3.47	350.52	15372.22	187.88	2665.90	7.47	352.42	1.57E+00	7486.26569		70.33741	
Pond 21	17.5	19.60	2.04	178.22	2476.78	30.27	2130.96	3.46	54.26	2.41E-01	981.695060		8.133617	
Pond 21	20	18.20	2.09	236.16	3284.83	40.15	2285.93	4.68	72.02	3.20E-01	316.888647		2.525638	
Pond 21	32.5	12.30	2.30	566.67	7332.33	89.62	2554.38	19.01	263.42	1.17E+00	2919.72031	12768.62	33.54472	124.9542
Pond 22	10	15.10	5.94	114.55	16349.84	199.83	1579.63	3.71	632.51	2.81E+00				
Pond 22	10	15.10	5.94	113.92	16245.86	198.56	1581.21	4.07	694.76	3.09E+00	0		0	
Pond 22	14.5	17.00	3.96	109.05	6743.17	82.42	1598.62	3.43	253.30	1.13E+00	2275.91441		34.12980	
Pond 22	17	20.00	2.58	82.28	1325.42	16.20	1458.16						CH4 Contaminated do	
Pond 22	19.5	19.10	2.96	30.14	344.86	4.21	1358.87	4.76	106.76	4.74E-01	779.683489		14.40223	
Pond 22	32	12.40	2.21	175.90	2040.27	24.94	1649.40	5.38	71.89	3.20E-01	655.909582	4048.917	17.86484	72.43297
Pond 23	10	14.80	5.94	203.28	30808.40	376.55	1989.87	9.51	1609.56	7.15E+00				
Pond 23	14.5	17.40	3.96	211.76	14263.24	174.33	1928.46	10.80	804.81	3.58E+00	4462.09232		86.91718	
Pond 23	17	20.70	2.58	137.86	2458.22	30.04	1795.97	5.98	122.81	5.46E-01	919.680173		18.55235	
Pond 23	19.5	18.80	2.96	179.56	3534.43	43.20	1899.77	10.57	234.89	1.04E+00	329.595804		7.153945	
Pond 23	32	11.60	2.21	380.07	4530.88	55.38	2174.44	16.93	219.78	9.77E-01	2217.96076	8650.177	45.46683	172.4621

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Table A20 continued. Interior Fen August 14-15, 1990.

SUMMARY														
Pond #	In situ Hours	Temp oC	Wind Speed m/sec	CO2 Flux Total CO2 Rate umol/L	CO2 Flux Rate umol/m2/hr	CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec	CO2 Flux /Period mg/m2	CO2 Flux /Day mg/m2/d	CH4 Flux /Period mg/m2	CH4 Flux /Day mg/m2/d
Pond 24	10.5	14.00	4.95	188.87	19640.53	240.05	2246.68	7.37	864.18	3.84E+00				
Pond 24	15	17.40	3.47	121.98	5031.94	61.50	2190.71	5.86	283.29	1.26E+00	2442.57433		41.30876	
Pond 24	17	20.60	2.58	132.10	2336.34	28.56	1976.26	4.59	94.04	4.18E-01	324.204336		6.037308	
Pond 24	19.5	18.00	2.96	164.71	3129.47	38.25	2131.70	5.25	113.80	5.06E-01	300.619750		4.156795	
Pond 24	32.5	11.10	2.30	354.05	4294.51	52.49	2461.10	9.89	131.22	5.83E-01	2123.25883	5662.535	25.48160	83.98305
											Avg.	8124.027		119.3478
											Count	5		5
											Std.Dev.	3405.147		41.41033

Table A22. Interior Fen September 10–11, 1990.

Pond #	In situ		Wind	CO2 Flux		Total DIC	Total CH4	CH4 Flux		CO2	CO2	CH4	CH4	
	Hours	Temp	Speed	Total CO2	CO2 Flux			Rate	Rate	Rate	Flux	Flux	Flux	Flux
		oC	m/sec	umol/L	umol/m2/hr	CO2/m2/s	umol/L	umol/L	umol/m2/hr	ugCH4/m2/sec	mg/m2	mg/m2/d	mg/m2	mg/m2/d
Pond 19	15.3	16.00	1.39	20.40	44.61	0.55	1946.45	3.89	37.04	1.65E-01				
Pond 19	17	15.50	4.17	19.90	327.79	4.01	2047.61	2.38	194.26	8.63E-01	13.9274160		3.145681	
Pond 19	35.4	12.00	5.56	50.71	4493.63	54.92	2383.61	5.14	718.11	3.19E+00	1951.70917		134.3009	
Pond 19	37.8	13.00	6.00	34.56	2802.18	34.25	2507.32	2.10	346.67	1.54E+00	385.219043		20.44382	
Pond 19	39.7	12.00	6.00	36.63	2965.11	36.24	1509.54	3.30	529.83	2.35E+00	241.072776	2549.437	13.32282	168.4064
Pond 20	15.3	15.50	1.39	141.33	1132.81	13.85	1626.88	2.87	26.91	1.20E-01				
Pond 20	16.8	14.50	4.17	130.98	8889.41	108.65	1598.92	2.62	208.46	9.26E-01	330.733216		2.824454	
Pond 20	35.6	9.50	5.56	175.93	19881.13	242.99	1629.36	4.76	620.02	2.76E+00	11899.4937		124.6029	
Pond 20	37.9	12.00	6.00	124.55	16682.39	203.90	1599.39	3.31	531.14	2.36E+00	1850.11387		21.18133	
Pond 20	39.7	12.00	6.00	133.38	18059.51	220.73	3162.73	3.30	529.79	2.35E+00	1413.99512	15209.16	15.70179	161.2864
Pond 21	14.7	13.50	1.39	516.77	4214.03	51.50	2016.15	11.27	98.58	4.38E-01				
Pond 21	16.2	14.00	4.17	367.32	26840.45	328.05	1769.59	7.88	620.17	2.76E+00	1058.95775		8.912525	
Pond 21	35.5	9.50	5.56	639.98	78727.61	962.23	2095.71	15.01	1956.81	8.70E+00	44708.0740		396.8555	
Pond 21	37.7	12.00	6.00	499.61	75200.78	919.12	1952.33	10.72	1719.58	7.64E+00	7619.45542		66.17499	
Pond 21	39.6	11.00	6.00	435.38	63352.96	774.31	1931.07	8.41	1313.40	5.84E+00	5639.13731	56892.16	44.88809	498.1505
Pond 22	14.7	17.00	1.39	48.99	321.44	3.93	1213.68	5.19	51.05	2.27E-01				
Pond 22	16.4	16.00	4.17	74.02	4705.82	57.52	1174.98	13.47	1115.17	4.96E+00	188.019525		15.86057	
Pond 22	35.2	11.50	5.56	115.54	13081.53	159.89	1445.62	16.73	2304.94	1.02E+01	7356.84647		514.3850	
Pond 22	37.4	13.50	6.00	94.82	12663.92	154.78	1412.46	19.75	3297.02	1.47E+01	1246.07961		98.59449	
Pond 22	39.2	12.00	6.00	73.77	8758.76	107.05	1308.41	10.35	1660.74	7.38E+00	824.772961	9438.742	69.40864	685.3975

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Table A22 continued. Interior Fen September 10-11, 1990.

