Sediment Stratigraphy in Storage Basins
of the Lambert Creek/Vadnais Lake Watershed

Final Research Report

prepared for

Vadnais Lake Area Water Management Organization

by

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Introduction

This report evaluates the potential for sediments in the riparian wetlands of Lambert Creek to release/retain phosphorous under a range of physico/chemical condition. The study represents part of a comprehensive workplan by the Vadnais Lake Area Water Management Organization (VLAWMO) to assess control options for decreasing nutrient loading to Vadnais Lake from the Lambert Creek watershed. The specific objectives of the VLAWMO work plan addressed in this report are:

(2.2) Sediment Stratigraphy in Storage Areas:
Determine the lithology and phosphorus content of existing sediments in Rice, Grass, and Lambert lakes to depths reasonable for the excavation of a sedimentation basin suitable for permanent phosphorus removal.

(2.5) Phosphorus Cycling in Rice Lake:
Determine the lithology and chemical composition of the surface sediments from Rice Lake as a factor controlling phosphorus release/retention within the basin.

(2.6a) Sediment Phosphorus Sources:
Determine the spatial variation in phosphorus burdens in sediment cores from Sobota Slough, and Rice, Grass, and Lambert lakes in order to locate areas contributing high phosphorous loads to downstream systems. In Sobota Slough the sediment survey shall attempt to locate areas contaminated by sewage sludge that may constitute "hot-spots" for phosphorus loading.

(2.6b) Phosphorus Content of Interstitial Waters:
Determine concentrations of ortho- and total phosphorus in soil interstitial waters to assess mid-summer phosphorus release due to oxidation of former lake sediments.

The mainstem of Lambert Creek flows through a series of four wetland basins (Sobota Slough, Rice Lake, Grass Lake, Lambert Lake). Mass balance analysis of flow data from gauging stations at the outlets of these sub-watersheds indicates that, from April to September, Sobota, Rice and Grass export far more phosphorus than they receive through inflows (Walker 1990a, b). Lambert Lake, the last wetland in the chain, shows a net retention of P. The wetlands themselves represent former lake basins that were ditched and drained around the turn of the century. Some years later sewage sludge from the City of White Bear Lake was discharged into Sobota Slough. Although both perturbations happened decades ago, phosphorus may still be "leaking" from labile nutrient reservoirs created by these past events. Present-day hydraulic properties of the basins, including fluctuating water levels, short residence times, and channelized flow, also limit the ability of these wetlands to assimilate external nutrient loads. Thus a series of control measures – principally hydraulic modifications – have been proposed to increase the phosphorus retention capacity of some of the basins and to limit internal mobilization of nutrients from sedimentary reservoirs.

This study describes the lithology, origin, and phosphorus content of sediments in the Lambert Creek wetlands. On the basis of these results the source(s) and processes controlling phosphorous release are discussed. Finally the report considers the influence that sedimentary properties may have on proposed hydraulic modifications.

Methods

Field Coring

Sediment coring was conducted with a modified square-rod piston sampler equipped with a 5-cm diameter stainless-steel core-barrel (Wright 1980). This devise is suitable for quantitative recovery of fine-grained lacustrine sediments to depths of 10-20 meters. The corer was also be equipped with a serrated cutting edge, along with modifications to permit the core tube to be rotated back and forth (Wright et al. 1984). Corers with these modifications are able to recover wood or undecomposed fibrous peat that characterizes the upper meter or two of most peat deposits. The uppermost section of flocculent lake sediments was collected in a clear polycarbonate core barrel and extruded vertically to prevent disturbance or mixing of the sediment/water interface. All cores were extruded and logged in the field; general sediment stratigraphy was noted and recorded to the nearest cm. Core sections were wrapped in plastic food-wrap and aluminum foil, or in the case of the fluid uppermost lake sediments, stored in wide-mouth polypropylene jars. Cores were returned to the lab and stored in a cold-room at 4 °C. Coring sites were located by compass triangulation to "on-shore" landmarks and/or proximity to geographic features visible on low-level aerial photographs.

Core Description and Sampling

Sediment cores were unwrapped in the laboratory, scraped with a stainless-steel spatula to remove surface smearing, and described lithologically. Sediment descriptions included a semi-quantitative assessment of texture, color, particle-size, and composition as modified from Troels-Smith (1955) Sediment subsamples for laboratory analysis were removed from each core section following description. The subsamples consisted of 10- or 20-cm core increments taken at regular 20-cm intervals. Subsamples were placed in Kapak heat-sealed bags, homogenized, and stored at 4 °C.

Soil Lysimetry

Pore-waters in the surface peats of Grass Lake were sampled using standard 12" soil tension-lysimeters. The lysimeters were buried at two depths (15 and 30 cm) at each of four sampling stations, evacuated with a vacuum hand-pump, and allowed to fill for several hours. All stations and depths were sampled repeatedly between August 28 and October 25, 1991. Lysimeter positions were marked with short lengths of PVC tubing held in place within the loose surface peat by metal rods that were anchored in the firm peat below. At each sampling the lysimeters were relocated in exactly the same position by inserting them into the PVC sleeves to a pre-determined depth. The samples were analyzed for ortho-P (within 24 hours of retrieval) and total-P at the St.Paul Water Utility Vadnais Lab.

Laboratory Analyses

Extraction

Sediments were extracted for phosphorus and iron determinations according to fractionation procedures adapted form Hieltjes and Lijklema (1980) and Engstrom and Wright (1984); see Figure 1. Total phosphorus was measured as the ortho-P extracted by sequential digestion with 30% hydrogen peroxide (1 hr at 85°C) followed by 0.5 M HCl (0.5 hr at 85°C). Exchangeable and Fe/Al-bound phosphorus (NaOH-SRP) were estimated as the ortho-P extracted with 0.1 M sodium hydroxide (16 hr at 25°C); hydrolyzable organic phosphorus (NaOH-ORP) was calculated from the difference between the total-P and the ortho-P in this second extract. The sediment residue from the hydroxide extraction was further treated with 0.5 M HCl (24 hr at 25°C) to determine the calcium-bound pool of phosphorus (HCl-P). Finally the residual (organically-bound) phosphorus was estimated from the difference between the total-P and the sum of the hydroxide and HCl extraction. Prior to treatment, sediment aliquots were dried for 24 hr at 90° C, ground to a powder in a ceramic mortar and pestle, and subsampled by weight (ca. 0.1 g) on an electronic analytical balance. Extraction temperatures for total-P were maintained in a hot-water bath, and extracts were separated from sediment residue by centrifugation and filtration through 0.45 µ HA-Millipore™ membrane filters. All dilutions were done according to weight on a top-loading electronic balance. Extracts were stored in acid-washed polypropylene bottles prior to analysis.

Analytical

Phosphorus: Total-P, HCl-P, and NaOH-SRP sediment-fractions and lysimeter pore-waters were analyzed for ortho-phosphorus by the ascorbic acid method; persulfate digestion was used prior to analysis of NaOH-TP in sediment extracts and Total-P in the lysimeter samples (Standard Methods).

Residual-P (organic P) and NaOH-ORP (hydrolyzable organic P) sediment fractions were determined by difference. Standard absorbance curves were constructed from a serial dilution of an analytical P-standard in the appropriate matrix for each fraction.

Iron: Acid-extractable Fe was analyzed from the same H_2O_2/HCl extract as that used for Total-P determinations. Concentrations were measured by direct-current plasma/atomic emission spectroscopy (DCP/AES) on a Spectraspan IIIB DCP with simultaneous multi-element capabilities; all samples were measured at least four times and standards (Spex™ brand) and blanks of the same matrix were run between every four samples. Samples were diluted so as to provide Fe concentrations at least one order of magnitude above detection (3 s.d. above background = 50 ppb for Fe).

Loss-on-Ignition: Bulk density, organic matter, and carbonate content of sediment samples were determined by standard loss-on-ignition techniques (Dean 1974). Approximately 1-cm^3 aliquots of fresh wet sediment were dried at 110° C, and burned at 550° and 1000° C; samples were weighed wet and between each heating on an electronic analytical balance.

Replication: Extractions and analyses were replicated as follows:

Analysis	Total Samples	Replicates	% Replication
P-fractions	124	14	11%
Fe	40	4	10%
LOI	180	18	10%

Results

Sediment Core Collection

Sediment cores from each of the four wetlands in the Lambert Creek watershed were collected between December 27, 1990 and January 15, 1991. Coring was conducted in the early winter when the peat surface was frozen sufficiently to allow the use of a snowmobile, but before the frost had penetrated so deeply as to inhibit coring. These wetlands are so densely vegetated with cattails that foot travel with a modest load of equipment is extremely difficult. Sediment cores, ca. 3 m in length, were collected at four stations located within the central open-water region of Rice Lake (cores no. 5-8) and from each of two central locations (areas of lowest elevation near the drainage ditch) in Grass and Lambert lakes (cores no. 5 & 6). Cores, ca. 1 m in length, were collected from 8 station in Sobota Slough (cores no. 1-8) and from each of four marginal (slightly drier) stations in Rice, Grass and Lambert lakes (cores no. 1-4). Coring sites, located by compass triangulation to on-shore landmarks, were plotted on high-resolution aerial-photo maps of the four wetlands; approximate locations are illustrated in Figure 2.

Cores were usually recovered in 1-m long sections taken by a single drive of the square-rod piston sampler. However, several drives of shorter length were required where sediments were composed of very dense peat, because this type of material tended to jam in the core-barrel and inhibit full recovery on longer 1-m drives. This problem was encountered at drier sites in Sobota Slough (cores no.1-3, 5 & 6), where in some cases woody material was penetrated during coring operations. At most locations the surface peat was composed of a loosely woven mat of cattail roots that tended to clog the core barrel and inhibit recovery of deeper sediments. In all such cases, the corer was moved laterally a few meters, and coring was repeated until a more complete section was obtained. The collection of surface sediments was also inhibited at some locations by deep frost penetration. This problem developed after a period of sub-zero temperatures and was most pronounced at drier coring sites (primarily in Lambert Lake and Sobota Slough). Frozen materials had to be removed with an ice-chisel and were not collected. In such cases the depth of the frozen surface was noted, and all core depths were corrected to reflect actual stratigraphic position below the sediment surface. The coring log is summarized in Appendix A.

Core Lithology

Sediment cores were unwrapped in the laboratory, scraped with a stainless-steel spatula to remove surface smearing, and described lithologically. Subsamples were taken at 10-cm intervals (5-cm at sharp transitions) along the length of each core, dispersed in water, and examined under a dissecting microscope to assess sediment composition. Sedimentary constituents were classified by composition according to Troels-Smith (1955), and were quantified on an abundance scale of 1-4 (roughly 25-100%). Stratigraphic profiles of sediment composition are illustrated for all cores, grouped by wetland, in Figure 3 (a-e). The nine sediment constituents recognized in these figures are coded according to the following scheme:

Woody materials		
Tl	*Turfa lignosa*	Roots, stems, and branches of woody plants
Dl	*Detritus lignosus*	Fragments of woody plants > 2 mm
Herbaceous materials		
Th	*Turfa herbosus*	Roots, stems, and leaves of herbaceous plants
Dh	*Detritus herbosus*	Fragments of herbaceous plants > 2 mm
Dg	*Detritus granosus*	Plant fragments < 2 mm, > 0.1 mm
Mosses		
Tb	*Turfa bryophytica*	Mosses and moss fragments
Lacustrine materials		
Ld	*Limus detrituosus*	Plant and animal fragments < 0.1 mm
Lc	*Limus calcareus*	Marl - carbonate particles < 0.1 mm
Sand and silt		
Ga	*Grana arenosa*	Fine- medium sand

This classification is ordered so as to represent a general trend of origin from drier to wetter habitats. Woody and herbaceous materials indicate swamp or marsh conditions, while lacustrine materials represent open-water environments. Mosses can be either terrestrial or aquatic, but in the cores from this study they are mostly associated with lacustrine sediments. Sand and slit (minor constituents in most of the cores) are also more indicative of open-water sedimentation.

Sobota Slough

Sediments from this wetland are typically composed of highly compact peat containing abundant woody and herbaceous materials. This is particularly true for cores 1, 2, 5, and 6. These profiles contain relatively little lacustrine sediment and represent relatively dry swamp habitats. Two cores (3 & 4) collected around the margin of the wetland near the White Bear Lake Public Works facility show marsh type sediments grading upward to lacustrine deposits. This sequence, which is opposite of the trend found in cores from the other three wetlands, indicates flooding of what were formerly drier sites. The hydrological change was probably caused by some combination of road construction, ditching, or filling along the edge of the wetland. Cores 7 and 8, collected in the very wettest portion of the marsh, are dominated by lake-type sediments. Core-7 grades upward into herbaceous materials representing shallower water, whereas core-8, which was collected from an open pool in 50 cm of water, shows no such trend. Both of these cores contain abundant small bundles of thin blue fibers within an overall matrix of fine-grained sediment; the fibers appear to be man-made. Only one other core from Sobota Slough (core-3) contains identifiable material derived from dumping or filling of the marsh. The upper 20 cm of this section is composed of a light-colored compact debris with very high carbonate content (see LOI section below).

Rice Lake

The sediments from this wetland are primarily composed of lacustrine materials, particularly the four 3-m cores (no. 5-8) collected from the region of open-water. The 1-m cores (no. 1-4) collected from more terrestrial areas around the margin of the wetland show marsh-type sediments (herbaceous materials) at the surface overlying lake-type sediment below. Core-2 shows this trend most clearly, whereas core-1 also contains a deeper interval of marsh-dominated peat. The open-water cores exhibit a similar pattern with herbaceous detritus becoming more prevalent in the uppermost half-meter. The lower two meters of these long cores also contains abundant shell fragments and fine-grained carbonates that disappear in the upper meter of sediment. The overall trend from lake to marsh-type sediments in this wetland must represent a lowering of water level caused by ditching operation in the early 1900s.

Grass Lake

The cores from this wetland are similar to those from Rice Lake; they are dominated at depth by lake sediments and are overlain above by marsh peat containing abundant roots, stems, and other herbaceous detritus. This transition is clearly evident in all cores and typically occurs within 50 cm of the surface (except in core-1 where it is deeper). The two long cores (no. 5 & 6) also show deeper intervals where herbaceous materials are more abundant. The upward trend toward marsh-type sediments can likewise be attributed to lake drainage and ditching at the turn of the century.

Lambert Lake

Cores from this site are highly variable in composition both spatially and stratigraphically. Herbaceous materials representing marsh-like conditions are abundant throughout all of the sections. Lake sediments tend to be more prevalent at depth, but even here herbaceous constituents represent at least 50% of the sediment. The two long cores (no. 5 & 6) penetrate fully to underlying glacial sands, which are present at remarkably shallow depths in this wetland (2.5 and 1. 25 m, respectively). A thin section of lacustrine sediments immediately overlies the sand, followed by an alternating sequence of marsh and lake deposits. Bryophyte remains are abundant in the upper meter of these two cores and in nearby core-1. The sediment sequence in Lambert Lake indicates that this wetland has been a shallow marsh throughout most of its history. Lake sediments occur intermixed with herbaceous peat, even in the deepest part of the present-day basin. The shallow peat depth at core-sites 5 & 6 suggests that only a thin veneer of sediment overlies much of the Lambert Lake wetland (although isolated basins with deeper peat may occur elsewhere).

Loss-on-Ignition

Organic matter, carbonate, and inorganic (mineral matter) content of the sediments were determined at selected core levels by loss-on-ignition techniques. Volumetric aliquots of fresh wet sediment were dried at 110° C, ignited at 550° and 1000° C, and weighed between each heating on an analytical balance. Weight loss following the two ignitions represents CO_2 from organic matter and carbonate, respectively; the remaining inorganic ash is composed primarily of silicate minerals, biogenic-silica (from diatoms), and iron oxides. LOI profiles are shown in Figure 4 (a-e).

Sobota Slough

In general marsh peat tends to be higher in organic matter than lacustrine sediments, which typically contain abundant diatoms, mineral particles, and carbonates. This pattern is clearly illustrated in the eight cores from Sobota Slough. Those cores dominated by woody and herbaceous materials (no. 1, 2, 5 & 6) are more than 80% organic matter by dry weight, whereas, the two cores dominated by lake sediments (no. 7 & 8) are substantially less organic. The same relationship holds stratigraphically; cores grading upward to lake sediment decrease in organic content (core-4) while the reverse is true for those grading upward to peat (core-7). However, it is important to note that even 50% organic content – the lowest concentration in any of the eight cores – is still very high compared to open water sediments in most present-day lakes. Although cores from the wettest region of Sobota Slough (no. 7 & 8) are dominated at depth by lake sediments, their low mineral matter content implies that deposition occurred in a small pool surrounding by peatland, which would inhibit the inwash of mineral soil from surrounding uplands. The fill material at the top of core-3 is almost 90% carbonate by weight.

Rice Lake

Sediments from this wetland are considerably lower in organic content than those of Sobota Slough, particularly at depth in the four long cores where lacustrine materials are most abundant. These deeper sediments are composed of 30-40% organic matter, 10-40% carbonate, and 30-50% mineral matter. This composition is comparable to that found in small to moderate-sized lakes in the region today. An up-core increase in organic matter to 60-70% and a comparable drop in carbonate to less than 5% represents the transition to shallow water conditions that was also inferred from lithological evidence (above). The four short cores from sites marginal to the open-water zone (no. 1-4) are similar in composition to the upper sections of the four long cores: 60-75% organic matter, 20-30% mineral matter, and < 5% carbonate.

Grass Lake

Sediment composition and stratigraphy in this wetland is similar to that from Rice Lake. The lower two meters of the the two long cores (no. 5 & 6) contain roughly equal proportions of organic, carbonate, and mineral matter. With the up-core transition to herbaceous peat, organic content rises > 60%, and carbonate largely disappears from the sediments.

Lambert Lake

The upper sediments from this wetland are intermediate in composition between the organic-rich peats of Sobota Slough and the carbonate-rich lake sediments found at depth in Grass and Rice lakes. They are generally 50-70% organic matter, 30-40% mineral matter, and contain < 5% carbonate by weight. This composition reflects the intermixture of lacustrine sediment and marsh peat seen in the lithological description. The two long cores (no. 5 & 6) grade downward into less organic sediments with abundant carbonate (10-40%) as do the lowermost samples from the four 1-m cores (no. 1-4). The trend is quite variable, however, reflecting the stratigraphic fluctuation between marsh and lake sediments at these sites. The underlying glacial sands contain little or no organic matter.

Phosphorus

A chemical extraction scheme was developed to identify the labile pools of sedimentary phosphorus that could be potentially released to Lambert Creek from the four riparian wetlands. The total amount of P in each sample was subdivided into four fractions: (1) NaOH-SRP (soluble reactive P extracted by dilute NaOH) is considered to represent Fe-/Al-bound P; this fraction, which is also known as non-apatite inorganic P (NAIP) is thought to be highly labile and easily mobilized, particularly under anaerobic conditions. (2) NaOH-ORP (the difference between total-P and ortho-P extracted by dilute NaOH) is though to represent hydrolyzable organic-P associated with humic and fulvic acids; this fraction is also labile and probably contributes to high levels of total-P found in humic-stained waters during periods of high discharge. (3) HCl-P (the remaining P extracted by dilute HCl following the NaOH extraction) is assumed to represent Ca-bound P, and is also known as apatite inorganic P (AIP); this fraction is not readily mobilized. (4) Residual-P (the P not extracted in any of the above fractions) is that bound in organic matter; this is the most refractory fraction and is not released except by microbial degradation of the peat. In reality, these fractions are operationally defined by the extraction procedures used and are only estimates of actual composition. Stratigraphic phosphorus profiles are shown in Figure 5 (a-e), and the percentage composition of the various fractions is summarized in Figure 6.

Sobota Slough

Sediments in this wetland exhibit major spatial differences in phosphorus concentrations and composition, with levels for total-P in the two central cores (no. 7 & 8) exceeding that at other six sites by up to an order of magnitude. The maximum P content in cores 7 and 8 (5 and 6 mg/g, respectively) is the highest in this study; phosphorus concentrations in the other cores from Sobota Slough are 0.5-1 mg/g, which is typical for the other three wetlands as well. The two central cores are composed largely of lacustrine sediments in which NaOH-SRP accounts for nearly half of the total phosphorus pool. By contrast, the other six cores are dominated by an average of 60% Residual-P. Phosphorus composition is stratigraphically consistent in most profiles and shows little variation among the cores within each group (Fig. 6). The only exception is core-4 which shows an up-core increase in total-P and NaOH-SRP with the transition from peat to lake sediment.

The most probable source for the high phosphorus flux from Sobota Slough are sediments from the vicinity of cores 7 and 8 in the central open-water area of this wetland. The high phosphorus concentrations at these two sites may also indicate contamination by sewage sludge, for which Sobota Slough was at one time a disposal site. It seems unlikely that the more terrestrial peat-covered areas contribute significantly to the phosphorus export, given the small pool of labile-P in these areas.

Rice Lake

The total phosphorous content of Rice Lake sediments is typically between 0.5 and 1.0 mg/g. In the top 20 cm of the four 1-m cores (1-4) most of this phosphorus is sequestered in the two organic pools, with approximately 50% as residual-P and 30% as NaOH-ORP (Fig. 6). Below this surface material to a depth of about 1 meter, P composition is quite variable. One stratigraphic level in core-3 shows exceptionally high total-P concentrations (5 mg/g) of which over half is composed of NaOH-SRP. Because of this variability, the only consistent stratigraphic trend in the 1-meter cores is a down-core decrease in NaOH-ORP (hydrolyzable organic-P) from 30% to 15%.

In contrast, the phosphorus pool in the four long cores shows a very distinct change from top to bottom. In all four cores, the uppermost sediments (0-30 cm) contain roughly twice the total-P of the lower two meters. All four P-fractions are represented equally in the surface sediments, whereas phosphorus at depth is almost entirely HCl-P (60%) and residual-P (30%). This stratigraphic pattern runs parallel to a lithological up-core increase in herbaceous detritus and is associated with the higher organic and lower carbonate content of the upper sediments. On average the surface sediments in these open-water cores contain proportionally more inorganic-P (NaOH-

SRP and HCl-P) and less organic-P (NaOH-ORP and residual-P) than do the four short cores that were collected from the surrounding vegetational mat.

Grass Lake

Grass Lake sediments contain roughly the same amount of total-P as those of Rice Lake with which they are lithologically most similar. Concentrations are typically between 0.5 and 1.0 mg/g except in core-3, which contains about twice this level; the P content of core-4 is also somewhat higher. The composition of the phosphorus pool in the upper sediments (35% residual-P and 30% NaOH-ORP) is consistent among the six cores and is similar to the phosphorus distribution observed in the surface peats of Rice Lake. At intermediate depths (40-60 cm) P composition is quite variable with some levels dominated by labile NaOH-SRP. Below one meter the two long profiles (no. 5 & 6) show the same P distribution as observed at depth in Rice Lake – the two refractory pools (HCl-P and residual-P) dominate. The lowermost samples (between 60 and 100 cm) in cores 3 and 4 are transitional in P composition between the peat surface and the deeper sediments of the long cores. As noted in Rice Lake, these trends in phosphorus stratigraphy parallel an up-core increase in organic matter and drop in carbonate content at the transition from lacustrine sediments to peat.

Lambert Lake

Sediments in this wetland contain, on average, the lowest P content of any of the the four wetlands. Total phosphorus concentrations are consistently below 1 mg/g. In the two long cores (no. 5 & 6), P concentrations are slightly higher in the upper organic-rich sediments. Residual (organically bound) P dominates the total pool at all depths, although the HCl-P fraction is larger at depth (below 50 cm) where more carbonate-rich sediments are found. The two labile phosphorus pools (NaOH-SRP and NaOH-ORP) make up only a small fraction of the total-P anywhere in these profiles.

Fe Analysis

Sedimentary iron was analyzed from the same extracts from which total-P was determined and is here termed total-Fe. In reality the peroxide/HCl treatment does not appreciably dissolve silicate-bound Fe, so that Fe from this extraction more properly represents amorphous oxides of inorganic iron along with Fe sorbed to organic particulates. The purpose of this analysis was to determine the degree to which phosphorus distributions in the Lambert wetlands are controlled by Fe content; colloidal ferric precipitates are important scavengers for inorganic P in lacustrine environments and could influence P cycling in wetland sediments as well.

Iron profiles from the three wetlands for which analyses were done display little stratigraphic or spatial variation (Fig. 7a-c). Concentrations generally range from 10 to 20 mg/g dry sediment. Values are somewhat lower in Lambert Lake sediments, particularly at the base of the cores where silt and sand predominate. Fe concentrations are slightly elevated in the topmost 10-cm of cores 5-7 from Rice Lake, which may account in part for the higher concentrations of NaOH-SRP in these samples.

The relationship between sedimentary Fe and the various forms of phosphorus is illustrated in Figure 8. Although all P fractions show a positive relationship with Fe, the correlations are generally weak, especially for the two organic pools (NaOH-ORP and residual-P). The relationship with NaOH-SRP ($r = 0.47$) is somewhat stronger, as would be expected for a phosphorus pool that is though to be bound to inorganic Fe and Al. The same reasoning would not hold for Fe and HCl-P (Ca-bound P), which are even more highly correlated ($r = 0.58$). In this case the relationship seems to be driven by one or two points with high P; for the remaining samples the correlation is substantially lower ($r = 0.42$). In general, the weak relationship between Fe and P – for individual wetlands or for the entire group – indicates that other factors in addition to Fe content are controlling the retention of inorganic phosphorus in these sediments.

Soil Lysimetry

Soil tension-lysimeters were deployed in Grass Lake during late summer and early fall to collect soil pore-waters and assess phosphorus release caused by oxidation of drained wetland sediments coupled with hydraulic flushing during storm events. The lysimeters were placed in a transect at various distances lateral to the central ditch so as to span a moisture gradient from wet to dry sites (Fig. 2), and were sampled repeatedly during a two-month period. The sampling plan was designed to follow P release on a small spatial scale relative to fluctuations in water level and stream flow.

In a preliminary survey in early July, paired lysimeters were deployed in close proximity to one another (ca. 2 meters apart) to assess small-scale patchiness in pore-water P content. The results of the survey showed considerable difference between sample pairs taken from the same transect station, with greatest variability at the drier sites (Table 1). It was concluded that the lysimeters would have to be replaced in exactly the same locations at each sampling to prevent this local pore-water variation from obscuring temporal trends in P release. The lysimeters were subsequently deployed at two fixed depths (15 and 30 cm) at each of four stations to assess vertical as well as spatial difference in pore-water P content.

Table 1. Phosphorus concentrations in paired lysimeters

Transect Station	Total-P (ppb)		Ortho-P (ppb)	
	Lys-1	Lys-2	Lys-1	Lys-2
911-912	962	806	803	638
913-914	980	820	877	640
931-932	833	910	724	811
933-934	8601	3546	2179	494
961-962	774	1589	385	1243
963-964	986	2427	704	2054
993-994	2658	1372	0	72
9111-9112	4374	2510	0	417

Phosphorus concentrations in the shallow lysimeters show a strong spatial/temporal trend with respect to the flow regime of Lambert Creek (Fig. 9). During the initial period of low flow (Julian day 240-250) P concentrations were much higher at the drier end of the transect (sites 994 and 964; total-P = 3.5-5.5 ppm) than near the central ditch (sites 914 and 933; total-P = 0.5 -1.3 ppm). During a major storm-water pulse September 8-17 (day 251-260), phosphorus levels rose dramatically at the wet end of the transect and declined at the drier location (especially site 964). P levels at the wet sites apparently peaked subsequent to maximum flow and then declined to pre-flood conditions. This pattern is most clearly seen in curves for total-P. Similar fluctuations are also seen in the deep lysimeters, however, the pattern is slightly different in that P concentrations in the wet sites decline noticeably prior to the storm event. The deep lysimeter from the driest site (994) measured little temporal variation in P content.

It should be stressed that the lysimeter analysis was designed as a pilot study and as such, covers only a small area in one wetland, is of short duration, and involves less frequent sampling than might be desired to track hydrological events. The potential for large spatial differences is P release (and uptake) is high, and the pattern displayed here may not hold for other areas or during other times of the year. It is, therefore, recommended that lysimetric analysis of local phosphorus dynamics be continued in some fashion during subsequent phases of this project.

Analytical Replication

Replicate analyses were performed on a selection of sediment samples representing a range of stratigraphic levels in several cores from each of the wetlands. Duplicate samples of wet sediment were taken from each replicated level and processed separately following the same analytical procedures. Results from this replication (Appendix B) are summarized as the mean coefficient of variation (CV) for each procedure, where the CV for each level equals the standard deviation of the replicates normalized to their average.

In the loss-on-ignition procedure, the mean CV was 3.06% for organic content and 4.05% for carbonate content. For the various phosphorus fractions the mean CV ranged from 5.21% (NaOH-TP) to 8.15% (NaOH-SRP), and for Fe determinations it was a low 1.25%. Although these mean CVs are reasonably low, as an average they tend to hide the fact that a small number of samples showed large differences between replicates (as much as 13-26%). For the most part, however, replicate values were very close to one another, especially considering the heterogeneity of fibrous wetland sediments which are hard to sample uniformly. Finally, error estimates for those parameters that are calculated by difference (NaOH-ORP, and Residual-P) will be subject to the combined uncertainty of the measured variables, and may in some cases be large relative to the calculated term.

Discussion

Phosphorus Sources

Mass balance analysis of the Lambert Creek drainage indicates that all riparian wetlands with the exception of Lambert Lake are net exporters of dissolve phosphorus (Walker 1990a, b)). Under natural conditions, wetlands are known to retain more nutrients than they discharge, although their capacity to assimilate additional anthropogenic loading is clearly limited (Howard-Williams 1985, Richardson 1985). The key to nutrient dynamics in the Lambert wetlands, particularly with respect to remedial actions to reduce phosphorus export, lies in understanding the source of the phosphorus and the mechanisms controlling its flux. If one assumes that in their natural state the Lambert wetlands effectively retained most influent P, several hypotheses can be advanced to explain the present day situation of large net phosphorous losses:

(1) Ditching and drainage of what were formerly shallow lakes has exposed P-rich lake sediments to terrestrial conditions; microbial decomposition of these lacustrine deposits under aerobic conditions, and subsequent uptake of released nutrients by emergent macrophytes results in the export of phosphorus from this natural reservoir. Continued P release today is sustained by either:

(a) upward diffusion, advection, or macrophyte "pumping" from deeper phosphorus stores.

(b) direct release from a phosphorus-rich surface peat that was originally enriched in nutrients at the time of ditching and initial macrophyte colonization.

(2) Discharge of sewage sludge into Sobota Slough at the head of the drainage system has created a rich labile nutrient reservoir that continues to release phosphorus long after dumping has stopped. Part of this historical phosphorus load has been translocated to downstream wetlands (Rice, Grass)

where it has been incorporated at least temporarily in the accreting peat surface; release from this secondary pool continues today as well.

(3) Net P exports from each of the wetlands are sustained by diffuse non-point sources that are not monitored at the gauging stations. These external sources, together with the gauged inflow from upstream, exceed that which can be retained by internal nutrient cycling. Although the wetlands appear to be exporting significant amounts of phosphorus, their net contribution to downstream loading is small.

If the first of these hypotheses is correct, phosphorus release might best be curtailed by returning the now drained wetlands to their former lacustrine state. Lakes are typically much more effective at retaining phosphorus than are shallow wetlands, due primarily to sedimentation and burial of organic and inorganic forms of P in a cold, anoxic, quiescent environment. If aerial exposure of formerly inundated sediments enhanced P release, reflooding should effectively reverse this process.

Stratigraphic evidence from this study shows that lacustrine sediments do indeed underlie peat deposits in at least parts of all four wetlands. These lake sediments are most clearly seen in Grass Lake, Rice Lake, and western end of Sobota Slough where they typically occur within 0.5-1 meter of the peat surface. The transition to peat almost certainly represents colonization of former lake bottom by marsh vegetation following drainage in the early 1900s. The peat deposits overlying lake sediment are consistently higher in total phosphorus and particularly in the labile pools, NaOH-SRP and NaOH-ORP, than are the surface peats in Lambert Lake and the eastern end of Sobota Slough. Sediment profiles from these later sites are peaty throughout, and what phosphorus they contain is predominantly in the refractory forms, HCl-P and residual (organic)-P. Lambert Lake is the one sub-watershed that retains more P than it exports, and from the distribution of phosphorus burdens in Sobota Slough, it is seems unlikely that the drier eastern end contributes significantly to the loading from this wetland. Thus high phosphorus loads and lacustrine deposits are spatially correlated, supporting the contention that buried lake sediments may be the ultimate source for the P exported from the Lambert Creek wetlands.

If former lake sediments contribute to internal phosphorus loading, what is the mechanism for translocating P from the buried reservoir to the peat surface? The contact between marsh peat and lacustrine deposits is at least a half meter below the surface, and in most cases the underlying sediments are actually lower in phosphorus, especially labile forms, than the upper peats. This upward concentration gradient in the solid phase, does not preclude a downward gradient in dissolved P that could drive a diffusional flux. But the fact that the lake sediments are permanently saturated and presumably anoxic, means that microbial activity that might release P from organic- and apatite-bound phases would be minimal. While an upward flux of P might be aided by hydraulic advection or nutrient pumping by the surface vegetation, it is difficult to see how these processes could tap the largely refractory P-reservoir in the underlying sediments. Moreover, the dominant macrophyte in these wetland, *Typha latifolia* (cattails), obtains most of its nutrients from adventitious roots near the peat surface, and not through its more deeply submerged rhizome system (Correll *et al*. 1975).

If buried lake sediments are not presently supplying phosphorus to the peat surface, it is still possible that a large portion of the labile surface/subsurface pool originated from decomposition of the lacustrine deposits at the time the lakes were converted to marshes. Plants colonizing the drained lake bottoms could have tapped this rich source of nutrients and stored them in stems, rhizomes, and other components of the accreting peat surface. The source of labile phosphorus now leaking from these wetlands was simply moved upward with the progressive accumulation of peat. Under this scenario, the current export of P is a transient non-equilibrium response to environmental changes set in motion almost a century ago.

A sustained export of this duration seems improbable, however, particularly since it would require the entire phosphorus burden from more than a meter of lake sediment in Grass or Rice lake to support their respective modern P fluxes since the time of ditching. Nonetheless, some portion of the phosphorus export from these wetlands could derive from natural stores of P, either contained in the active peat surface or continuously supplied through upward translocation from sediments at depth.

If the second hypothesis is true, that phosphorus export is supported by an anthropogenic store of sewage sludge, then removal or isolation of this source may be advantageous. Moreover, reflooding the downstream wetlands to create detention basins would aid the retention of this additional load as well as that derived from natural sources.

Evidence of a man-made reservoir of phosphorus in Sobota Slough is contained in the two cores from the western end of the basin. The very high concentrations of labile NaOH-SRP throughout these profiles together with the presence of fine blue fibers within a matrix of lacustrine sediment implies that these deposits are a direct manifestation of sewage discharge. A substantial portion of the large phosphorus load to Lambert Creek probably originates from this restricted area of Sobota Slough.

In addition to continued mobilization of P from the primary reservoir in Sobota Slough, a portion of the phosphorus flux from Rice and Grass lakes may derive from secondary pools of labile P that were established during the period of upstream sewage disposal. Several cores from both of these wetlands show very high levels of NaOH-SRP and -ORP - typically at subsurface depths of 40-60 cm (Fig. 5b, c) – that could represent historically high export from Sobota Slough. These subsurface peaks may have been laid down at the time of high P discharge and subsequently buried, or alternatively may represent uptake by plants at the surface and translocation to rhizome layers deep within the peat (cf. Davis and van der Valk 1983). If these P reservoirs result from historic discharge into Sobota Slough, then present-day P loading to Lambert Creek would represent a long-term transient response to historic human impacts, similar to that discussed for drained lake sediments (see above). While it has been many decades since sewage discharge was curtailed, and even longer since ditching and drainage, wetlands are known to leak nutrients long after anthropogenic inputs are diverted (Howard-Williams 1985); the actual length of time required for a return to pre-impact conditions in unknown.

Finally, it is possible that these riparian wetlands actually take in as much P as they release, and that net export is a consequence of mass-balance error. That is, more P enters these wetlands (from local non-point sources, groundwater discharge, etc.) than is actually measured at the gauging stations. If true, this situation implies that (1) internal phosphorus cycling is currently in stable equilibrium (no change in storage), and (2) the capacity of the wetlands to assimilate additional phosphorus has been exceeded. There is no direct evidence from the sediments to support or refute this hypothesis; rather it is uncertainty with the alternatives – that the wetlands are exporting nutrients from buried phosphorus stores that were created long ago – that raises questions about nutrient mass balance. On the other hand, Lambert Creek is a well monitored system in which most of the water enters and leaves through gauged structures. Although it seems unlikely that sizable P inputs go unmeasured, some portion of the net export probably originates outside each of the wetlands, contributing to the impression that they leak more P than they actually do.

Release and Transport

Whatever the ultimate source(s) of phosphorus export to Lambert Creek may be, it is the processes that regulate nutrient release/retention within the wetlands that ultimately need to be understood for control purposes. The analysis of sedimentary reservoirs of phosphorus can be used to infer likely sources or sinks within the wetlands based on an understanding of geochemical cycling among the various pools. These measurements are static, however, in that they give potential for flux but do not measure it directly.