SUMMARY

Pond #	In situ		Wind	CO2 Flux		Total DIC	CH4 Flux		CO2	CO2	CH4	CH4	
	Hours	Temp	Speed	Total CO2	CO2 Flux		Total CH4	Rate	Rate	Flux	Flux	Flux	Flux
	oC		m/sec	umol/L	umol/m2/hr	umol/L	umol/L	umol/m2/hr	ugCH4/m2/sec	mg/m2	mg/m2/d	mg/m2	mg/m2/d
Pond 23	14.9	16.00	1.39	107.54	843.96	10.32	1651.02	4.49	42.80	1.90E-01			
Pond 23	16.5	15.50	4.17	90.54	5941.52	72.62	1598.22	3.91	319.77	1.42E+00	238.848645		4.640926
Pond 23	35.4	10.00	5.56	117.95	12746.66	155.79	1698.86	6.01	794.83	3.53E+00	7791.10096		168.9734
Pond 23	37.5	12.00	6.00	571.14	86361.53	1055.53	1832.49	37.88	6076.67	2.70E+01	contaminated do not use		
Pond 23	39.3	11.00	6.00	239.66	33629.51	411.03	1821.12	10.53	1644.00	7.31E+00	3928.06158	11761.97	75.11578 244.6525
Pond 24	15	15.50	1.39	123.99	976.32	11.93	1715.76	3.21	30.09	1.34E-01			
Pond 24	16.9	15.00	4.17	113.85	7677.89	93.84	1700.91	2.93	236.67	1.05E+00	361.745874		4.054862
Pond 24	35.4	10.00	5.56	134.48	14872.07	181.77	1788.81	4.19	554.11	2.46E+00	9202.63515		117.3521
Pond 24	37.5	12.00	6.00	108.05	14108.55	172.44	1775.51	2.93	470.63	2.09E+00	1338.90462		17.21558
Pond 24	39.4	12.00	6.00	109.30	14302.95	174.81	1707.45	3.58	573.67	2.55E+00	1187.60105	11868.35	15.87332 151.6524
Tw. Pd. 1525 h		16.00	1.39	18.93	31.09	0.38	816.63	1.27	12.09	5.37E-02			
Tw. Pd. 1645 h		16.00	4.17	23.28	622.50	7.61	931.65	0.97	80.64	3.58E-01			
Tent Pd 1530 h		15.00	1.39	76.48	536.35	6.56	1178.66	7.74	71.32	3.17E-01			
Tent Pd 1700 h		15.00	4.17	32.97	1329.82	16.25	1058.84	1.50	120.78	5.37E-01			
											Avg.	17953.30	318.2576
											Count	6	6
											Std.Dev.	19539.19	222.4515

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Table A23. Interior Fen October 10-11, 1990.

Pond #	SUMMARY												
	In situ Hours Temp oC	Wind Speed m/sec	CO2 Flux Total CO2 Rate umol/L	CO2 Flux Rate umol/m2/hr	CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec	CO2 Flux /Period mg/m2	CO2 Flux /Day mg/m2/d	CH4 Flux /Period mg/m2	CH4 Flux /Day mg/m2/d
Pond 19	12.7	7.00	5.56	71.38	5957.60	72.82	1303.54	11.72	1420.69	6.31E+00			
Pond 19	14.1	9.50	5.56	86.80	8578.62	104.85	1253.44	18.63	2428.36	1.08E+01	447.715380		43.10943
Pond 19	34.7	4.00	2.22	48.91	240.07	2.93	1095.89	1.40	13.53	6.01E-02	4006.32829		403.4012
Pond 19	37.1	5.00	6.00	47.20	3160.73	38.63	1019.77	1.30	170.18	7.56E-01	175.821495	4553.965	3.453765 442.5879
Pond 20	12.7	4.50	5.56	63.10	4401.26	53.79	950.28	1.72	192.74	8.57E-01			
Pond 20	14.2	7.50	5.56	73.62	6358.08	77.71	953.61	2.76	340.02	1.51E+00	343.223041		6.180064
Pond 20	34.8	4.00	2.22	79.16	522.85	6.39	918.67	1.45	14.03	6.24E-02	3118.43862		58.34787
Pond 20	37	4.50	6.00	64.62	5247.05	64.13	906.91	1.35	174.10	7.74E-01	279.263183	3702.358	3.311120 67.13969
263 Pond 21	12.6	4.50	5.56	230.91	22728.42	277.79	1273.36	6.48	727.30	3.23E+00			
Pond 21	14	7.50	5.56	60.42	4778.33	58.40	983.65	0.89	109.52	4.87E-01	847.207979		9.372386
Pond 21	34.7	4.00	2.22	108.18	794.14	9.71	971.99	1.79	17.35	7.71E-02	2537.70143		21.01038
Pond 21	37	4.50	6.00	93.37	8853.92	108.21	851.53	1.94	249.60	1.11E+00	488.191519	3809.607	4.911823 34.71599
Pond 22	12.1	5.00	5.56	73.14	5630.04	68.81	960.75	2.94	334.93	1.49E+00			
Pond 22	13.7	7.00	5.56	143.15	14423.00	176.28	1071.50	5.76	697.55	3.10E+00	705.866975		13.21566
Pond 22	34.3	4.00	2.22	145.91	1146.79	14.02	965.75	0.54	5.25	2.34E-02	7056.22872		115.8217
Pond 22	36.7	4.00	6.00	80.32	7050.25	86.17	905.70	1.07	135.17	6.01E-01	432.803705	7995.023	2.696209 128.5206
Pond 23	12.3	5.50	5.56	58.20	4079.00	49.85	920.06	2.74	317.20	1.41E+00			
Pond 23	13.8	8.00	5.56	62.82	5182.23	63.34	895.68	2.42	302.62	1.34E+00	305.620804		7.437792
Pond 23	34.4	4.00	2.22	52.85	276.91	3.38	844.58	1.16	11.25	5.00E-02	2480.08950		51.85065
Pond 23	36.7	4.50	6.00	44.98	2782.28	34.01	867.75	1.23	158.10	7.03E-01	154.794866	2886.385	3.115961 61.25585

Table A23 continued. Interior Fen October 10-11, 1990.

SUMMARY

Pond #	In situ Hours	Temp oC	Wind Speed m/sec	CO2 Flux		Total DIC umol/L	CH4 Flux		CO2	CO2	CH4	CH4	
				Total CO2 umol/L	Rate umol/m2/hr		Rate CO2/m2/s	Total CH4 umol/L	Rate umol/m2/hr	Rate ugCH4/m2/sec	Flux /Period mg/m2	Flux /Day mg/m2/d	Flux /Period mg/m2
Pond 24	12.4	4.00	5.56	247.55	24112.95	294.71	1321.18	7.96	878.46	3.90E+00			
Pond 24	13.9	6.50	5.56	51.73	3543.23	43.31	908.15	0.92	109.90	4.88E-01	882.232424		11.46502
Pond 24	34.5	3.50	2.22	76.50	483.44	5.91	882.44	0.55	5.24	2.33E-02	1824.89040		18.97451
Pond 24	36.8	5.00	6.00	59.67	4751.05	58.07	831.86	0.70	91.96	4.09E-01	264.865169	2929.269	1.788464 31.76476
										Avg.	4312.768		127.6641
										Count	6		6
										Std.Dev.	1907.437		158.1689

Table A24. Kinosheo Lake Bog June 05,1990

SUMMARY

Pond #	In situ		Wind	CO2 Flux		CO2 Flux Rate	Total DIC umol/L	CH4 Flux		CH4 Flux
	Hours	Temp oC	Speed m/sec	Total CO2 umol/L	Rate umol/m2/hr			Total CH4 umol/L	Rate umol/m2/hr	ugCH4/m2/sec
Pond 2	12	15.00	4.00	111.42	6703.32	81.93	100.85	2.86	206.92	9.20E-01
Pond 2	12	15.00	4.00	74.11	4081.64	49.89	73.76	3.52	254.32	1.13E+00
Pond 3	12	16.00	4.00	64.44	3522.93	43.06	59.20	2.42	178.97	7.95E-01
Pond 3	12	16.00	4.00	72.69	4116.93	50.32	72.62	1.89	139.96	6.22E-01
Pond 4	12	21.00	4.00	59.68	3749.56	45.83	51.88	1.41	117.86	5.24E-01
Pond 4	12	21.00	4.00	32.26	1528.07	18.68	30.36	1.35	112.19	4.99E-01
Pond 5	12	16.00	4.00	61.36	3301.34	40.35	59.30	5.58	413.24	1.84E+00
Pond 5	12	16.00	4.00	59.90	3195.94	39.06	55.14	5.66	419.10	1.86E+00
Pond 6	12	20.00	4.00	48.71	2765.69	33.80	47.75	10.98	894.94	3.98E+00
Pond 6	12	20.00	4.00	61.74	3798.12	46.42	52.87	37.92	3090.48	1.37E+01
Pond 7	12	8.00	4.00	39.35	1116.18	13.64	33.34	1.06	63.21	2.81E-01
Pond 7	12	8.00	4.00	40.72	1195.92	14.62	43.95	1.20	71.59	3.18E-01
Pond 8	12	15.50	4.00	105.14	6358.66	77.72	97.21	2.52	184.18	8.19E-01
Pond 8	12	15.50	4.00	100.89	6055.90	74.02	94.66	2.37	173.63	7.72E-01
Pond 9	12	14.50	4.00	92.98	5322.05	65.05	91.28	1.98	141.44	6.29E-01
Pond 9	12	14.50	4.00	63.71	3291.32	40.23	70.32	2.49	177.39	7.88E-01
Pond 10	12	10.00	4.00	63.37	2741.38	33.51	66.40	0.90	56.69	2.52E-01
Pond 1	12	8.00	4.00	53.12	1916.74	23.43	141.22	1.11	66.16	2.94E-01
Pond 1	12	8.00	4.00	46.87	1553.62	18.99	129.16	0.70	41.79	1.86E-01
Pond 1	12	9.00	4.00	34.43	895.13	10.94	120.03	0.29	17.70	7.87E-02
Pond 1	12	9.00	4.00	35.68	969.76	11.85	126.09	0.31	18.80	8.36E-02

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Table A25. Kinosheo Lake Bog June 19 and 28, 1990

SUMMARY										
Pond #	In situ		Wind Speed m/sec	CO2 Flux		CO2 Flux Rate CO2/m2/s	Total DIC umol/L	CH4 Flux		CH4 Flux Rate CH4/m2/sec
	Hours	Temp oC		Total CO2 umol/L	Rate umol/m2/hr			Total CH4 umol/L	Rate umol/m2/hr	
Pond 2	11	20.00	0.83	28.10	89.02	1.09	0.00	11.71	75.77	3.37E-01
Pond 4	11	20.00	0.83	272.17	1608.62	19.66	0.00	3.61	23.33	1.04E-01
Pond 6	11	13.50	0.83	65.09	243.23	2.97	0.00	8.52	44.53	1.98E-01
Pond 7	11	13.50	0.83	55.73	196.08	2.40	0.00	0.61	3.18	1.41E-02
Pond 8	11	19.50	0.83	28.37	88.14	1.08	0.00	1.41	8.97	3.99E-02
June 28										
Pond 1	10	15.60	2.45	31.89	258.00	3.15	122.90	0.63	10.39	4.62E-02
Pond 1	10	15.60	2.45	30.33	233.05	2.85	120.10	0.43	7.07	3.14E-02
Pond 2	10.5	23.00	2.45	30.03	348.85	4.26	31.97	2.13	44.55	1.98E-01
Pond 6	10.5	21.20	2.45	24.24	207.90	2.54	26.08	1.69	33.39	1.48E-01
Pond 7	10.5	18.10	2.45	31.00	284.31	3.47	33.89	0.95	17.01	7.56E-02
Pond 8	11	24.50	2.45	23.45	236.77	2.89	25.75	1.36	29.56	1.31E-01
Pond 9	11	23.00	2.45	92.21	1598.55	19.54	80.87	2.45	51.13	2.27E-01
Pond 10	11	16.80	2.45	21.61	107.10	1.31	22.57	1.89	32.67	1.45E-01
Pond 10	11	16.80	2.45	21.74	109.16	1.33	21.37	1.00	17.27	7.67E-02
Pond 10	11	16.80	2.45	20.91	95.39	1.17	22.36	0.58	9.97	4.43E-02
Pond 10	11	16.80	2.45	20.17	83.21	1.02	24.34	0.53	9.11	4.05E-02
Pond 10 (S. en		16.80	2.45	20.08	81.64	1.00	21.65	0.62	10.73	4.77E-02
Very sm.pond		26.00	2.45	30.35	408.32	4.99	28.65	5.11	116.16	5.16E-01
Very sm.pond		23.00	2.45	53.22	814.79	9.96	56.68	3.23	67.52	3.00E-01

0.2

Table A26. Kinosheo Lake Bog July 5-6, 1990.

SUMMARY

Pond #	In situ Hours	Temp oC	Wind Speed m/sec	CO2 Flux		Total DIC umol/L	Total CH4 umol/L	CH4 Flux		CO2	CO2	CH4	CH4	
				Total CO2 umol/L	Rate umol/m2/hr			Rate ugCO2/m2/sec	Rate umol/m2/hr	Rate ugCH4/m2/sec	Flux /Period mg/m2	Flux /Day mg/m2/d	Flux /Period mg/m2	Flux /Day mg/m2/d
Pond 1	14	18.60	2.55	28.37	256.44	3.13	0.00	0.26	4.92	2.19E-02				
Pond 1	14	18.60	2.55	39.55	461.11	5.64	132.14	0.39	7.33	3.26E-02	0		0	
Pond 1	17.3	19.00	3.53	26.15	620.48	7.58	0.00	0.28	15.01	6.67E-02	78.5232312		0.589965	
Pond 1	22	17.50	0.39	24.19	25.27	0.31	0.00	0.34	0.95	4.21E-03	66.7704917		0.600195	
Pond 1	30	16.00	0.93	34.93	119.13	1.46	0.00	0.25	1.61	7.17E-03	25.4150552	256.0631	0.163943	2.031158
Pond 2	14	23.50	2.55	176.30	3476.46	42.49	0.00	20.53	452.82	2.01E+00				
Pond 2	14	23.50	2.55	375.42	7702.72	94.14	409.47	22.10	487.36	2.17E+00	0		0	
Pond 2	17.5	23.50	3.53	76.95	3702.15	45.25	0.00	11.01	650.66	2.89E+00	878.174775		31.86482	
Pond 2	22	14.10	0.39	39.76	56.25	0.69	0.00	5.94	14.91	6.63E-02	372.081099		23.96059	
Pond 2	30	9.50	0.93	204.15	903.17	11.04	0.00	13.45	68.13	3.03E-01	168.858077	2128.670	5.314372	91.70967
Pond 6	14	21.00	2.55	21.87	166.86	2.04	0.00	0.94	19.30	8.58E-02				
Pond 6	14	21.00	2.55	26.55	259.12	3.17	31.86	0.94	19.17	8.52E-02	0		0	
Pond 6	17.5	21.90	3.53	19.54	359.07	4.39	0.00	1.20	68.27	3.03E-01	47.6010406		2.448230	
Pond 6	22	12.70	0.39	50.14	75.72	0.93	0.00	1.36	3.26	1.45E-02	43.0441906		2.574830	
Pond 6	30	11.50	0.93	76.38	307.32	3.76	0.00	1.71	9.30	4.14E-02	67.4134704	237.0880	0.803948	8.740514
Pond 7	14	19.40	2.55	29.47	289.74	3.54	0.00	0.68	13.26	5.89E-02				
Pond 7	14	19.40	2.55	33.10	357.84	4.37	36.20	0.69	13.39	5.95E-02	0		0	
Pond 7	17.5	20.20	3.53	19.79	324.40	3.96	0.00	0.64	35.20	1.56E-01	52.5327373		1.360572	
Pond 7	22	17.80	0.39	39.18	66.79	0.82	0.00	0.66	1.87	8.31E-03	38.7286038		1.334400	
Pond 7	30	15.20	0.93	55.76	238.20	2.91	0.00	0.94	5.86	2.61E-02	53.6785860	217.4098	0.494916	4.784835

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Table A26. Kinosheo Lake Bog July 5-6, 1990.