The sedimentary analyses from this study reveal patterns in phosphorus abundance that are consistent with mass-balance calculations of nutrient loading from the sub-watersheds (Walker 1990a, b). The three wetlands that are net exporters of dissolved P – Sobota, Rice, and Grass – possess sediments that are rich in labile forms of phosphorus (NaOH-SRP and NaOH-ORP).

These deposits are typically found near the peat surface where they would be in contact with sheet flow during periods of high discharge. In most cases, those cores richest if phosphorus were taken near the wettest areas. Their upper sections consists of a loosely woven mat of cattail rhizomes overlying a slurry of coarse detritus; during periods of high flow much of this layer actually floats. This structure clearly enhances contact between flood-waters and phosphorus-rich strata during periods of high discharge when downstream phosphorus concentrations and loading also tend to peak.

Those sediments in the open-water area of Rice Lake are best viewed as permanently inundated peats, rather than as truly lacustrine muds. The overlying water is less than a half meter deep, and the upper sediments consist largely of coarse plant detritus from the adjacent macrophyte beds. Large floating islands of peat and cattails detach from the margins and drift about creating an environment that is hydrologically similar to adjacent areas of the peat surface under flood conditions. Water residence times are short and the sediment surface is in constant interchange with water flowing through the marsh, especially during warm summer months when flocculent sediments are buoyed to the surface by methane production. These condition enhance P exchange between sediment and water, and inhibit permanent burial of large phosphorus stores as normally occurs in deeper lakes. The surface sediments are somewhat richer in total-P, especially NaOH-SRP, than surface layers in the surrounding peat mat, and thus may be a significant source for the P flux from this wetland.

In contrast, are those cores taken from Lambert Lake and the drier eastern three quarters of Sobota Slough. These sediments consist of highly compact peat intermixed with woody debris. Phosphorus content is low and largely comprised of forms resistant to mobilization – residual (organic) bound-P and HCl (apatite) bound-P. These wetland areas are less frequently inundated, and because of the compact nature of the peat surface, exchange of buried phosphorus with influent waters is probably limited.

The concentration of iron in lacustrine sediments provides a measure of the capacity of sedimenting particles to adsorb inorganic forms of phosphorus (NaOH-SRP). In the surface of the open-water sediments from Rice Lake, molar ratios of Fe/NaOH-SRP range from 13 to 17, but increase down-core to values of 100-400 in the underlying lacustrine deposits (Fig. 10). Similar values and trends are found in the two long cores from Grass Lake, and are attributable to the large up-core increase in (non-apatite) inorganic phosphorus. While it is difficult to determine whether Fe concentrations are actually controlling P retention in these shallow wetlands, these values are comparable to ratios found in lake sediments in the Vadnais chain of lakes, for which iron dosing has been instituted as a phosphorus control measure (Walker 1987, 1988). If deeper permanent pools are established in some of the

Lambert wetlands, additional iron inputs to enhance P sedimentation and retention may be desirable.

A more direct assessment of phosphorus release is provided by the lysimetric analysis of pore waters in Grass Lake. This analysis shows a spatial/temporal trend involving the translocation of a large phosphorus pulse from the margin of the wetland toward the central drainage channel coincident with a flood event in early September. Phosphorus concentrations are typically higher at marginal sites during periods of base flow, and at central sites following peak discharge. This pattern may reflect greater microbial release of organically-bound P at marginal sites where the surface peat is unsaturated, warmer, and probably aerobic. During flood events this pool of exchangeable P is flushed from system and appears at downstream gauging stations as a peak in loading. These results imply that fluctuations in water level may be a critical factor limiting phosphorus retention in the Lambert wetlands. Reflooding these areas to create permanent retention basins for phosphorus storage would have the added benefit of inundating areas where current wet/dry cycles seem to enhance P release.

Control Options

The stratigraphic results from this study along with mass-balance calculations by Walker (1990a, b) indicate that the Lambert wetlands have little capacity to assimilate external phosphorus loads and may well release significant amounts of P from existing sedimentary reservoirs. In their present configuration, phosphorus retention in these wetlands is probably limited by (1) short residence times, (2) fluctuating water levels, (3) flocculent P-rich surface sediments, and (4) channelized ditch flow (at low stage), and (5) shallow depths of existing open-water areas. A number of proposed hydraulic modifications that might mitigate these problems are discussed in detail by Walker (1991). In the following section these control methods are further evaluated in light of the sedimentary data obtained in this study.

The three basic methods for hydraulic modification considered by Walker (1991) include:

- Inlet Modification to promote sheet flow across the marsh surface so as to enhance infiltration and inhibit surface desiccation;

- Excavation to increase water depth and detention volume, and to remove P-rich sediments;

- Outlet Modification to raise water levels, increase retention time, and create a depositional environment conducive to phosphorus burial.

Inlet modification involves infilling the drainage ditch so as to redistribute flow across the upper end of the marsh; the intent would be to raise the local water table during periods of low to average flow and prevent the surface of the wetland from drying. More diffuse flow would have the advantage of promoting infiltration, especially in Lambert Lake where the organic sediments are thin, and would enhance nutrient exchange with the surface of the marsh.

Results from the lysimeter study support the contention that fluctuating water levels promote the release and export of phosphorous from the Lambert wetlands. It is also clear that export occurs primarily during flood events when water flows out across the marsh surface (see also Howard-Williams 1985). The upper sediments of Rice and Grass lake contain large pools of labile P, possibly derived from external loading, and this reservoir may continue to loose P to sheet flow, even after inlet modification, unless a more effective retention basin is created by outlet controls (see below).

Nutrient retention in Lambert Lake, which is currently a net sink for phosphorus, might be further enhanced by promotion of sheet flow; the sediments from this site may have the capacity to assimilate additional P if water flow could be dispersed throughout the marsh. Infiltration, which may already be an important nutrient sink (Walker 1991), might increase as well. On the other hand, the sediments in Lambert lake are currently composed of dense peat with a low P content. The wetland is quite terrestrial and contains extensive areas of woody vegetation where surface flooding is probably infrequent. Inundating the marsh surface could have the unwanted effect of promoting microbial decay of stable peat reserves and thus mobilizing currently refractory phosphorus pools.

Excavation of existing sediments to increase hydraulic storage would be most effective in the central part of Rice Lake, where an extensive area of open water already exists. Dredging to a depth of about a meter would remove sediments rich in labile forms of P and would expose underlying lacustrine deposits that are lower in P and richer in Fe. The more refractory pools of HCl-P and residual (organic)-P in the lake muds should be stable so long and they remain submerged. Dredging would presumably be combined with outlet modifications to raise water level, and so would have the added benefit of eliminating the floating cattail islands that would otherwise disintegrate as water depth and open-water fetch increased. Rising lake levels would also attack the vegetational mat surrounding the open-water area, which would contribute to basin infilling and, at least initially, P-loading to downstream systems. A preemptive removal of these sediments would create a deeper and presumably more effective retention basin than would otherwise result from simply elevating the outlet. Although organic deposits are not particularly thick in Rice Lake (4-5 m, Ruhl 1991), deeper excavation into these unstable materials could result in subsidence along the margins and accelerated infilling of the basin.

Dredging has also been proposed as a means of eliminating P-rich sediments from Sobota Slough. Although the area occupied by these materials is limited to the western edge of the marsh, the depth to which they extend is unknown. If the high phosphorus levels derive from sewage discharge, then the disposal of dredge spoils may require an analysis of other possible contaminants contained in the sediments. The surface peat in this area of the marsh is either floating or highly flocculent, a fact which might aid it its removal. Topographic maps dating from 1967 show an open-water zone as well. Thus dredging would re-establish a permanent pool in this wetland, which is not otherwise feasible by outlet modification because of flood-control constraints (Walker 1991).

Outlet control structures to raise water level and reflood some of the existing wetlands is the most feasible and cost-effective means of controlling P loading to Lambert Creek. This type of hydraulic modification would mitigate most factors contributing to P release by creating an open-water environment in which nutrient retention is more efficient. Model simulation by Walker (1991) demonstrate a high potential for water quality improvement in the detention basins due to sedimentation of particulate materials and infiltration. The effects of outlet modification on dissolve phosphorus species is more difficult to predict. However, P retention in deep standing water is typically greater than that in wetlands, principally because of the greater biological and chemical stability of lacustrine sedimentary environments.

The effects of raising the water level in Lambert Lake are less certain, principally because this wetland does not currently leak excess phosphorus. Efficient phosphorus retention may result from the shallow depth of the peat, the terrestrial nature of the peat surface, or low levels of labile P in the sediments. Because the proposed increase in water level would only inundate a portion of the marsh, water level fluctuations could impact higher ground and there promote decomposition. On the other hand, current fluctuations, which exceed those simulated for a raised outlet, do not generate a net export of P.

With the possible exception of Lambert Lake, the creation of permanent storage pools by outlet modification should have strong positive effects on P retention. Results from this study show that those areas of Rice and Grass lakes proposed for inundation contain large sedimentary pools of labile phosphorus. Inundating this nutrient reservoir to a depth of 1-2 meters should encourage more permanent burial. On the other hand, flooding these wetlands may cause mats of vegetation and peat to float to the surface and disintegrate, releasing particulate and dissolved nutrients to the water column. While a portion of this internal load will probably be lost downstream, the effect will likely be short-lived. As mentioned above, storage capacity could be further increased by shallow dredging. Additional chemical treatment with ferric chloride (or lime) could further enhance phosphorus removal, and should be instituted if internal iron supplies prove to be limiting after hydraulic modification.

Summary and Recommendations

The lithology, origin, and phosphorus content of sediments in the riparian wetlands of Lambert Creek were determined from stratigraphic analysis of 28 sediment cores. In Rice and Grass lakes, 0.5 - 1 meter of fibrous marsh peat overlies buried lake sediments; the lithologic transition between these two units represents ditching and drainage in the early 1900s. The upper marsh sediments are rich in labile forms of phosphorus (NaOH-SRP and NaOH-ORP), while the lower lacustrine materials contain less phosphorus, and that in refractory forms (HCl-P and residual-P). The sediments in Lambert Lake consist of an interleaving of marsh and shallow lake deposits; depth to underlying glacial sand is shallow (1.5 - 2.5 m near the central ditch), and phosphorus content is uniformly low and largely refractory. Sobota Slough can be separated into two regions based on sediment composition; an eastern three-quarters characterized by dense woody peat of low P content and the far western quarter near the outlet, where lacustrine sediments with very high levels of NaOH-SRP are found. The phosphorus reservoir in the western basin probably originates from the former discharge of sewage sludge into Sobota Slough.

Three of the four sub-watersheds export more phosphorus than they take in. The flux may ultimately derive from the mobilization of P from buried lake sediments or from temporary phosphorus stores created by sewage discharge into Sobota Slough. If the present-day phosphorus export is driven by these internal sources, nutrient cycling in the Lambert wetlands has been in disequilibrium for many decades. A portion of the phosphorus leaking from the sub-watersheds may also represent diffuse non-gauged inputs from local upland areas.

The more immediate source of phosphorus to Lambert Creek are the large pools of labile P in the surface/subsurface sediments of Rice and Grass lakes and the western basin of Sobota Slough. Lysimetric studies of pore-waters along a hydraulic gradient in Grass Lake suggest that peak phosphorus outputs are driven by sheet flow during storm events, and that desiccation during periods of low flow promotes P release through microbial degradation. Phosphorus release from the open-water area of Rice Lake may be mediated by redox changes as well as re-suspension of surface sediments by summer methane production. The dense fibrous peats of Lambert Lake and the drier areas of Sobota Slough probably contribute little to phosphorus export and may actually assimilate more P than they release.

Of the proposed hydraulic controls on phosphorus export, outlet modification at Rice and Grass lakes, possibly combined with shallow dredging in the central area of Rice Lake has the best potential for improving nutrient retention. Much of the nutrient load to Lambert Creek probably derives from the labile phosphorus stores in the central areas of these marshes. Initial flooding could produce a temporary P release from disintegration of buoyant sections of the vegetation mat; alternatively this material could be excavated prior to flooding, which would also create a deeper retention basin. Phosphorus pools in the underlying lake sediments are unlikely to be mobilized so long as they remain submerged. Raising the outlet level in Lambert Lake would provide a final detention basin for Lambert Creek prior to its discharge into Vadnais Lake. Since this wetland is currently a net sink for phosphorus, outlet modifications which could affect P cycling in unforeseen ways, might be delayed until the benefits of upstream detention basins are evaluated. Excavation of phosphorus-rich sediments from the western basin of Sobota Slough should be delayed until the extent of these deposits – and possible contaminants – are fully assessed. An expansion of the lysimetric survey during phase-II of the project is also recommended.

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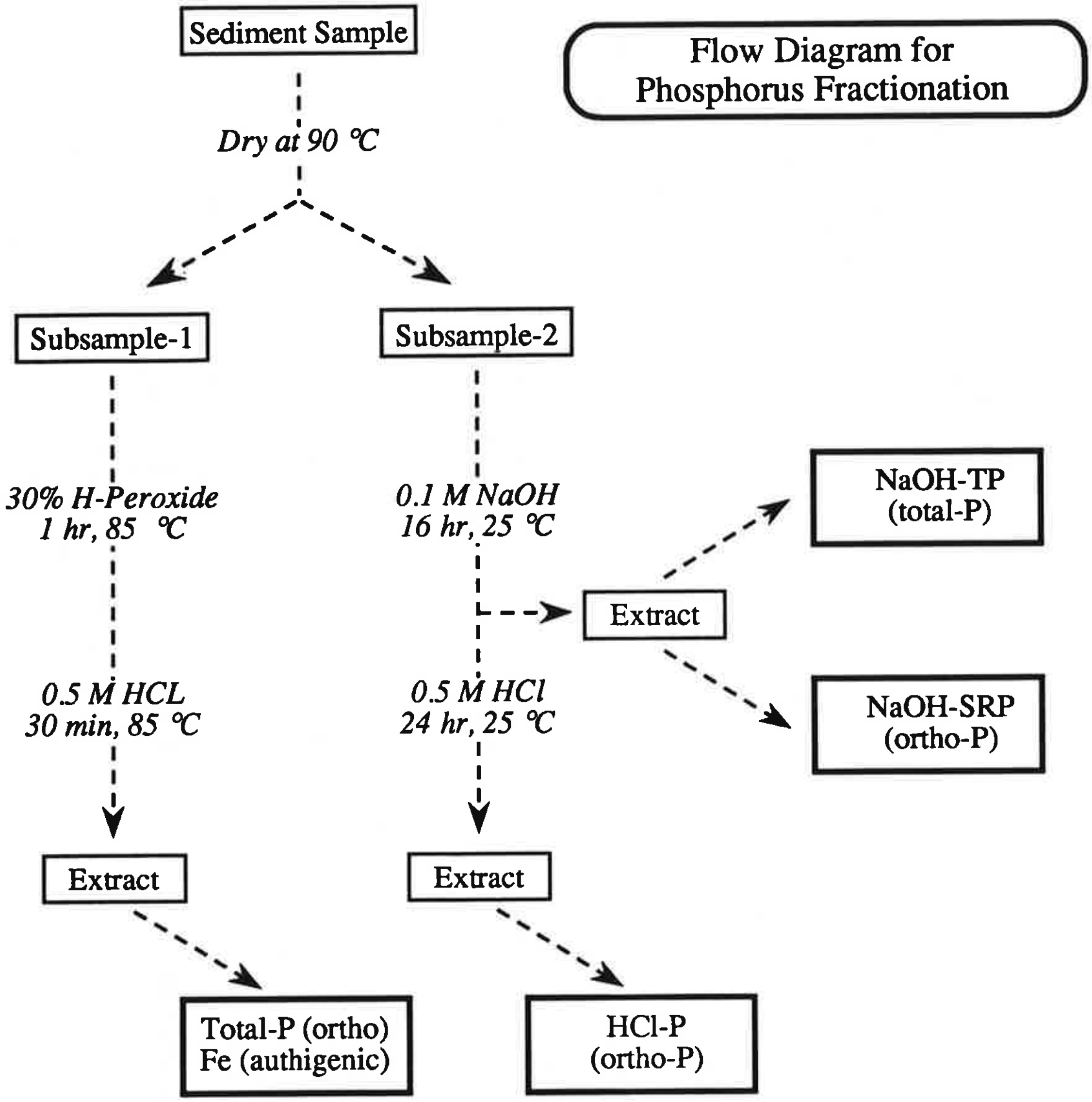
List of Figures



NaOH-ORP (Hydrolyzable Organic-P) = NaOH-TP – NaOH-SRP

NaOH-SRP (NAIP) represents Exchangeable-P + Fe/Al-bound P

HCl Extractable-P (Apatite-P) represents Ca-bound P

Residual-P (Organic-P) = Total-P – (NaOH-TP + HCl-P)