SUMMARY

Pond #	Hours	In situ Temp oC	Wind Speed m/sec	CO2 Flux		Total DIC umol/L	Total CH4 umol/L	CH4 Flux		CO2	CO2	CH4	CH4	
				Total CO2 umol/L	CO2 Flux Rate umol/m2/hr			CO2 Flux Rate ugCO2/m2/sec	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec	Flux /Period mg/m2	Flux /Day mg/m2/d	Flux /Period mg/m2	Flux /Day mg/m2/d
Pond 8	14	23.60	2.55	14.46	42.34	0.52	0.00	0.80	17.63	7.83E-02				
Pond 8	14	23.60	2.55	22.17	206.42	2.52	25.68	0.78	17.30	7.69E-02	0		0	
Pond 8	17.5	22.60	3.53	15.18	133.20	1.63	0.00	0.30	17.25	7.67E-02	26.1512526		0.967406	
Pond 8	22	15.90	0.39	138.86	316.48	3.87	0.00	4.06	10.82	4.81E-02	44.5186549		1.010328	
Pond 8	26	11.00	1.10	194.35	1075.45	13.14	0.00	5.86	37.12	1.65E-01	122.490176		1.533971	
Pond 8	30	10.10	0.93	213.60	972.89	11.89	0.00	8.78	45.51	2.02E-01	180.253805	560.1208	2.644222 9.233893	
Pond 10	14	19.20	2.55	28.54	269.09	3.29	0.00	2.16	41.78	1.86E-01				
Pond 10	14	19.20	2.55	31.32	321.01	3.92	31.62	2.19	42.38	1.88E-01	0		0	
Pond 10	17.5	20.10	3.53	14.91	61.51	0.75	0.00	1.74	95.60	4.25E-01	29.4538895		3.863527	
Pond 10	22	17.40	0.39	26.37	30.93	0.38	0.00	2.76	7.72	3.43E-02	9.15198110		3.719809	
Pond 10	26	16.10	1.10	39.55	175.38	2.14	0.00	3.29	24.87	1.11E-01	18.1559535		1.043040	
Pond 10	30	14.80	0.93	59.00	252.98	3.09	0.00	3.62	22.17	9.85E-02	37.6959005	141.6865	1.505212 15.19738	
											Avg.	590.1732		21.94957
											Count	6		6
											Std.Dev.	767.3681		34.46622

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Table A27. Kinosheo Lake Bog July 13-14, 1990

Pond#	In situ		Wind	CO2 Flux		Total DIC	Total CH4	CH4 Flux		CO2	CO2	CH4	CH4	
	Hours	Temp	Speed	Total CO2	CO2 Flux			Rate	Rate	Rate	Rate	Flux	Flux	Flux
		oC	m/sec	umol/L	umol/m2/hr	CO2/m2/s	umol/L	umol/L	umol/m2/hr	ugCH4/m2/sec	/Period	/Day	/Period	/Day
Pond 1	11	19.50	2.45	34.62	373.12	4.56	144.47	0.27	5.05	2.25E-02				
Pond 1	14	20.60	3.12	31.39	549.94	6.72	0.00	0.20	6.43	2.86E-02	60.9222300		0.275590	
Pond 1	17	22.50	3.05	34.10	596.41	7.29	0.00	0.17	4.90	2.18E-02	75.6593411		0.271857	
Pond 1	21	22.50	0.47	25.93	49.68	0.61	0.00	0.16	0.62	2.74E-03	56.8557342		0.176468	
Pond 1	32.5	20.70	2.18	35.77	371.65	4.54	0.00	0.29	5.06	2.25E-02	106.595213	334.9200	0.522043	1.390839
Pond 6	11	23.90	2.45	28.91	341.20	4.17	32.55	1.92	41.10	1.83E-01				
Pond 6	14	27.50	3.12	21.60	370.02	4.52	0.00	0.99	36.49	1.62E-01	46.9408067		1.862124	
Pond 6	17	28.70	3.05	21.82	348.42	4.26	0.00	1.11	36.62	1.63E-01	47.4174217		1.754582	
Pond 6	21	23.70	0.47	44.22	125.03	1.53	0.00	1.15	4.69	2.08E-02	41.6641601		1.321660	
Pond 6	32.5	19.60	2.18	47.39	539.96	6.60	0.00	3.36	56.36	2.50E-01	168.244444	339.6466	5.616277	11.78192
Pond 7	11	21.00	2.45	43.52	570.41	6.97	45.63	1.00	19.74	8.77E-02				
Pond 7	14	23.00	3.12	29.58	549.85	6.72	0.00	0.88	29.34	1.30E-01	73.9368121		1.178045	
Pond 7	17	24.40	3.05	23.95	343.50	4.20	0.00	0.73	21.95	9.76E-02	58.9604917		1.231183	
Pond 7	21	23.50	0.47	25.56	51.08	0.62	0.00	0.84	3.43	1.52E-02	34.7227656		0.812241	
Pond 7	32.5	20.50	2.18	47.40	561.20	6.86	0.00	1.44	24.84	1.10E-01	154.908170	360.0315	2.600243	6.498658
Pond 8	11	24.30	2.45	29.35	357.00	4.36	33.66	6.76	146.62	6.52E-01				
Pond 8	14	30.40	3.12	20.01	361.36	4.42	0.00	1.02	39.90	1.77E-01	47.4121486		4.476450	
Pond 8	17	39.10	3.05	323.92	12161.97	148.65	0.00	1.25	49.55	2.20E-01	826.540090		2.146722	
Pond 8	21	22.50	0.47	119.21	404.16	4.94	0.00	2.70	10.65	4.73E-02	1105.81918		1.926281	
Pond 8	32.5	21.00	2.18	116.61	1739.70	21.26	0.00	17.69	309.82	1.38E+00	542.395884	2815.442	29.48366	42.45557

Table A27 continued. Kinosheo Lake Bog July 13-14, 1990

SUMMARY														
Pond#	In situ Hours	Temp oC	Wind Speed m/sec	CO2 Flux Total CO2 umol/L	CO2 Flux Rate umol/m2/hr	CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate umol/m2/sec	CO2 Flux /Period mg/m2	CO2 Flux /Day mg/m2/d	CH4 Flux /Period mg/m2	CH4 Flux /Day mg/m2/d
Pond 10	11	20.70	2.45	34.40	391.95	4.79	38.46	2.15	41.94	1.86E-01				
Pond 10	14	22.40	3.12	25.48	404.30	4.94	0.00	1.50	49.39	2.19E-01	52.5530495		2.191794	
Pond 10	17	23.70	3.05	19.37	199.67	2.44	0.00	1.45	42.88	1.91E-01	39.8620860		2.214479	
Pond 10	21	22.70	0.47	30.64	68.26	0.83	0.00	1.81	7.19	3.19E-02	23.5778597		1.602326	
Pond 10	32.5	20.70	2.18	51.64	636.74	7.78	0.00	3.78	65.62	2.92E-01	178.365937	328.5867	6.698379	14.18453
Pond 25	15	27.80	3.25	21.45	457.65	5.59	24.63	0.85	38.75	1.72E-01				
Pond 26	15	24.90	3.25	47.55	1487.63	18.18	54.41	1.03	44.51	1.98E-01				
Pond 27	15	25.00	3.25	51.11	1641.77	20.07	53.58	1.25	53.85	2.39E-01				
Pond 28	15	25.10	3.25	28.53	696.63	8.51	32.83	0.34	14.91	6.63E-02				
Pond 29	15	21.30	3.25	49.35	1397.15	17.08	438.29	0.31	12.21	5.43E-02				
Pond 30	15	27.00	3.25	23.18	515.73	6.30	29.13	0.68	30.44	1.35E-01				
Kinoshe	11	20.80	3.25	28.99	594.08	7.26	967.62	0.08	3.18	1.41E-02				
											Avg.	835.7255		15.26230
											Count	5		5
											Std.Dev.	1106.758		15.98411

Table A28. Kinosheo Lake Bog July 17, 1990.

SUMMARY

Pond #	In situ Hours	Temp oC	Wind Speed m/sec	CO2 Flux		Total DIC umol/L	CH4 Flux		CO2	CO2	CH4	CH4		
				Total CO2 umol/L	Rate umol/m2/hr		Rate CO2/m2/s	Total CH4 umol/L	Rate umol/m2/hr	Rate ugCH4/m2/sec	Flux /Period mg/m2	Flux /Day mg/m2/d	Flux /Period mg/m2	Flux /Day mg/m2/d
Pond 1	11	23.00	1.77	31.93	279.52	3.42	144.59	0.35	5.31	2.36E-02				
Pond 1	11	23.00	1.77	35.11	325.74	3.98	0.00	0.34	5.07	2.25E-02				
Pond 1	14	23.70	2.47	31.11	386.18	4.72	0.00	0.32	6.97	3.10E-02	45.4611237	0.291835		
Pond 1	16.5	24.80	2.65	27.43	351.52	4.30	0.00	0.30	7.08	3.15E-02	40.5733267	375.4230	0.281083	2.500013
Pond 6	11	24.20	1.77	71.66	892.72	10.91	71.09	4.65	72.59	3.23E-01				
Pond 6	11	24.20	1.77	90.03	1168.78	14.29	0.00	6.76	105.65	4.70E-01				
Pond 6	14	28.00	2.23	34.17	484.61	5.92	0.00	2.29	50.11	2.23E-01	100.013173	3.341538		
Pond 6	16.5	27.80	2.65	28.55	432.10	5.28	0.00	2.93	75.82	3.37E-01	50.4190393	656.4314	2.518507	25.57110
Pond 7	11	24.10	1.77	27.18	222.96	2.73	28.01	0.93	14.44	6.42E-02				
Pond 7	11	24.10	1.77	38.89	398.46	4.87	0.00	1.02	15.81	7.03E-02				
Pond 7	14	24.10	2.23	40.79	537.40	6.57	0.00	1.14	22.35	9.93E-02	55.9755083	0.899338		
Pond 7	16.5	26.40	2.65	30.63	455.95	5.57	0.00	1.28	31.73	1.41E-01	54.6342731	482.6608	1.081515	8.643728
Pond 10	11	23.60	1.81	43.47	468.33	5.72	47.12	3.48	54.69	2.43E-01				
Pond 10	11	23.60	1.81	42.66	456.16	5.58	0.00	3.37	52.92	2.35E-01				
Pond 10	14	24.60	2.28	44.09	625.65	7.65	0.00	4.34	88.40	3.93E-01	71.8013024	3.412913		
Pond 10	16.5	25.60	2.24	18.38	129.87	1.59	0.00	3.13	64.43	2.86E-01	41.5537248	494.6401	3.056616	28.23067
										Avg.	502.2888	16.23638		
										Count	4	4		
										Std.Dev.	115.9003	12.61396		

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Table A29. Kinosheo Lake Bog July 25, 1990.

SUMMARY														
Pond #	In situ Hours	Temp oC	Wind Speed m/sec	Total CO2 umol/L	CO2 Flux Rate umol/m2/hr	CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec	CO2 Flux /Period mg/m2	CO2 Flux /Day mg/m2/d	CH4 Flux /Period mg/m2	CH4 Flux /Day mg/m2/d
Pond 1	11	23.50	2.46	40.83	580.21	7.09	144.71	0.86	18.28	8.12E-02				
Pond 1	11	23.50	2.46	41.99	603.89	7.38	141.73	0.98	20.96	9.32E-02				
Pond 1	18	25.60	1.88	26.30	240.18	2.94	119.40	0.27	4.71	2.09E-02	128.164330		1.437665	
Pond 1	22	20.00	1.37	30.72	174.07	2.13	128.99	0.45	4.82	2.14E-02	36.4545883	359.1685	0.305152	3.802513
Pond 6	10	19.80	2.78	51.39	778.50	9.52	51.07	2.26	48.75	2.17E-01				
Pond 6	10	19.80	2.78	48.18	712.05	8.70	50.32	2.15	46.26	2.06E-01				
Pond 6	17.5	23.80	1.88	195.57	2887.98	35.30	189.55	37.63	616.47	2.74E+00	599.487090	1918.358	39.76350	127.2432
272 Pond 7	10	21.30	2.78	46.63	724.06	8.85	47.43	2.28	51.54	2.29E-01				
272 Pond 7	10	21.30	2.78	47.11	734.65	8.98	46.78	2.21	49.89	2.22E-01				
272 Pond 7	17.5	26.50	1.88	35.40	405.76	4.96	35.77	1.70	29.96	1.33E-01	187.294664	599.3429	4.790702	15.33024
Pond 10	10	21.70	2.78	67.33	1191.13	14.56	73.10	5.78	132.12	5.87E-01				
Pond 10	10	21.70	2.78	66.89	1181.57	14.44	73.37	5.76	131.51	5.85E-01				
Pond 10	17	27.30	3.11	25.50	498.75	6.10	28.43	4.75	171.59	7.63E-01	259.506159		16.97398	
Pond 10	22	24.20	1.37	48.58	422.75	5.17	55.11	3.59	43.43	1.93E-01	101.365409	721.7431	8.600974	51.14991
											899.6533			49.38147
											Count	4		4
											Std.Dev.	695.6346		55.68515

Table A30. Kinosheo Lake Area August 02 and 10, 1990.