Figure 1

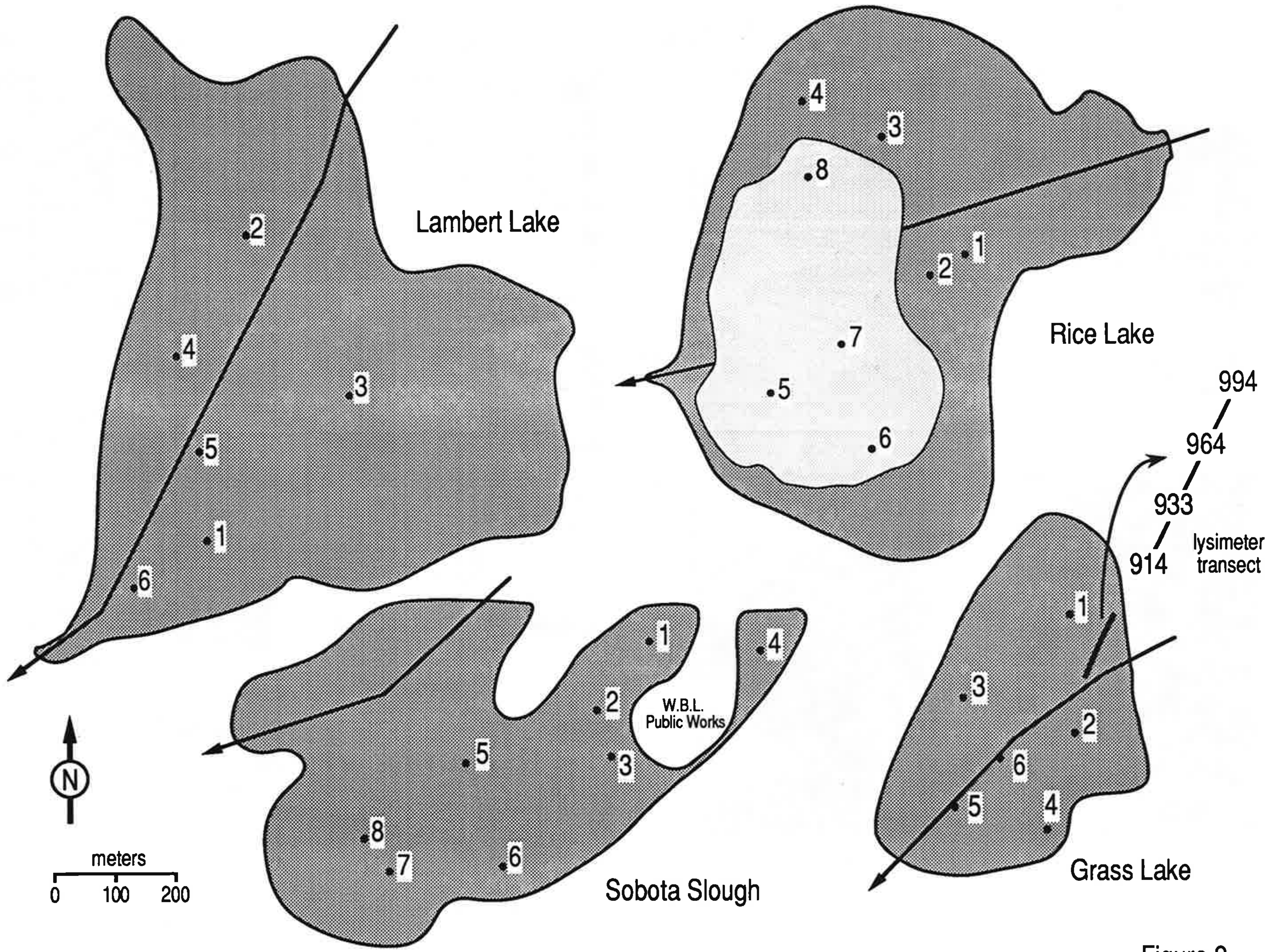
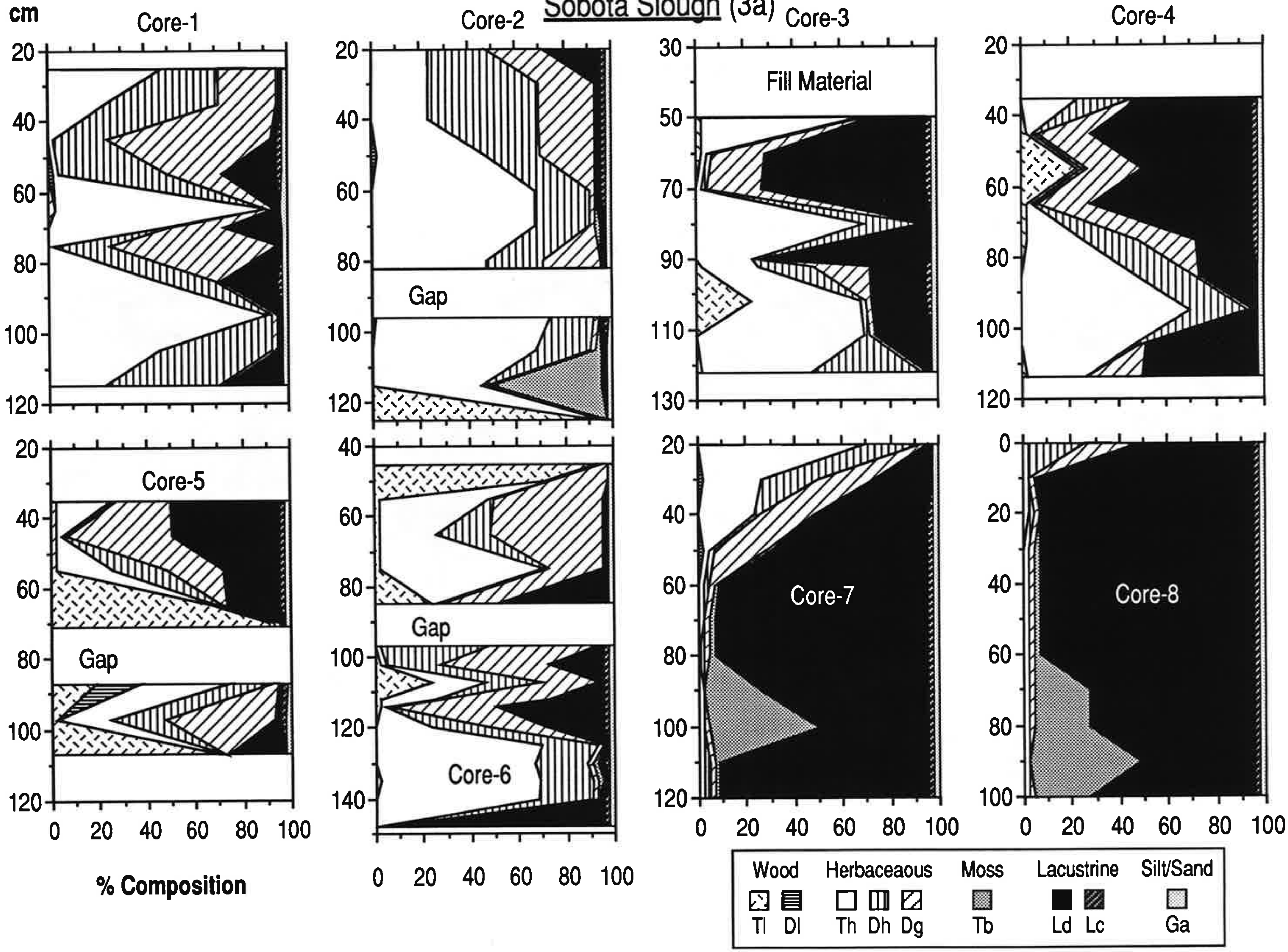
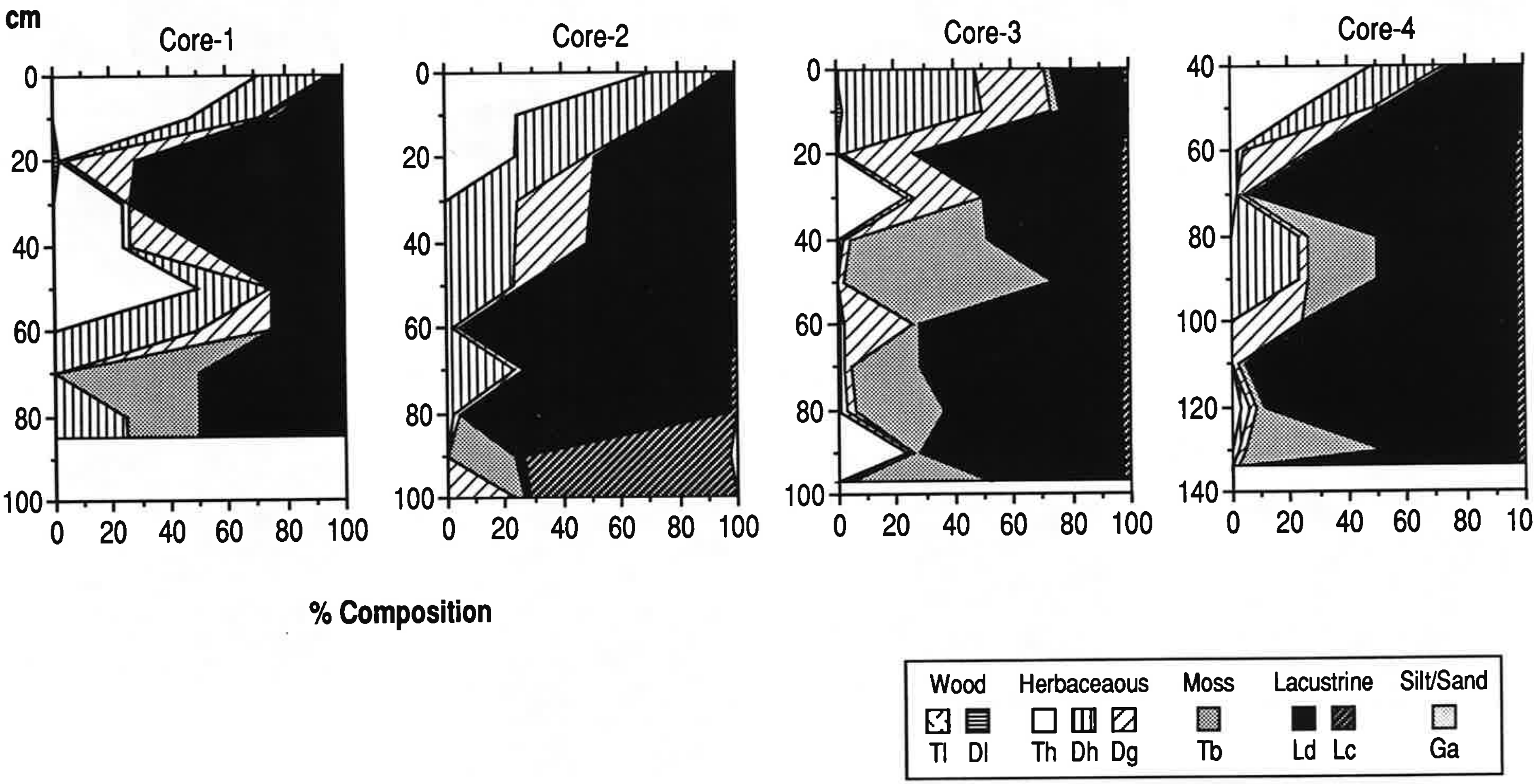

Lambert Lake
2
4
3
5
1
6
Rice Lake
4
3
8
1
2
7
5
6
994
964
933
914
lysimeter transect
Grass Lake
1
3
2
6
5
4
Sobota Slough
1
4
2
W.B.L. Public Works
5
3
8
7
6
N
meters
0
100
200

Figure 2

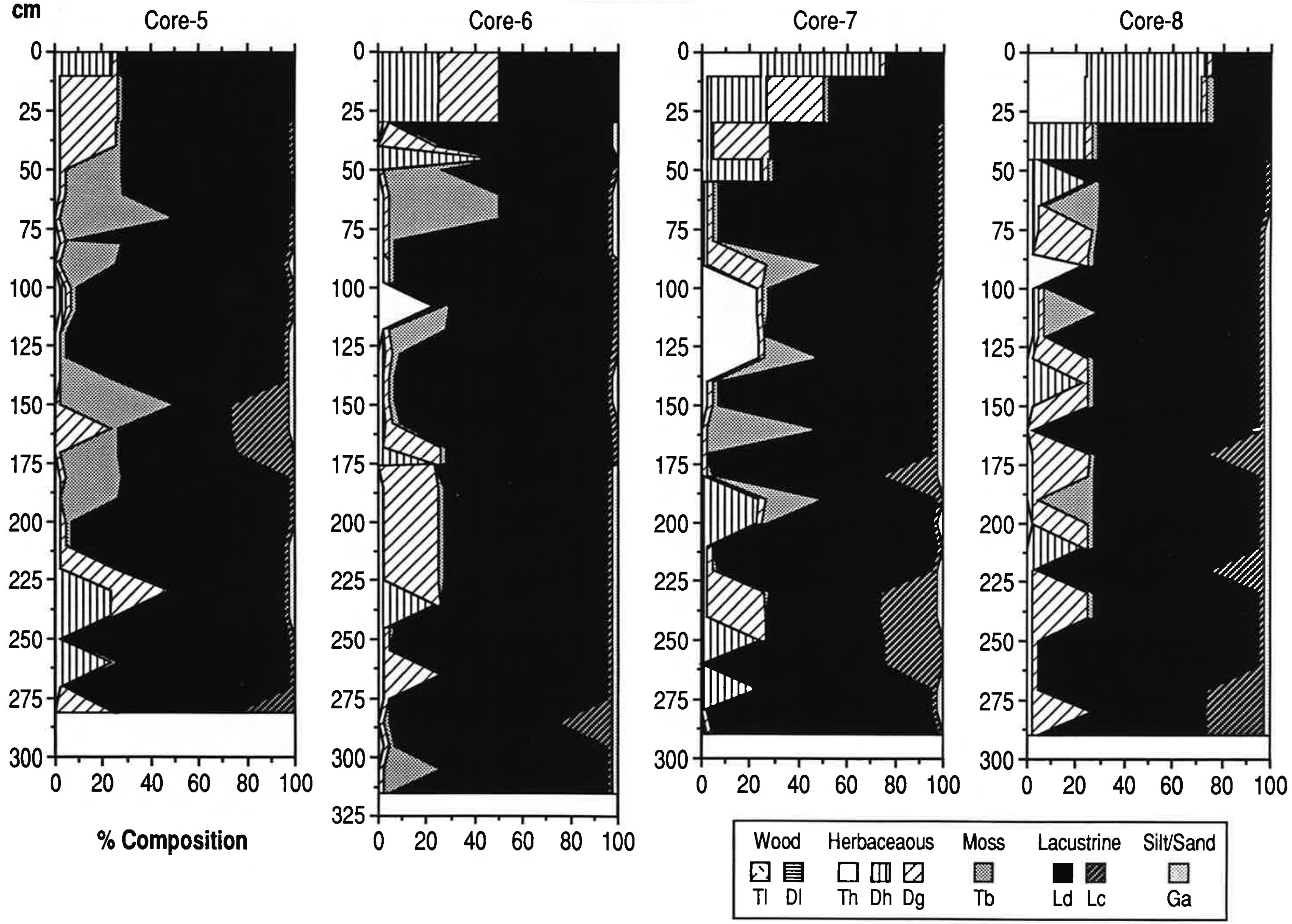
Sobota Slough (3a)



Rice Lake (3b)


cm
Core-1
Core-2
Core-3
Core-4
0
20
40
60
80
100
120
140
% Composition
Wood
Herbaceaous
Moss
Lacustrine
Silt/Sand
Tl
Dl
Th
Dh
Dg
Tb
Ld
Lc
Ga