August 02		SUMMARY								
Pond #	In situ Hours	Temp oC	Wind Speed m/sec	Total CO2 umol/L	CO2 Flux Rate umol/m2/hr	CO2 Flux Rate gCO2/m2/se	Total DIC umol/L	Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec
Pond 1	14	22.70	4.04	29.59	1454.54	17.78	137.49	0.11	9.61	4.27E-02
Pond 1	18	23.20	4.23	32.37	1954.17	23.88	131.68	0.05	5.07	2.25E-02
Pond 6	14	27.60	4.04	79.63	6560.44	80.18	88.83	0.46	45.10	2.00E-01
Pond 6	missing									
Pond 7	14	27.90	4.04	41.36	2916.74	35.65	43.88	1.25	124.24	5.52E-01
Pond 7	18	25.80	4.23	30.72	1981.24	24.22	33.93	1.31	140.95	6.26E-01
Pond 10	14	26.10	4.04	32.68	1955.34	23.90	38.74	2.60	248.53	1.10E+00
Pond 10	18	25.90	4.23	26.65	1561.92	19.09	30.25	3.41	367.69	1.63E+00
August 10										
Pond 1	13	16.70	2.79	32.30	321.65	3.93	133.47	0.15	2.98	1.33E-02
Pond 1	18	17.80	3.35	27.61	529.64	6.47	120.78	0.19	8.15	3.62E-02
Pond 6	12	20.20	2.79	33.01	405.41	4.96	49.93	6.02	131.48	5.84E-01
Pond 6	18	21.20	3.35	58.86	2022.29	24.72	91.99	2.12	97.11	4.32E-01
Pond 7	12	18.40	2.79	50.42	714.85	8.74	53.53	4.43	91.50	4.07E-01
Pond 7	18	16.60	3.35	41.01	1027.43	12.56	44.82	3.29	135.14	6.01E-01
Pond 10	12	17.30	2.79	96.73	1569.71	19.19	100.90	19.18	382.30	1.70E+00
Pond 10	18	18.60	3.35	44.16	1246.56	15.24	50.97	8.09	348.13	1.55E+00

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Table A31. Kinosheo Lake Area August 15-16, 1990.

SUMMARY														
Pond #	In situ Hours Temp oC	Wind Speed m/sec	Total CO2 umol/L	CO2 Flux Rate umol/m2/hr	CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec	CO2 Flux /Period mg/m2	CO2 Flux /Day mg/m2/d	CH4 Flux /Period mg/m2	CH4 Flux /Day mg/m2/d	
Pond 1	13.30	4.00	30.25	897.90	10.97	131.94	0.18	12.41	5.51E-02					
Pond 1	13.30	4.00	30.95	944.78	11.55	122.94	0.14	10.02	4.45E-02					
Pond 1	13.30	4.00	30.01	881.30	10.77	124.92	0.13	9.29	4.13E-02					
Pond 1	13.30	4.00	31.14	957.51	11.70	121.88	0.13	8.81	3.91E-02					
Pond 1	16	17.60	4.00	29.94	1133.51	13.85	117.67	0.35	27.07	1.20E-01				
Pond 1	19	17.70	1.00	10.43	-30.22	-0.37	154.51	0.19	1.39	6.18E-03	72.8173415	0.682916		
Pond 1	21	16.90	1.00	27.18	82.02	1.00	122.44	0.25	1.74	7.75E-03	2.27924361	0.050117		
Pond 1	32	15.30	2.50	33.09	277.70	3.39	133.66	0.22	3.62	1.61E-02	87.0519069	0.471792		
Pond 1	34.5	15.40	2.50	30.94	244.65	2.99	130.66	0.26	4.41	1.96E-02	28.7290861	0.160609		
274 Pond 1	37	15.30	4.00	31.63	1115.02	13.63	131.24	0.51	37.27	1.66E-01	74.7815946	303.6104	0.833698	2.513296
Pond 6	14	18.20	4.00	83.34	5226.69	63.88	86.96	11.04	863.16	3.84E+00				
Pond 6	19	18.30	1.00	72.04	409.36	5.00	70.64	16.41	121.26	5.39E-01	619.965411	39.37678		
Pond 6	20.8	15.40	1.00	93.83	504.99	6.17	95.37	14.48	97.38	4.33E-01	36.2083331	3.148385		
Pond 6	31.5	9.30	2.50	162.61	1866.87	22.82	169.41	11.62	157.06	6.98E-01	558.336240	21.77957		
Pond 6	34	13.30	2.50	79.20	938.49	11.47	79.08	12.69	198.41	8.82E-01	154.294940	7.109261		
Pond 6	37	14.40	4.00	128.04	7731.79	94.50	134.49	38.46	2737.46	1.22E+01	572.238213	2025.436	70.46070	148.0431
Pond 7	16	18.20	4.00	32.31	1349.88	16.50	35.42	1.76	137.27	6.10E-01				
Pond 7	19	18.30	1.00	29.58	107.26	1.31	30.74	1.87	13.80	6.14E-02	96.1707026	3.625788		
Pond 7	21	17.50	1.00	30.89	111.25	1.36	35.35	3.13	22.52	1.00E-01	9.61414229	0.581205		
Pond 7	31.5	13.40	2.50	70.87	816.59	9.98	81.08	3.08	48.41	2.15E-01				
Pond 7	31.5	13.40	2.50	73.23	852.23	10.42	74.01	3.21	50.43	2.24E-01	218.447817	6.042839		
Pond 7	34	14.40	2.50	51.05	543.32	6.64	50.96	2.72	44.23	1.97E-01				
Pond 7	34	14.40	2.50	47.62	489.67	5.98	51.26	2.45	39.85	1.77E-01	120.192788	2.817466		
Pond 7	36	14.60	4.00	36.71	1425.16	17.42	39.61	1.98	141.45	6.29E-01				
Pond 7	36	14.60	4.00	41.22	1738.58	21.25	43.87	2.19	156.70	6.96E-01	115.053976	671.3753	3.730440	20.15728

Table A31 continued. Kinosheo Lake Area August 15-16, 1990.

SUMMARY													
Pond #	In situ Hours Temp oC	Wind Speed m/sec	Total CO2 umol/L	CO2 Flux Rate umol/m2/hr	CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec	CO2 Flux /Period mg/m2	CO2 Flux /Day mg/m2/d	CH4 Flux /Period mg/m2	CH4 Flux /Day mg/m2/d
Pond 10	16	18.10	4.00	29.57	1135.78	13.88	35.37	1.02	79.19	3.52E-01			
Pond 10	18.5	17.50	1.00	23.41	59.38	0.73	279.45	1.07	7.69	3.42E-02	65.7337564	1.737478	
Pond 10	20.5	16.80	2.50	22.24	119.95	1.47	23.99	1.00	17.69	7.86E-02			
Pond 10	20.5	16.80	1.00	23.90	59.23	0.72	28.49	0.99	6.94	3.08E-02	5.21881539	0.233973	
Pond 10	31.5	13.90	2.50	82.18	1008.98	12.33	91.85	3.55	56.70	2.52E-01	265.854008	6.073448	
Pond 10	34	14.70	2.50	69.95	850.11	10.39	75.91	4.37	71.74	3.19E-01	102.249992	2.568855	
Pond 10	36.2	14.90	4.00	56.21	2812.78	34.38	61.25	2.50	180.55	8.02E-01	181.312992	735.2528	4.541242
Pond 10(Aug 1	17.50	4.00	22.85	597.75	7.31	25.47	1.00	77.02	3.42E-01				
Pond 10(1800h	17.50	4.00	22.89	601.19	7.35	26.24	0.47	36.40	1.62E-01				
Pond 10 (S.en	17.50	4.00	23.63	656.37	8.02	26.69	0.54	41.28	1.83E-01				
Pond 10 (N.en	17.50	4.00	24.68	734.21	8.97	27.89	0.55	42.32	1.88E-01				
Pond 10 (Aug1	13.90	4.00	40.82	1655.54	20.23	41.08	0.99	69.38	3.08E-01				
Pond 10(0830h	13.90	4.00	33.88	1181.32	14.44	39.86	0.54	38.19	1.70E-01				
Pond 10 (S.en	13.90	4.00	31.53	1021.02	12.48	37.36	0.54	37.82	1.68E-01				
											933.9187		47.16881
										Count	4		4
										Std.Dev.	752.1294		67.70633

Table A32. Kinosheo Lake Area September 12-13, 1990.