Rice Lake (3c)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Core-6
Core-7
Core-8
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25
50
75
100
125
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175
200
225
250
275
300
325
0
20
40
60
80
100
% Composition
Wood
Herbaceaous
Moss
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Silt/Sand
Tl
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Th
Dh
Dg
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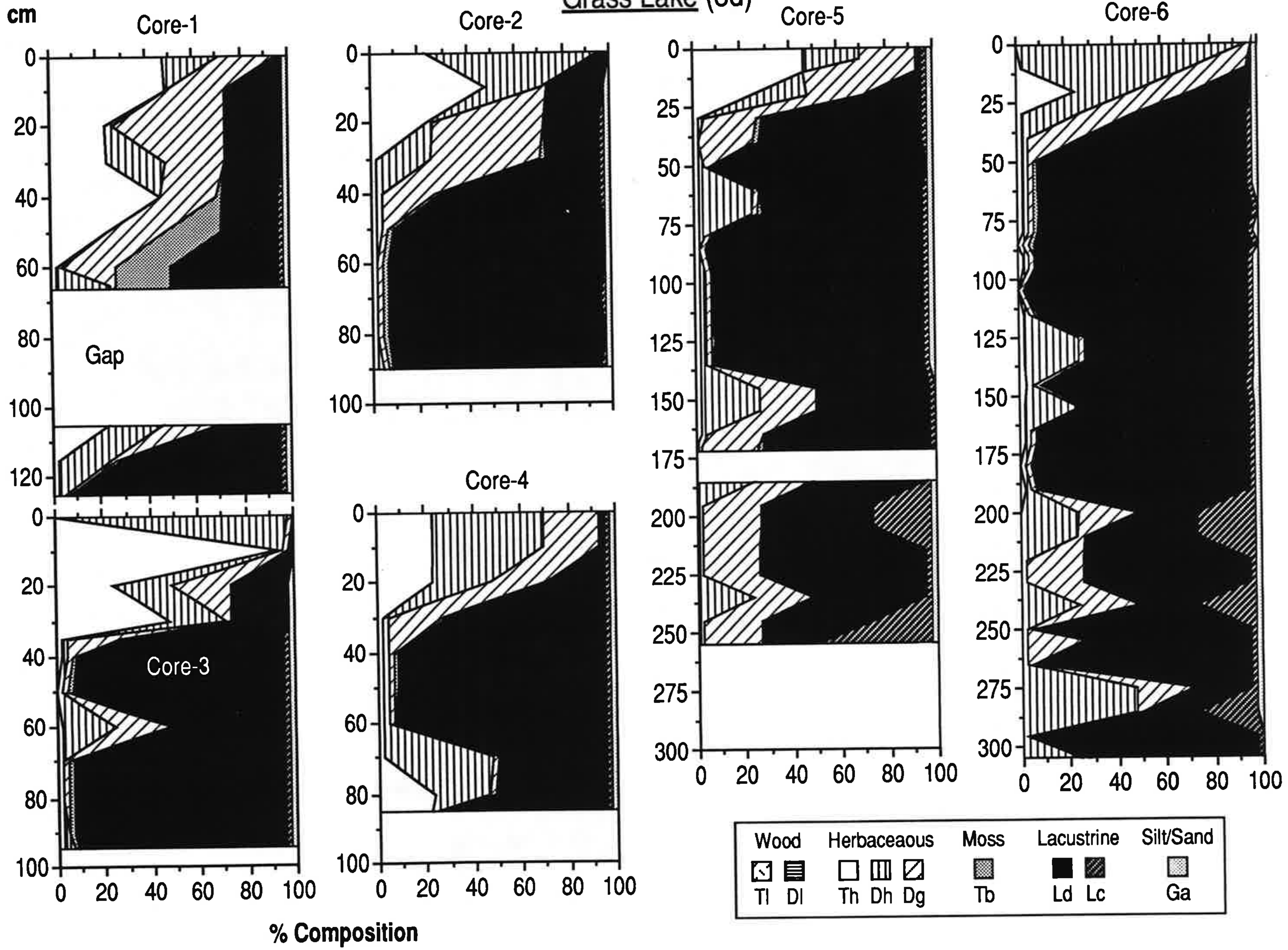
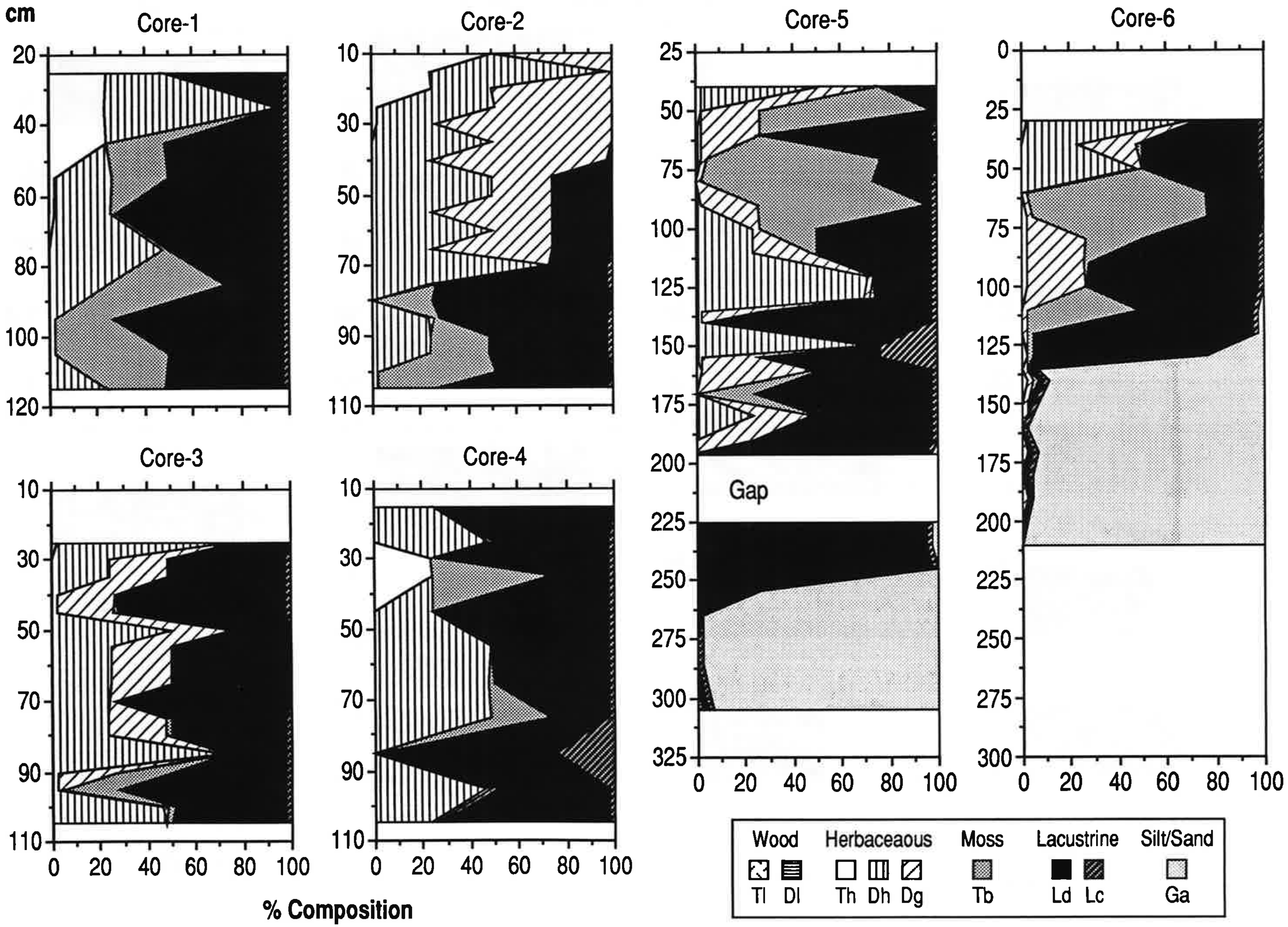
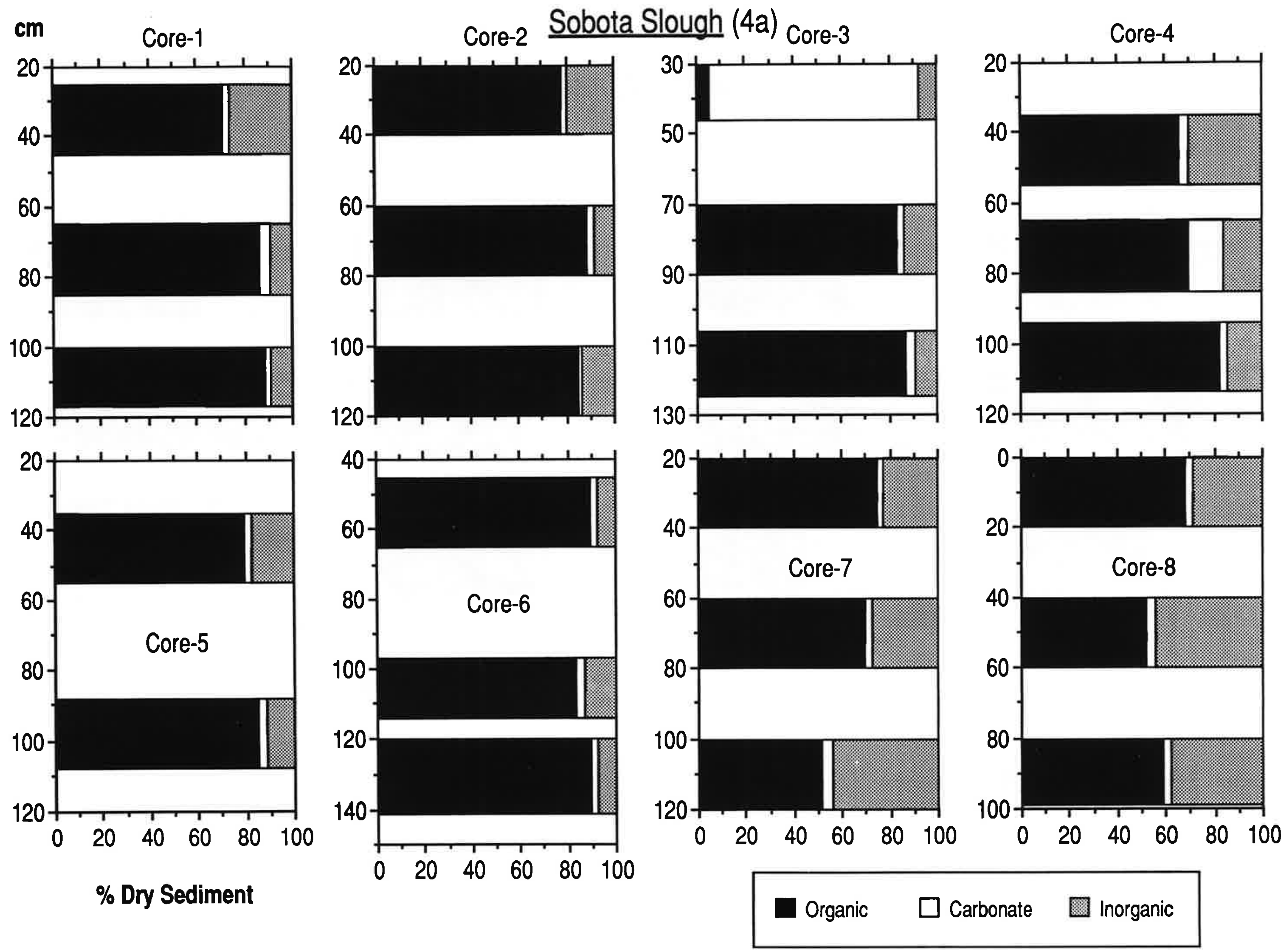
Ld
Lc
Ga

Grass Lake (3d)

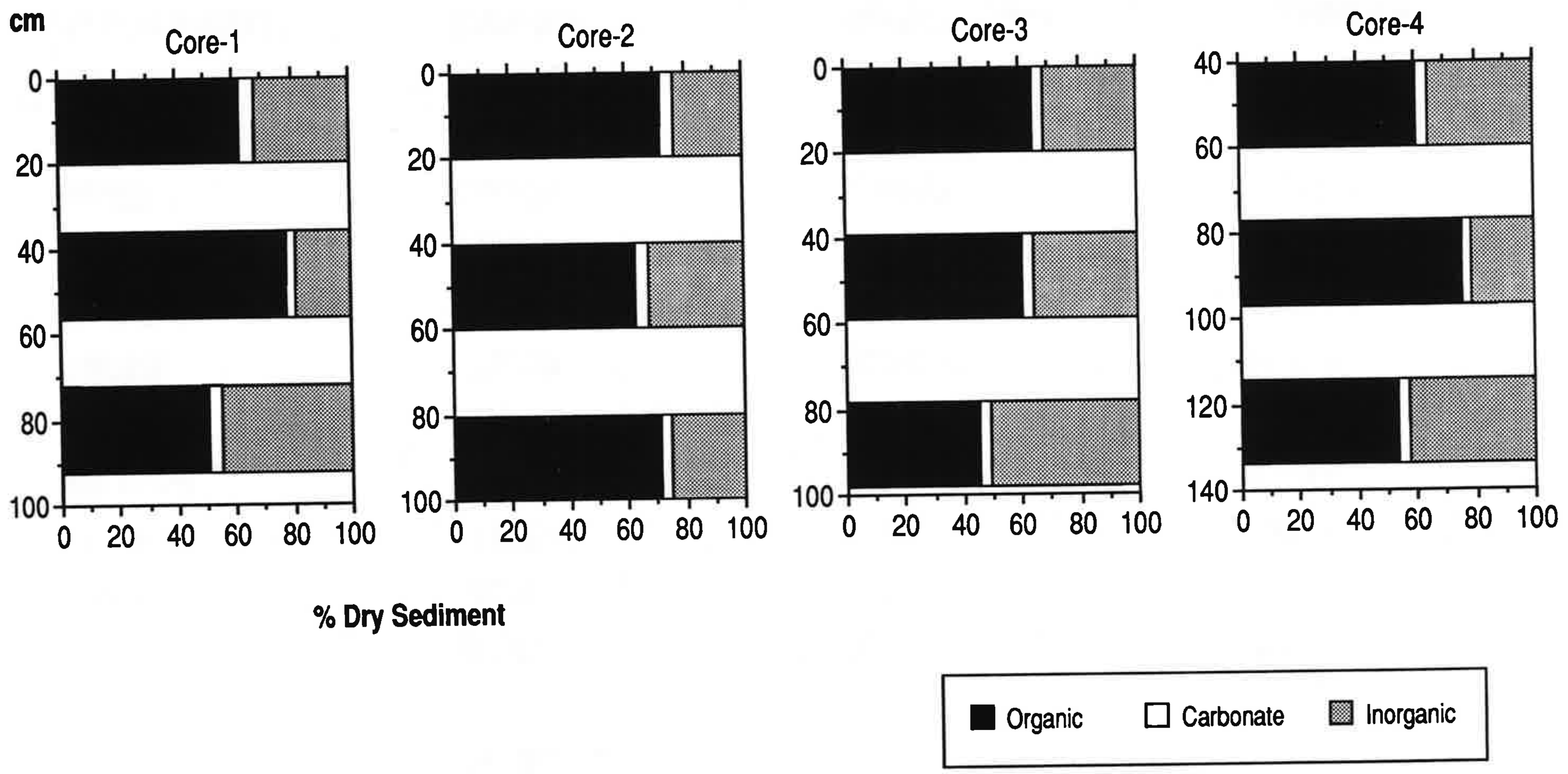


Lambert Lake (3e)



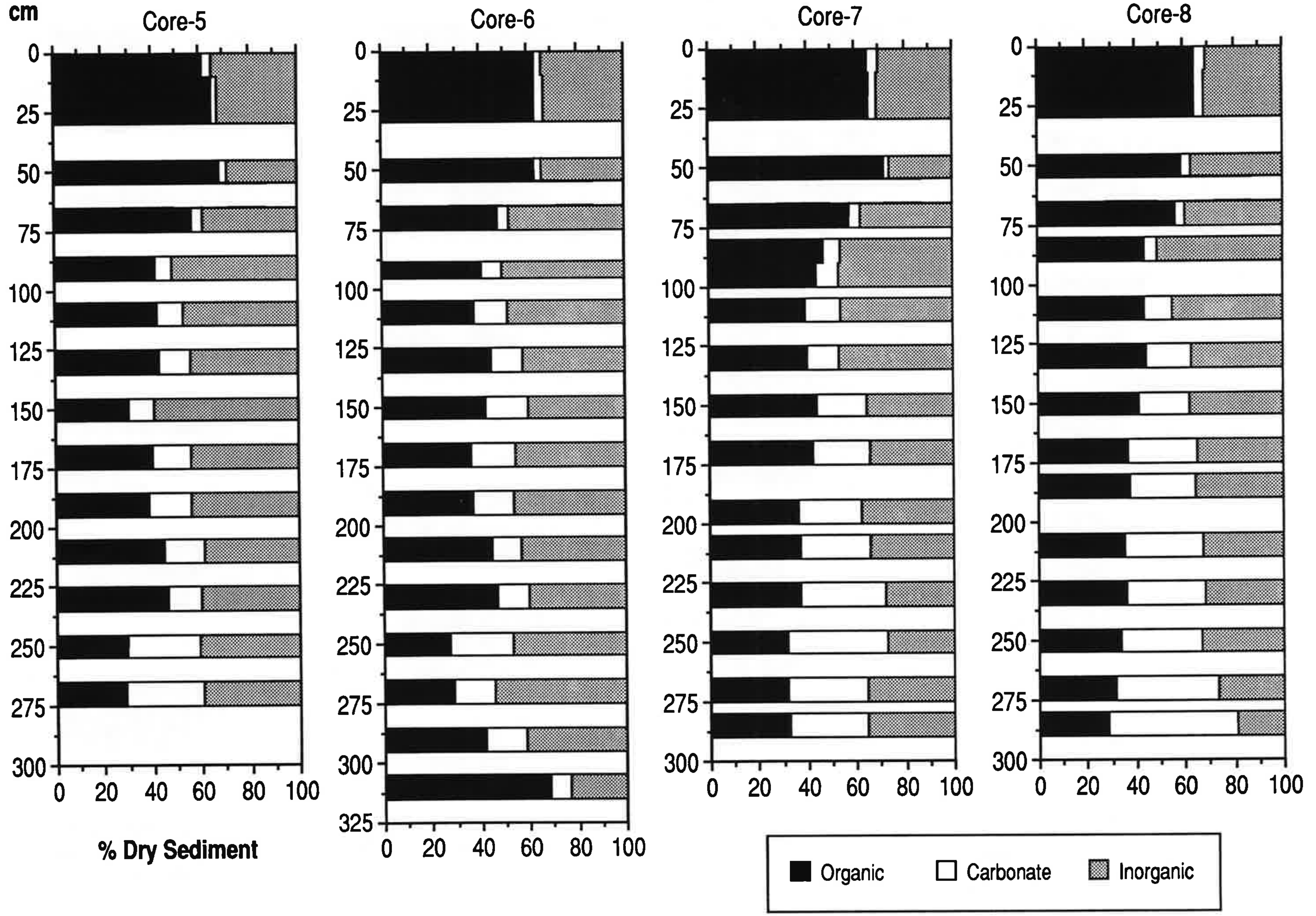

Sobota Slough (4a)
cm
Core-1
Core-2
Core-3
Core-4
Core-5
Core-6
Core-7
Core-8
20
40
60
80
100
120
30
50
70
90
110
130
140
0
% Dry Sediment
Organic
Carbonate
Inorganic

Rice Lake (4b)

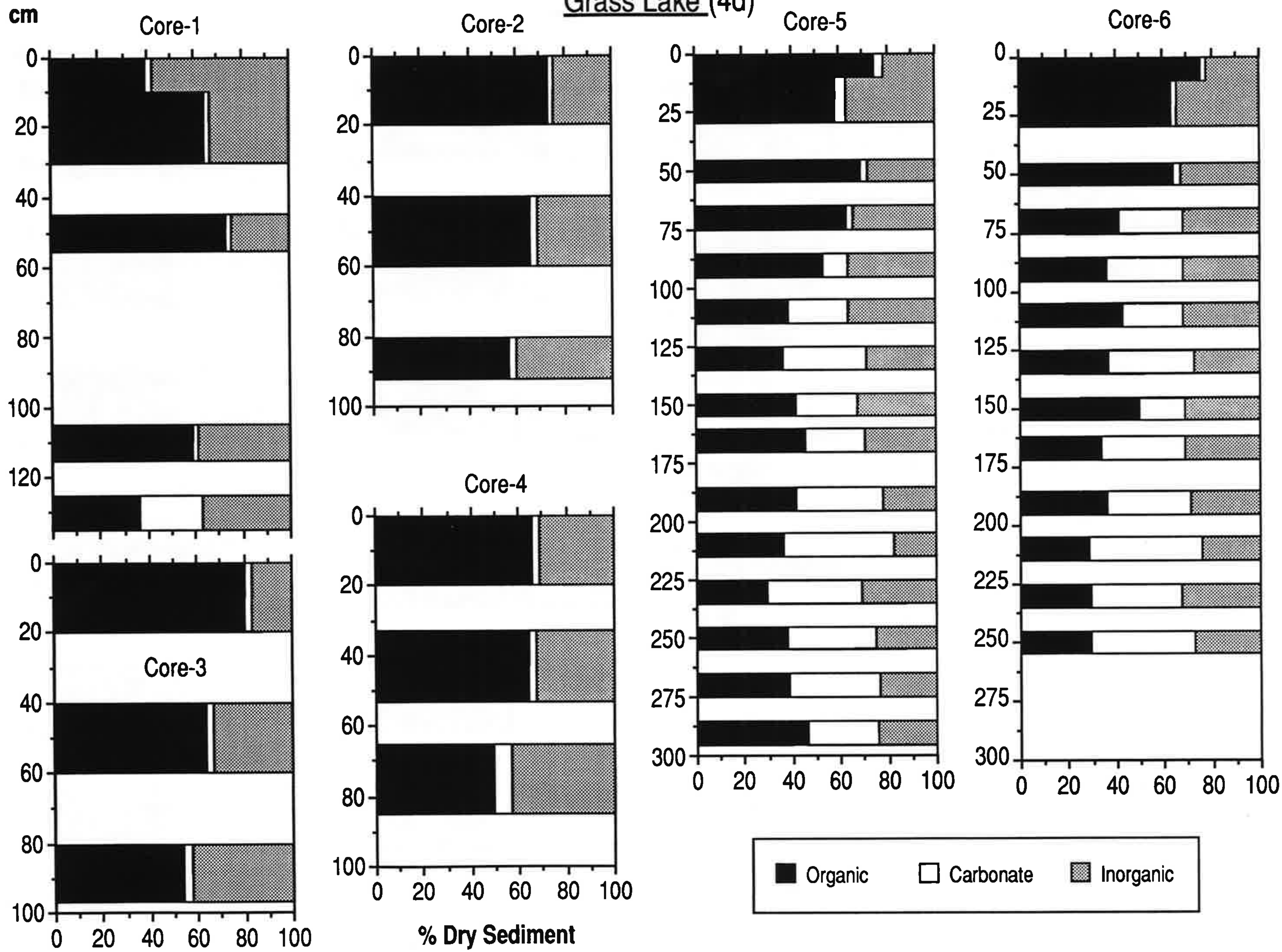


cm
Core-1
Core-2
Core-3
Core-4
0
20
40
60
80
100
120
140
% Dry Sediment
■ Organic
□ Carbonate
▨ Inorganic

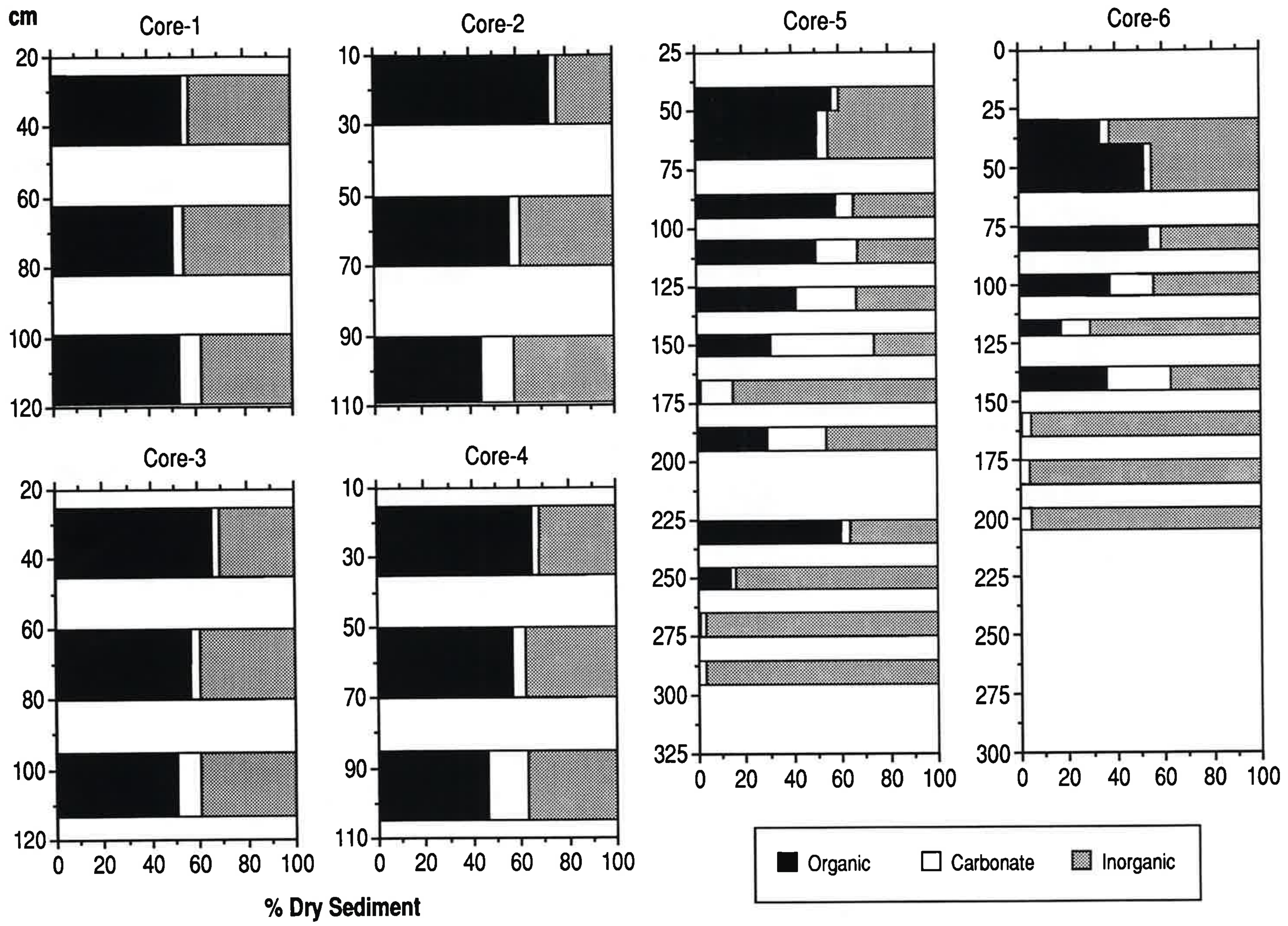
Rice Lake (4c)


cm
Core-5
Core-6
Core-7
Core-8
0
25
50
75
100
125
150
175
200
225
250
275
300
325
0
20
40
60
80
100
% Dry Sediment
■ Organic
□ Carbonate
▨ Inorganic

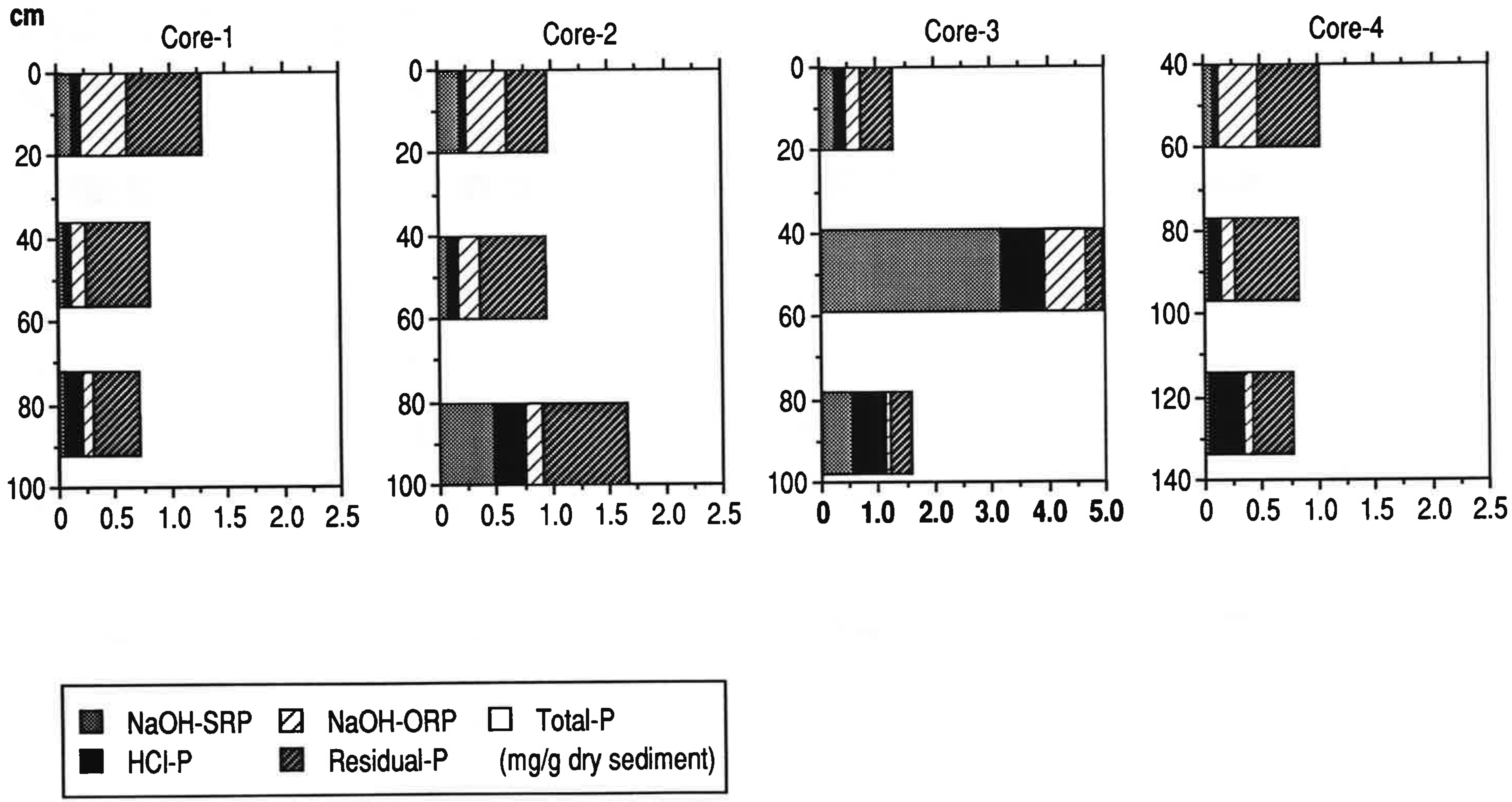
Grass Lake (4d)



Lambert Lake (4e)



Rice Lake 5b


cm
Core-1
Core-2
Core-3
Core-4
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20
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60
80
100
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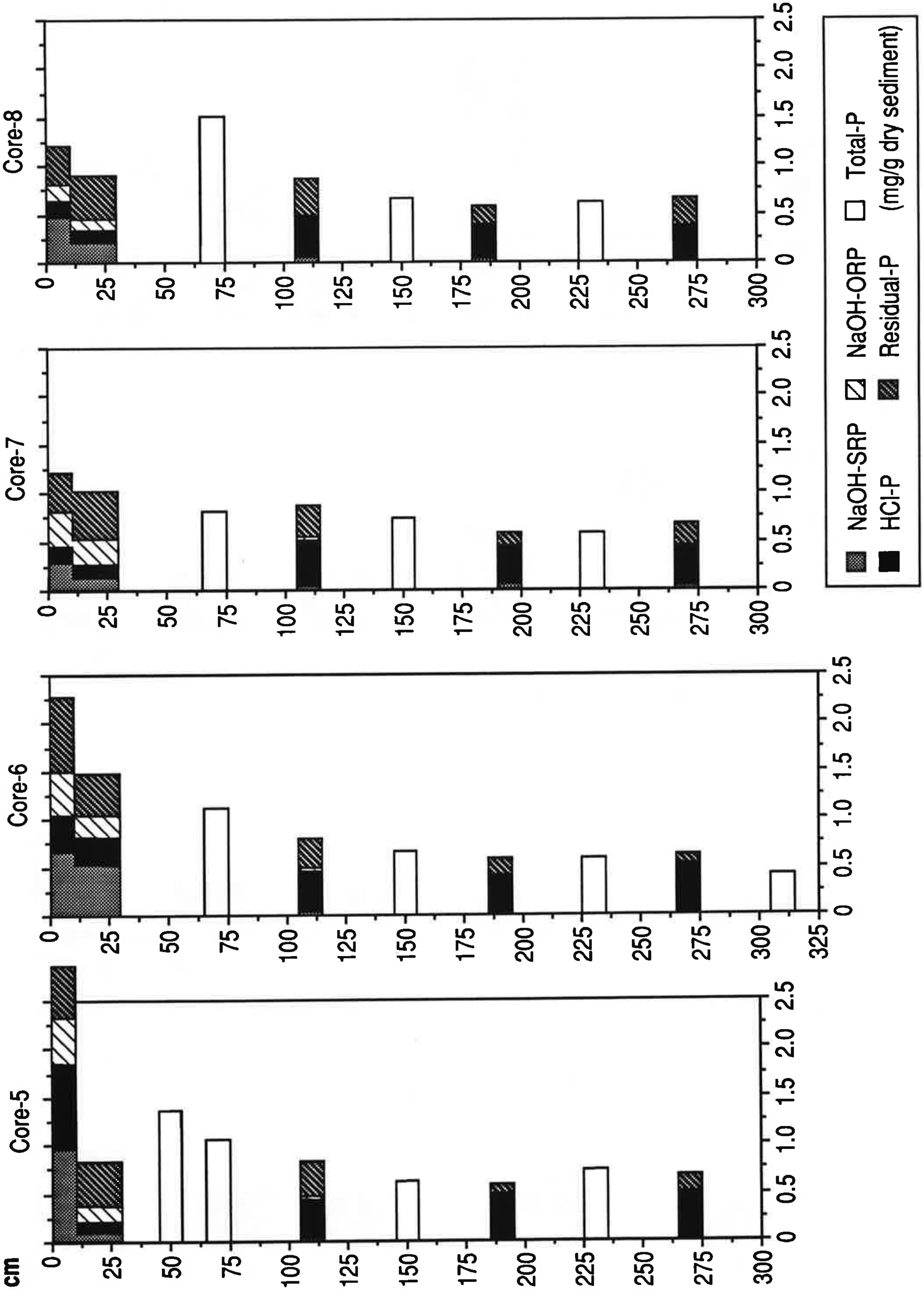
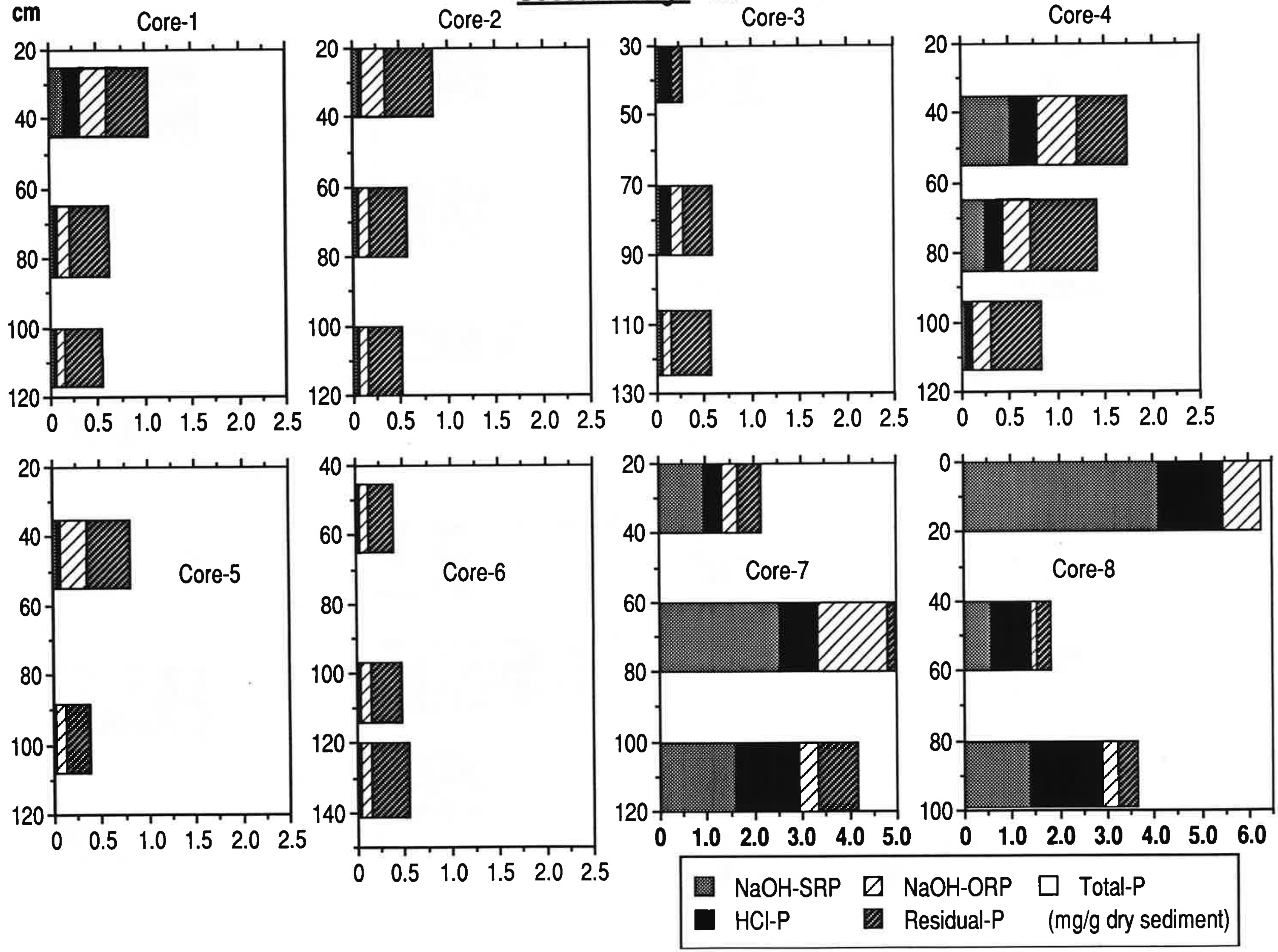
0.5
1.0
1.5
2.0
2.5
3.0
4.0
5.0
▩ NaOH-SRP
▨ NaOH-ORP
☐ Total-P
■ HCl-P
▨ Residual-P
(mg/g dry sediment)

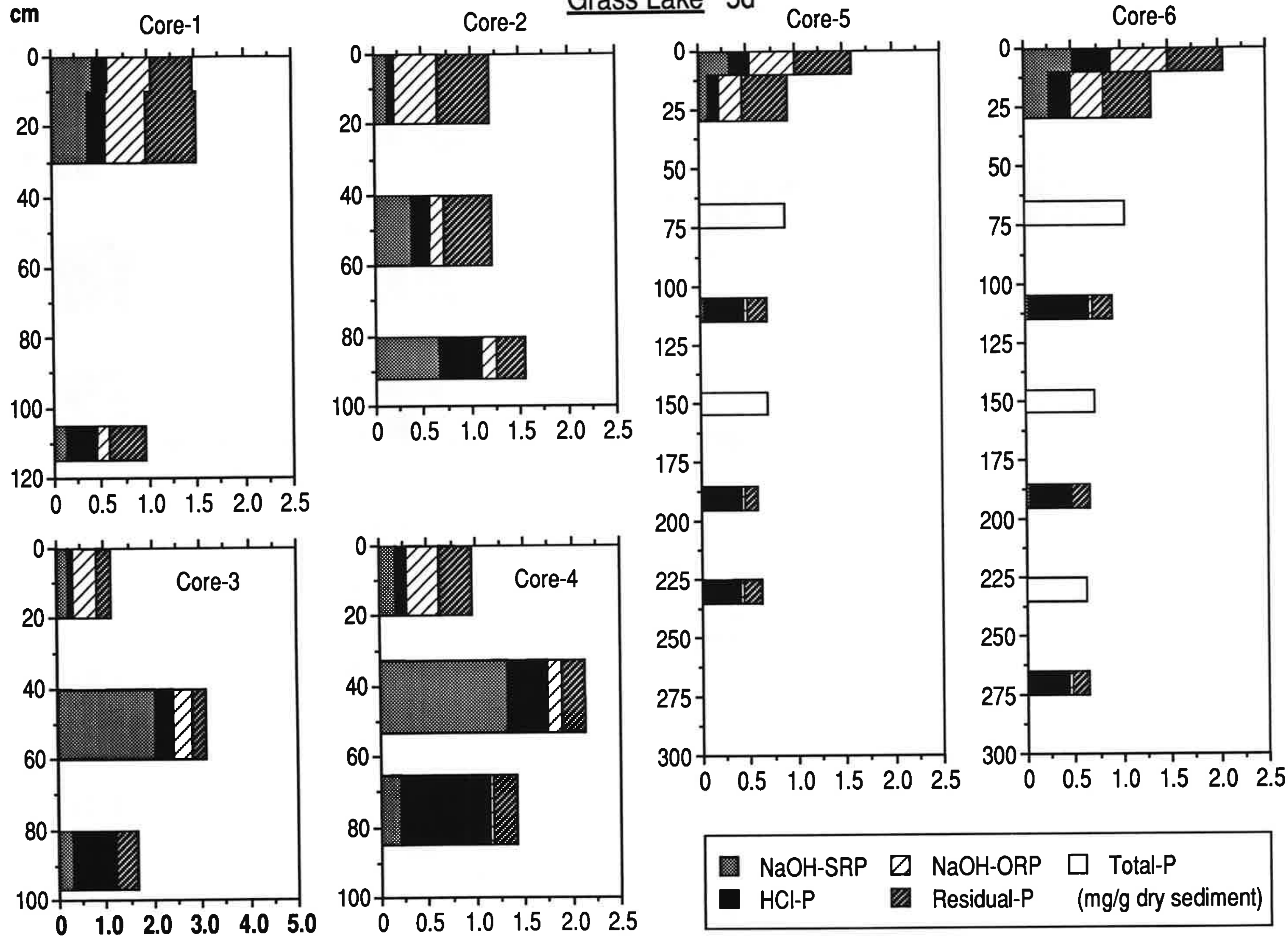
Rice Lake 5c


Core-5
Core-6
Core-7
Core-8
cm
0
25
50
75
100
125
150
175
200
225
250
275
300
325
0
0.5
1.0
1.5
2.0
2.5
▨ NaOH-SRP
■ HCl-P
▧ NaOH-ORP
▩ Residual-P
☐ Total-P
(mg/g dry sediment)