SUMMARY

Pond #	In situ Hours Temp oC	Wind Speed m/sec	CO2 Flux		CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux		CO2 Flux /Period mg/m2	CO2 Flux /Day mg/m2/d	CH4 Flux /Period mg/m2	CH4 Flux /Day mg/m2/d
			Total CO2 umol/L	Rate umol/m2/hr				Rate umol/m2/hr	Rate ugCH4/m2/sec				
Pond 1	11	9.50	6.00	37.37	2653.64	32.43	164.64	1.05	157.83	7.01E-01			
Pond 1	13.2	9.00	4.17	28.85	626.35	7.66	157.90	0.58	39.64	1.76E-01	162.359358	3.554602	
Pond 1	15.8	11.00	1.39	31.00	98.57	1.20	152.01	0.29	2.28	1.01E-02	40.6679610	0.855305	
Pond 1	34.2	9.50	5.56	45.51	3342.23	40.85	155.66	0.37	48.51	2.16E-01	1396.61956	7.497187	
Pond 1	38	4.00	5.56	38.01	1589.96	19.43	153.05	0.41	45.70	2.03E-01	406.905616	1783.602	2.826245 13.09630
Pond 2	10.5	9.50	6.00	62.93	6377.97	77.95	73.50	0.99	148.85	6.62E-01			
Pond 2	12.9	11.00	4.17	45.40	1920.99	23.48	55.80	1.02	74.36	3.30E-01	438.185220	4.285644	
Pond 2	15.5	20.00	1.39	35.12	222.18	2.72	42.31	1.01	10.91	4.85E-02	122.589468	1.773587	
276 Pond 2	34.3	4.50	5.56	81.42	6402.31	78.25	94.81	4.89	548.96	2.44E+00	2739.89000	84.20402	
Pond 2	37.2	5.00	5.56	233.90	23466.08	286.81	324.24	17.72	2020.14	8.98E+00			
Pond 2	37.2	5.00	5.56	97.90	8376.77	102.38	167.20	9.12	1039.50	4.62E+00	1448.81030	4261.211	49.05913 124.9995
Pond 6	10.7	9.00	6.00	65.47	6606.06	80.74	74.04	24.12	3560.48	1.58E+01			
Pond 6	13	17.00	4.17	25.95	897.04	10.96	24.07	5.44	461.67	2.05E+00	379.656781	74.00771	
Pond 6	15.6	19.00	1.39	20.80	66.67	0.81	17.97	2.84	29.85	1.33E-01	55.1241730	10.22375	
Pond 6	34.4	4.50	5.56	66.43	4764.57	58.23	71.41	1.04	116.65	5.18E-01	1998.20106	22.03345	
Pond 6	37.5	5.00	5.56	29.11	744.67	9.10	27.25	0.61	69.94	3.11E-01	375.730458	2515.264	4.627384 99.30654
Pond 7	10.8	9.00	6.00	52.14	4690.68	57.33	52.99	4.07	600.14	2.67E+00			
Pond 7	13.1	11.50	4.17	36.30	1317.19	16.10	35.77	4.14	304.62	1.35E+00	303.998366	16.64761	
Pond 7	15.7	13.50	1.39	40.83	202.57	2.48	39.74	4.82	42.18	1.87E-01	86.9302562	7.213344	
Pond 7	34.5	8.50	5.56	96.56	9458.80	115.61	105.81	12.59	1594.95	7.09E+00	3995.94059	246.2235	
Pond 7	37.7	7.50	5.56	76.78	6736.47	82.33	81.48	8.92	1097.17	4.88E+00	1140.14643	4931.166	68.91831 302.4560

Table A32 continued. Kinosheo Lake Area September 12-13, 1990.

SUMMARY

Pond #	In situ Hours	Temp oC	Wind Speed m/sec	CO2 Flux		Total DIC umol/L	CH4 Flux		CO2 Flux /Period mg/m2	CO2 Flux /Day mg/m2/d	CH4 Flux /Period mg/m2	CH4 Flux /Day mg/m2/d		
				Total CO2 umol/L	CO2 Flux Rate umol/m2/hr CO2/m2/s		Total CH4 umol/L	CH4 Flux Rate umol/m2/hr ugCH4/m2/sec						
Pond 8	11.2	12.00	6.00	85.28	10554.82	129.00	100.68	13.86	2223.93	9.88E+00				
Pond 8	13.4	17.00	4.17	105.52	7457.25	91.14	123.08	11.23	952.66	4.23E+00	871.784390	55.90804		
Pond 8	15	19.00	4.17	71.77	4977.35	60.83	82.79	9.25	822.95	3.66E+00	437.698086	22.72783		
Pond 8	34.2	4.50	5.56	318.36	32279.81	394.53	340.93	33.78	3790.28	1.68E+01	15737.4249	708.5928		
Pond 8	37.2	4.00	5.56	615.78	63695.17	778.50	624.35	73.35	8099.28	3.60E+01				
Pond 8	37.2	4.00	5.56	160.87	14795.71	180.84	190.66	24.64	2721.19	1.21E+01	4720.66632	20093.14	220.8124	930.4995
Pond 10	10.4	8.00	6.00	190.38	23753.48	290.32	222.57	1.95	280.35	1.25E+00				
Pond 10	12.7	11.00	4.17	26.55	589.09	7.20	21.86	0.94	68.52	3.05E-01	1258.51129	6.558665		
277 Pond 10	15.4	11.00	4.17	79.02	4297.43	52.52	91.92	0.45	32.43	1.44E-01	284.884548	2.140076		
Pond 10	34.9	8.00	5.56	487.36	56752.21	693.64	512.50	10.06	1256.44	5.58E+00	26190.2971	201.0637		
Pond 10	37.2	7.00	5.56	324.00	35751.78	436.97	394.68	12.57	1524.03	6.77E+00	4680.70213	29027.81	51.16056	233.6624
VSP 1	1350 hr	4.50	5.56	277.96	27867.58	340.60	319.01	2.83	318.04	1.41E+00				
VSP 2	1355 hr	5.00	5.56	413.36	43377.47	530.17	444.40	15.78	1798.92	8.00E+00				
										Avg.	10435.36	284.0033		
										Count	6	6		
										Std.Dev.	11357.37	332.7515		

Table A33. Kinosheo Lake Area October 12-13, 1990.