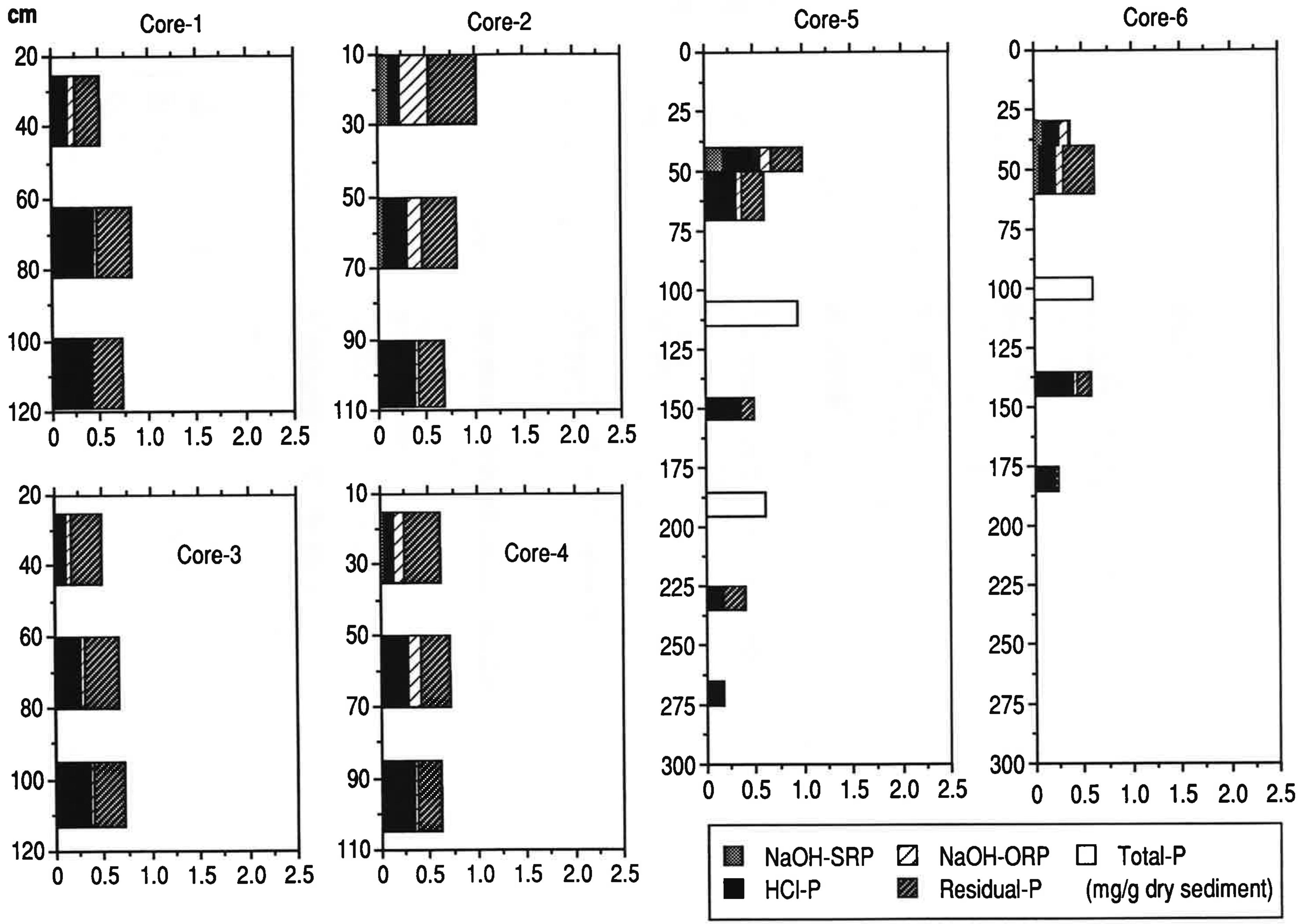
Sobota Slough 5a



Grass Lake 5d



Lambert Lake 5e



% Phosphorus Fractions: All Sites

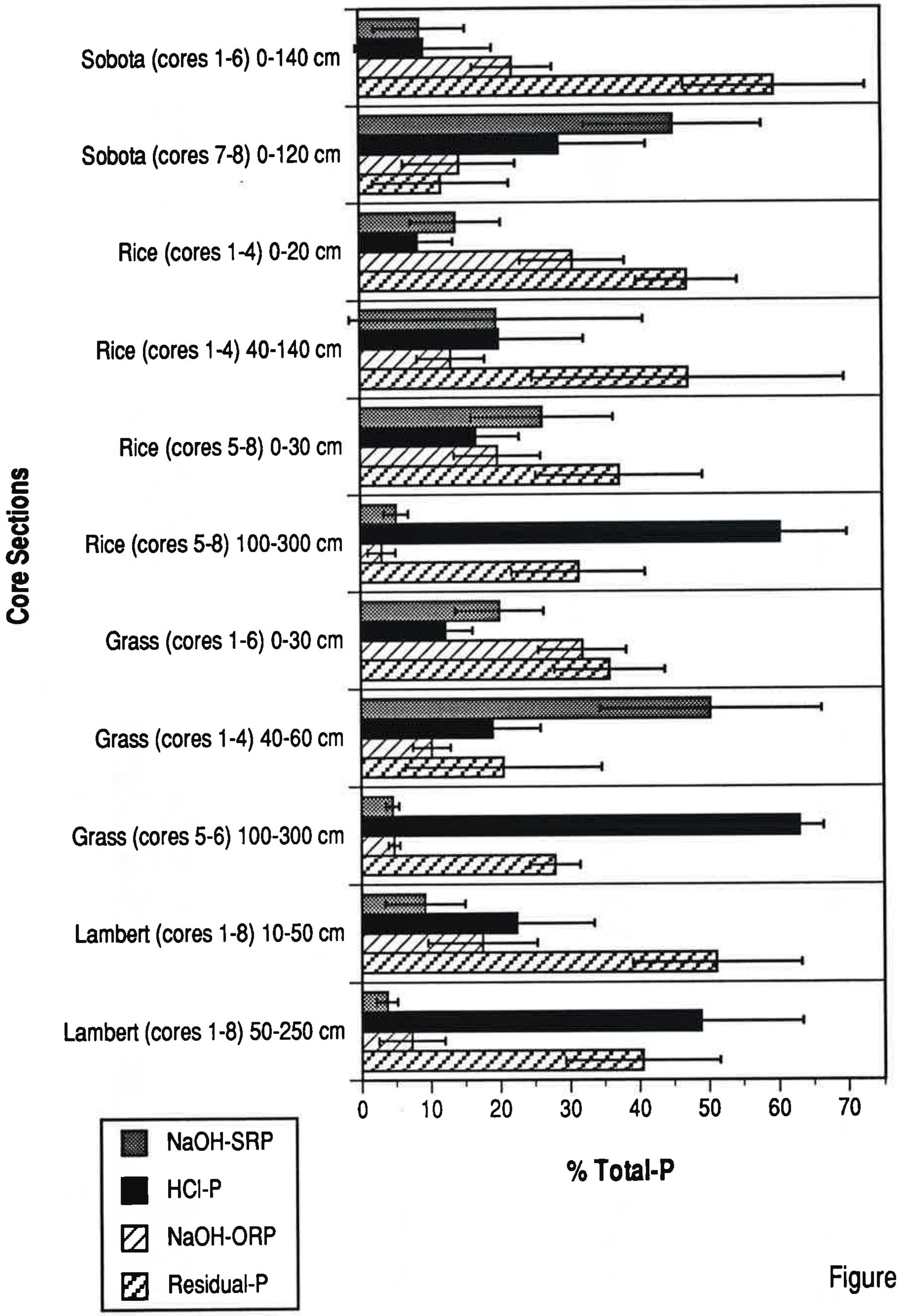
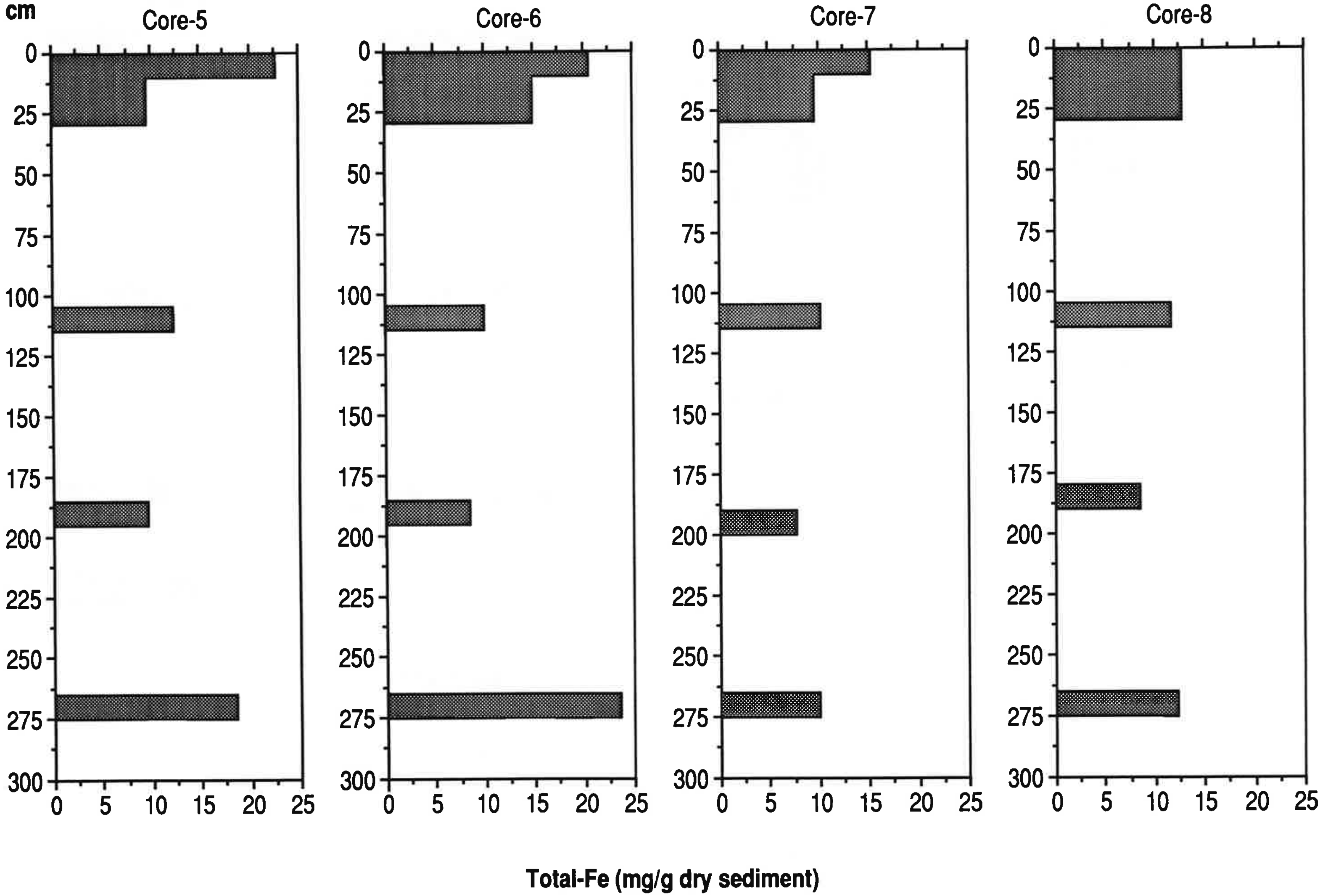
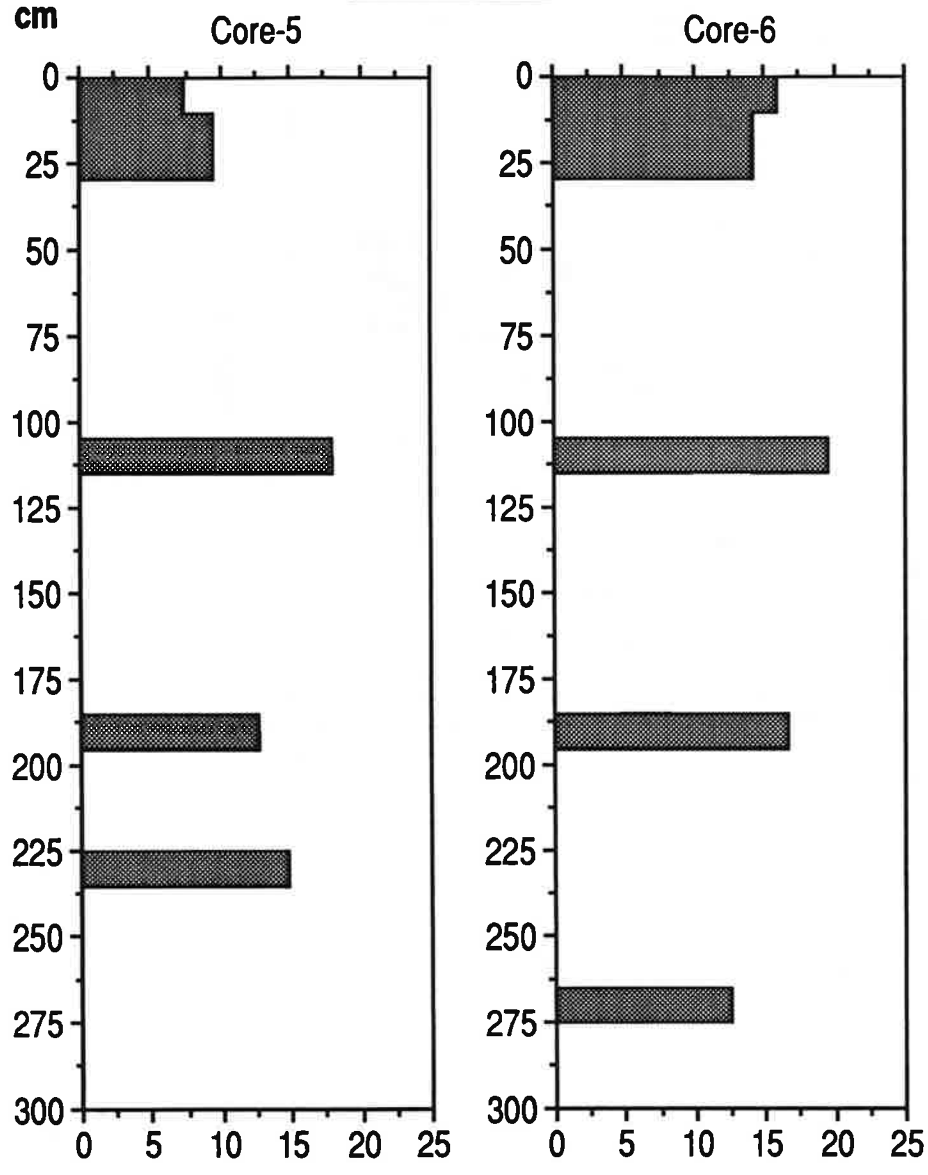


Figure 6

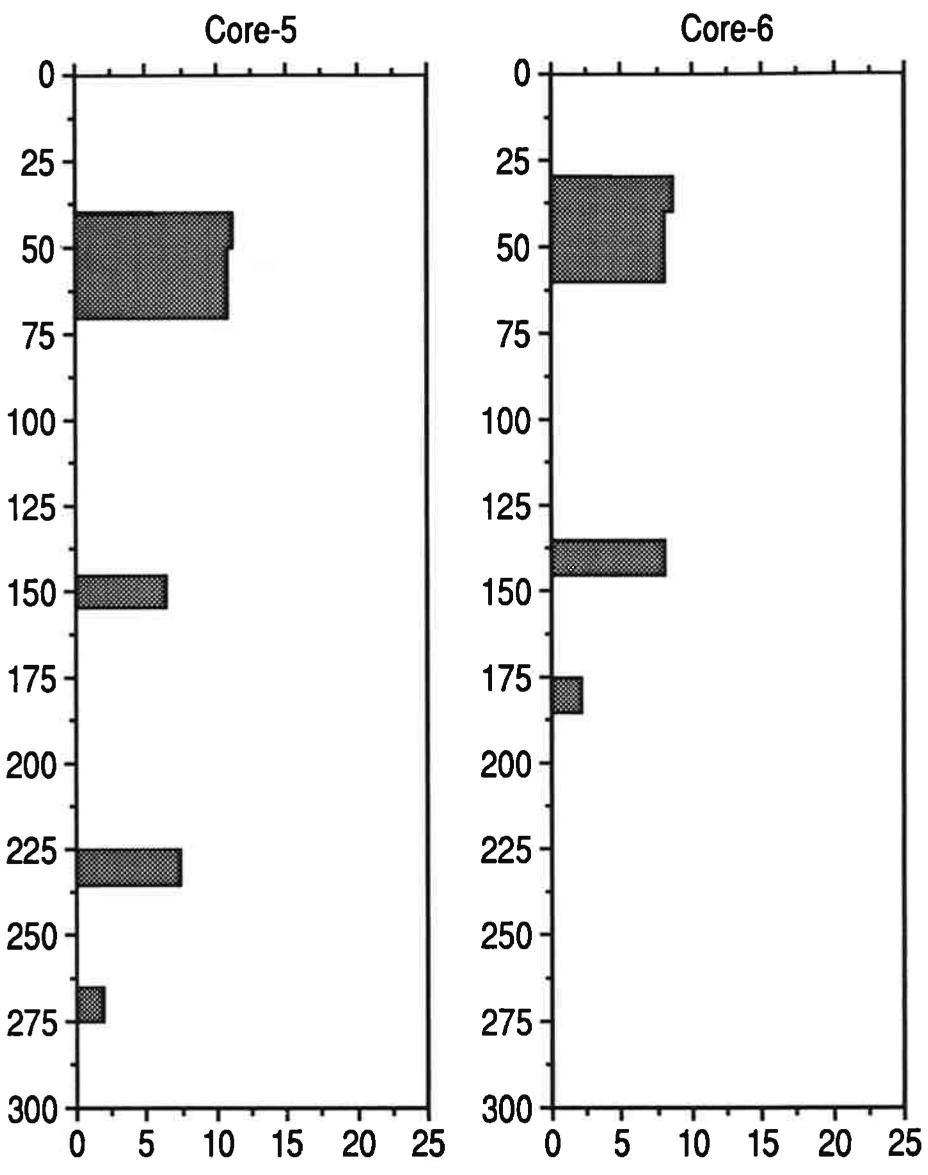
Rice Lake 7a


cm
Core-5
Core-6
Core-7
Core-8
0
25
50
75
100
125
150
175
200
225
250
275
300
0
5
10
15
20
25
Total-Fe (mg/g dry sediment)