SUMMARY

Pond #	In situ Hours Temp oC	Wind Speed m/sec	CO2 Flux		CO2 Flux Rate CO2/m2/s	Total DIC umol/L	CH4 Flux		CO2 /Period mg/m2	CO2 /Day mg/m2/d	CH4 /Period mg/m2	CH4 /Day mg/m2/d		
			Total CO2 umol/L	CO2 Flux Rate umol/m2/hr			Total CH4 umol/L	CH4 Flux Rate umol/m2/hr ugCH4/m2/sec						
Pond 1	9.7	3.50	1.39	38.94	87.43	1.07	179.52	1.40	8.28	3.68E-02				
Pond 1	11.4	3.50	1.39	42.82	109.62	1.34	185.82	0.95	5.61	2.49E-02	7.36962176	0.188895		
Pond 1	13.7	4.00	1.39	34.75	67.38	0.82	182.29	0.72	4.38	1.95E-02	8.95629139	0.183685		
Pond 1	16.1	4.00	1.39	32.01	51.33	0.63	180.53	0.72	4.35	1.93E-02	6.26803704	84.72731	0.167480	2.025229
Pond 2	9.75	3.00	1.39	51.93	155.73	1.90	79.73	0.79	4.58	2.03E-02				
Pond 2	11.5	7.00	1.39	54.41	221.95	2.71	82.53	1.31	9.01	4.00E-02	14.5407363	0.190205		
Pond 2	13.7	8.00	1.39	42.13	151.30	1.85	66.30	1.47	10.50	4.67E-02	18.4760130	0.351265		
Pond 2	15.6	7.50	1.39	37.31	113.45	1.39	58.73	1.34	9.36	4.16E-02	10.7751815	179.6592	0.294007	3.427605
Pond 3	9.9	4.50	1.39	80.05	341.70	4.18	117.30	1.53	9.48	4.22E-02				
Pond 3	11.6	7.00	1.39	35.20	94.87	1.16	59.09	2.87	19.71	8.76E-02	16.3277926	0.397080		
Pond 3	13.7	8.50	1.39	18.54	-8.95	-0.11	34.22	1.22	8.87	3.94E-02	4.06435193	0.491640		
Pond 3	15.7	6.50	1.39	22.33	7.10	0.09	38.42	1.22	8.18	3.63E-02	-0.0790405	84.05422	0.265923	4.777838
Pond 4	9.9	4.00	1.39	156.55	779.05	9.52	213.42	1.32	7.97	3.54E-02				
Pond 4	11.7	8.00	1.39	109.82	617.17	7.54	139.28	2.06	14.74	6.55E-02	55.2903278	0.327000		
Pond 4	13.9	8.50	1.39	34.22	101.16	1.24	61.77	0.70	5.13	2.28E-02	34.7671510	0.349737		
Pond 4	15.7	7.00	1.39	35.62	97.62	1.19	60.25	0.55	3.78	1.68E-02	8.09045653	402.6581	0.131835	3.317228
Pond 5	10.2	4.00	1.39	333.02	1810.17	22.12	398.37	0.37	2.25	1.00E-02				
Pond 5	11.7	8.00	1.39	131.39	765.64	9.36	175.81	0.83	5.95	2.65E-02	82.1683786	0.095182		
Pond 5	13.9	7.50	1.39	53.18	220.57	2.70	79.37	0.91	6.39	2.84E-02	47.7327466	0.217219		
Pond 5	15.7	6.00	1.39	39.03	110.68	1.35	58.66	1.91	12.56	5.58E-02	13.4817128	625.6705	0.280364	2.586618

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Table A33 continued. Kinosheo Lake Area October 12-13, 1990.

SUMMARY

Pond #	In situ Hours Temp oC	Wind Speed m/sec	CO2 Flux		CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux		CO2 /Period mg/m2	CO2 /Day mg/m2/d	CH4 /Period mg/m2	CH4 /Day mg/m2/d
			Total CO2 umol/L	Rate umol/m2/hr				Rate umol/m2/hr	Rate ugCH4/m2/sec				
Pond 6	10.1	4.50	1.39	51.26	169.88	2.08	69.88	4.54	28.07	1.25E-01			
Pond 6	11.7	6.00	1.39	43.88	141.47	1.73	56.34	4.07	26.79	1.19E-01	11.3021634	0.724177	
Pond 6	14	8.00	1.39	38.41	125.65	1.54	58.29	4.67	33.36	1.48E-01	13.2224680	1.082637	
Pond 6	15.9	7.00	1.39	38.80	118.66	1.45	51.98	4.78	32.82	1.46E-01	10.2119431	143.7375	1.005932 11.63895
Pond 7	10.2	4.00	1.39	44.23	122.72	1.50	62.00	1.60	9.70	4.31E-02			
Pond 7	11.9	4.00	1.39	44.56	124.68	1.52	57.16	1.44	8.72	3.88E-02	8.98081543	0.243189	
Pond 7	14	5.00	1.39	35.26	78.45	0.96	48.23	1.55	9.79	4.35E-02	9.38451205	0.310916	
Pond 7	15.9	4.50	1.39	37.25	86.23	1.05	49.68	1.43	8.86	3.94E-02	6.88329912	107.2508	0.283484 3.557908
Pond 8	10.7	5.50	1.39	124.87	640.34	7.83	154.95	4.70	30.35	1.35E-01			
Pond 8	12.3	7.00	1.39	134.58	752.39	9.20	161.04	6.95	47.67	2.12E-01	49.0240685	0.998607	
Pond 8	14.2	9.00	1.39	169.65	1074.38	13.13	201.00	12.30	91.30	4.06E-01	contaminated do not use		
Pond 8	13.2	7.00	1.39	84.04	418.01	5.11	104.97	5.28	36.25	1.61E-01	23.1738365	693.0998	0.604196 15.38691
Pond 9	10.7	6.50	1.39	70.73	320.99	3.92	88.40	3.27	22.00	9.78E-02			
Pond 9	12.5	8.00	1.39	47.26	186.62	2.28	64.51	2.02	14.45	6.42E-02	19.5428475	0.510276	
Pond 9	14.4	8.00	1.39	43.79	162.73	1.99	63.22	3.09	22.03	9.79E-02	14.6028131	0.554447	
Pond 9	16.7	7.00	1.39	38.10	114.07	1.39	55.11	2.73	18.71	8.31E-02	14.0059243	194.2248	0.749537 7.318029

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Table A33 continued. Kinosheo Lake Area October 12-13, 1990.

SUMMARY

Pond #	In situ Hours Temp oC	Wind Speed m/sec	CO2 Flux Total CO2 Rate umol/L	CO2 Flux Rate CO2/m2/hr	CO2 Flux Rate CO2/m2/s	Total DIC umol/L	Total CH4 umol/L	CH4 Flux Rate umol/m2/hr	CH4 Flux Rate ugCH4/m2/sec	CO2 /Period mg/m2	CO2 /Day mg/m2/d	CH4 /Period mg/m2	CH4 /Day mg/m2/d
Pond 10	10.5	4.00	1.39	276.77	1481.48	18.11	309.51	29.14	176.52	7.85E-01			
Pond 10	12.3	5.50	1.39	302.43	1745.62	21.34	351.90	17.70	114.27	5.08E-01	124.243630	4.071059	
Pond 10	14.2	6.00	1.39	316.43	1873.37	22.90	357.62	16.42	108.19	4.81E-01	155.254649	3.470348	
Pond 10	15.5	5.50	1.39	327.08	1899.03	23.21	379.81	24.58	158.70	7.05E-01	107.890600	1859.466	2.775590 49.52159
VSP 1	1020 hr	3.50	1.39	58.72	200.53	2.45	79.93	2.28	13.53	6.01E-02			
VSP 1	1557 hr	6.00	1.39	55.26	213.84	2.61	71.39	2.54	16.72	7.43E-02			
VSP 2	1025 hr	4.00	1.39	192.76	990.61	12.11	225.44	2.50	15.13	6.73E-02			
										Avg.	437.4549		10.35579
										Count	10		10
										Std.Dev.	547.1482		14.43287

Table A34. Pond Physical Dimensions

Location	Pond Number	Pond Size (m ²)	Water Depth (m)*
Kinosheo Lake Bog	1	21390	1.5-2.0
	2	32	0.1-0.4
	3	32	0.1
	4	250	0.1
	5	250	0.1
	6	560	0.1-0.2
	7	1470	0.5-1.0
	8	100	0.1-0.4
	9	100	0.1-0.3
	10	41620	2.0-2.5
Coastal Fen	11	460	0.1-0.3
	12	295	0.1-0.3
	13	320	0.05-0.2
	14	530	0.45-0.75
	15	450	0.05-0.2
	16	450	0.05-0.2
	17	600	0.05-0.2
	18	700	0.2-0.3
Interior Fen	19	100	0.2-0.5
	20	400	0.2-0.5
	21	500	0.05-0.5
	22	500	0.5
	23	300	0.1-0.3
	24	300	0.2-0.4

*Note: water depths shown were recorded when ponds were at the maximum depth and size in early June.