Grass Lake 7b



Lambert Lake 7c



Total-Fe (mg/g dry sediment)

Phosphorus vs Fe

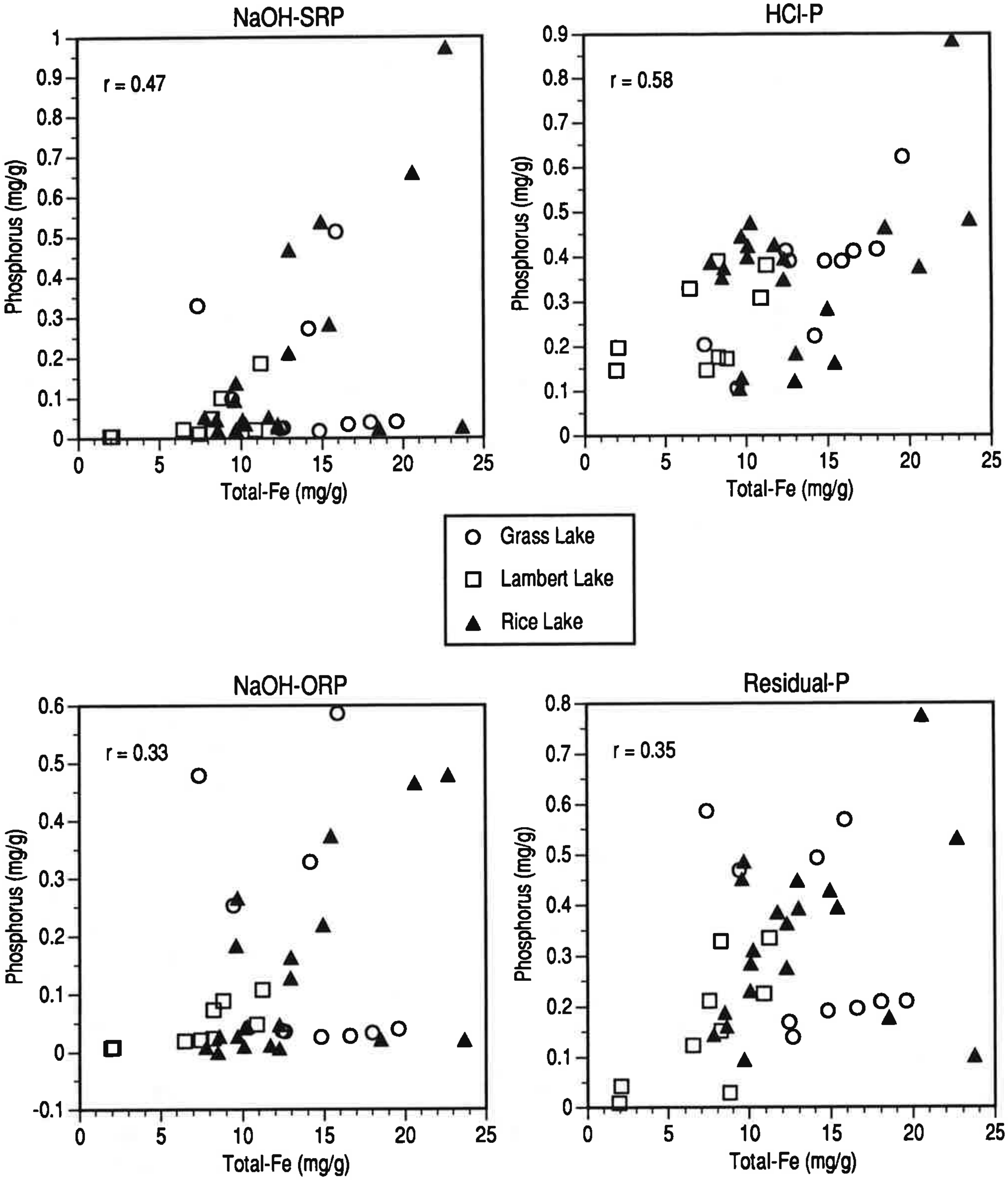


Figure 8

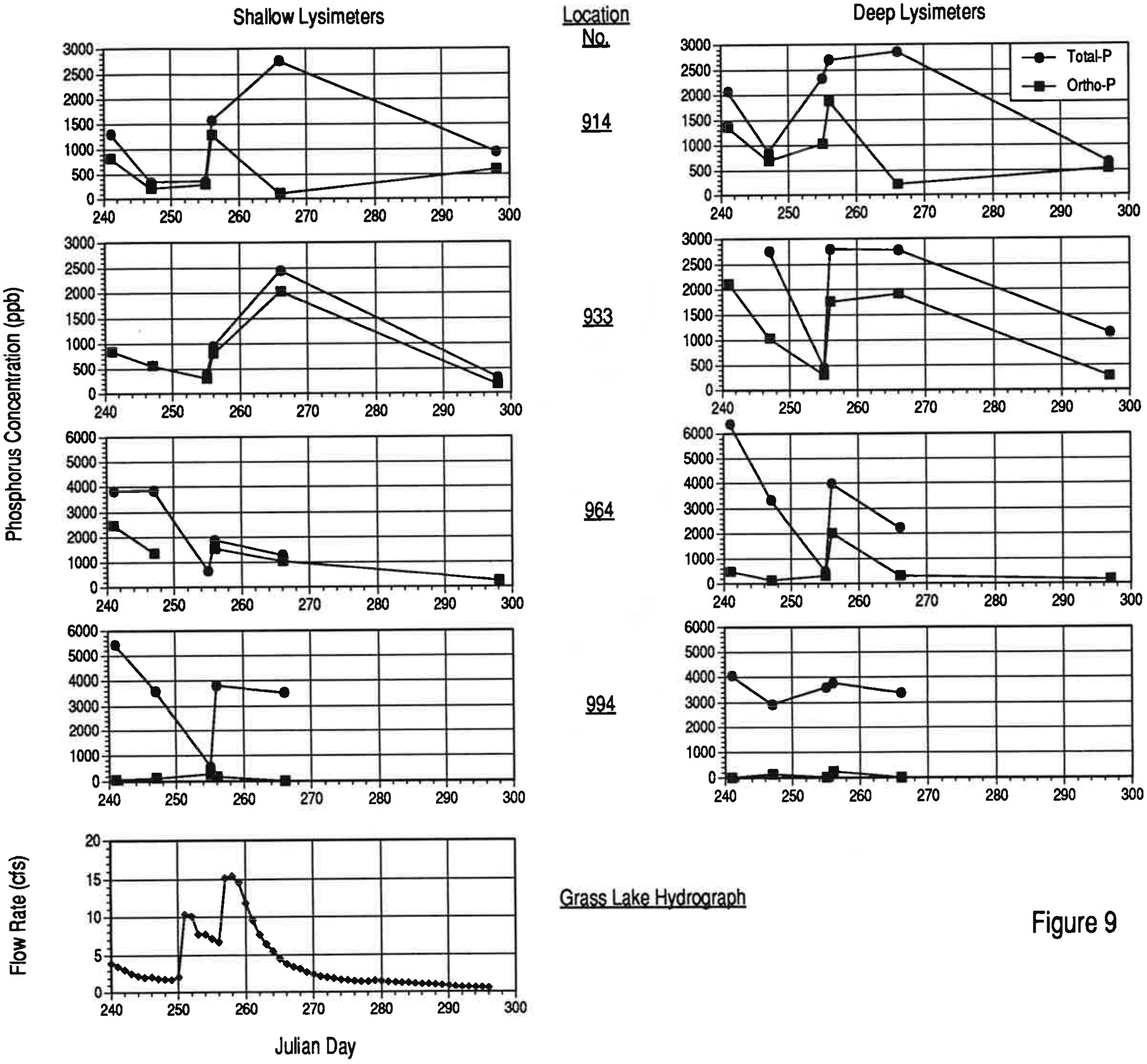

Shallow Lysimeters
Location No.
Deep Lysimeters
Total-P
Ortho-P
914
933
964
994
Phosphorus Concentration (ppb)
0
500
1000
1500
2000
2500
3000
4000
5000
6000
240
250
260
270
280
290
300
Grass Lake Hydrograph
Flow Rate (cfs)
0
5
10
15
20
Julian Day

Figure 9

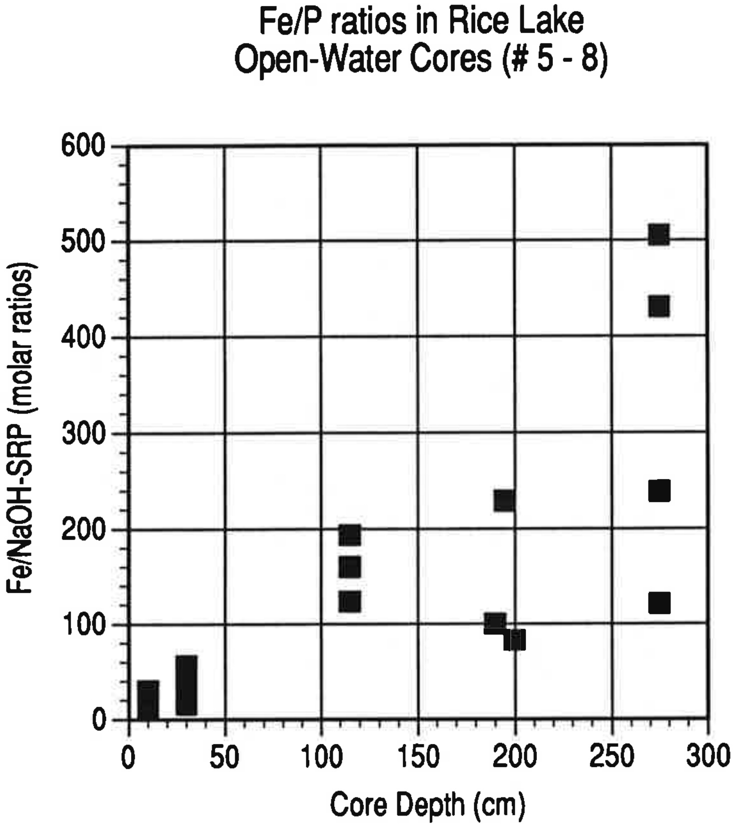

Fe/P ratios in Rice Lake
Open-Water Cores (# 5 - 8)
Fe/NaOH-SRP (molar ratios)
600
500
400
300
200
100
0
0
50
100
150
200
250
300
Core Depth (cm)

Figure 10

Lambert Wetlands Core Log

Site	Core#	Drive#	Depth	Recovery	Other Info.	Vegetation	Date	Coord-1	Coord-2
Grass	1	1	0-100	0-66	10 (water)	open cattails	12/27/90	339 (6)	222 (1)
Grass	1	2	105-180	105-179					
Grass	2	1	0-100	0-92	(gap: 13-17)	open cattails	12/27/90	245 (1)	184 (4)
Grass	3	1	0-100	0-97		dense cattails	12/27/90	216 (1)	136 (5)
Grass	4	1	0-85	0-85		open cattails	12/20/90	midway between (3) & (4)	
Grass	5	1	0-85	0-89		open cattails	12/19/90	42 (2) - 40 m distant	
Grass	5	2	85-170	85-172					
Grass	5	3	185-270	185-255					
Grass	6	1	0-85	0-80		dense cattails	12/20/90	222 (2)	132 (4)
Grass	6	2	85-170	85-170					
Grass	6	3	170-255	170-255					
Grass	6	4	255-305	255-305					
Lambert	1	1	0-100	0-94	25 (frozen)	open cattails	1/8/91	180 (1)	256 (2)
Lambert	2	1	0-100	0-97	10 (frozen)	dense cattails	1/10/91	109 (4)	344 (5)
Lambert	3	1	0-100	0-88	25 (frozen)	sedge/cattails	1/10/91	48 (4)	139 (6)
Lambert	4	1	0-100	0-90	15 (frozen)	open cattails	1/10/91	175 (1)	80 (4)
Lambert	5	1	0-100	0-96	40 (frozen)	dense cattails	1/10/91	60 (4)	177 (1)
Lambert	5	2	100-185	100-156					
Lambert	5	3	185-270	185-267	(sand)				
Lambert	6	1	0-100	0-92	30 (frozen)	dense cattails	1/10/91	48 (4)	288 (2)
Lambert	6	2	100-185	100-183	(sand)				
Rice	1	1	0-100	0-94		open cattails	12/27/90	71 (1)	150 (2)
Rice	2	1	0-100	0-100		dense cattails	12/27/90	68 (1)	154 (3)
Rice	3	1	0-100	0-98	50 (water)	small pool	1/8/91	72 (4)	147 (2)
Rice	4	1	0-100	0-95	40 (frozen)	grass/sedge	1/8/91	83 (4)	148 (3)
Rice	5	1	**0-81**	**0-81**	56 (water)	open water	1/15/91	324 (A)	232 (B)
Rice	5	2	**81-181**	**81-176**	[0-30 jars]		1/15/91		
Rice	5	3	**181-281**	**181-281**			1/15/91		
Rice	6	1	**0-88**	**0-88**	62 (water)	open water	1/15/91	58 (2)	312 (A)
Rice	6	2	**88-176**	**88-176**	[0-30 jars]		1/15/91		
Rice	6	3	**176-276**	**176-276**			1/15/91		
Rice	6	4	**276-315**	**276-315**			1/15/91		
Rice	7	1	**0-90**	**0-90**	62 (water)	open water	1/15/91	60 (5)	124 (2)

Appendix A

Lambert Wetlands Core Log

Site	Core#	Drive#	Depth	Recovery	Other Info.	Vegetation	Date	Coord-1	Coord-2
Rice	7	2	**90-190**	**90-188**	[0-55 jars]		1/15/91		
Rice	7	3	**190-290**	**190-290**			1/15/91		
Rice	8	1	**0-90**	**0-90**	60 (water)	open water	1/15/91	233 (A)	110 (5)
Rice	8	2	**90-190**	**90-190**	[0-45 jars]		1/15/91		
Rice	8	3	**190-290**	**190-290**			1/15/91		
Sobota	1	1	0-50	0-48	25 (frozen)	dense cattails	1/13/91	13 (1)	134 (2)
Sobota	1	2	50-125	50-92					
Sobota	2	1	0-76	0-62	20 (frozen)	dense cattails	1/13/91	70 (2)	350 (3)
Sobota	2	2	76-110	76-110					
Sobota	3	1	0-98	0-62	30 (frozen)	open cattails	1/13/91	347 (3)	44 (2)
Sobota	3	2	62-101	62-96	(new hole)				
Sobota	4	1	0-100	0-79	35 (frozen)	dense cattails	1/13/91	216 (4)	288 (5)
Sobota	5	1	0-52	0-36	35 (frozen)	cattail/shrub	1/13/91	68 (2)	180 (6)
Sobota	5	2	52-90	52-76					
Sobota	6	1	0-52	0-40	45 (frozen)	dense cattails	1/13/91	46 (2)	198 (6)
Sobota	6	2	52-75	52-69					
Sobota	6	3	75-98	75-97					
Sobota	7	1	0-100	0-100	20 (frozen)	dense cattails	1/13/91	42 (3)	160 (7)
Sobota	8	1	0-100	0-100	50 (water)	small pool	1/13/91	64 (2)	156 (7)

Appendix B: QA/QC Replicate Extractions & Analyses

Sample Number	Rep-1	Rep-2	C.V.		Rep-1	Rep-2	C.V.		Rep-1	Rep-2	C.V.
	LOI-% Organic				**LOI-%Carbonate**				**Total-P (mg/g)**		
GL-1 (0-10)	39.07	54.70	23.57		3.10	3.26	3.44		1.473	1.511	1.83
GL-3 (0-20)	80.47	77.67	2.50		2.79	2.50	7.75		1.136	1.148	0.75
GL-5 (85-95)	36.62	36.62	0.01		31.20	31.52	0.72				
GL-6 (10-30)	58.51	58.15	0.44		4.12	4.38	4.31		1.318	1.385	3.53
GL-6 (225-235)	29.55	28.01	3.80		39.33	40.93	2.82		0.618	0.850	22.29
LL-2 (0-20)	73.56	65.89	7.79		3.15	4.08	18.19		1.020	1.114	6.25
LL-5 (10-30)	50.52	50.70	0.25		4.44	4.94	7.54		0.601	0.700	10.77
LL-5 (245-255)	0.24	0.26	6.44		2.91	2.91	0.10				
RL-1 (36-56)	77.80	79.54	1.56		3.05	3.01	0.97		0.805	0.779	2.32
RL-4 (74-94)	53.42	51.39	2.74		4.09	4.27	3.10		0.780	0.751	2.60
RL-5 (185-195)	38.80	39.02	0.40		17.56	17.79	0.91		0.592	0.860	26.11
RL-6 (105-115)	37.91	38.22	0.58		13.60	13.79	0.97		0.786	0.819	2.94
RL-6 (305-315)	68.16	67.48	0.70		8.20	8.54	2.88		0.419	0.453	5.45
RL-7 (165-175)	42.23	42.46	0.39		23.81	23.80	0.04				
RL-8 (65-75)	56.83	57.26	0.53		3.85	3.92	1.28				
RL-8 (265-275)	31.46	31.49	0.06		41.87	41.81	0.10		0.661	0.570	10.53
SS-3 (76-95)	87.36	87.47	0.09		3.39	3.54	3.05		0.567	0.503	8.44
SS-7 (40-60)	69.75	66.63	3.24		3.30	2.68	14.77		4.980	4.983	0.04
	Mean C.V. (%)		**3.06**		Mean C.V. (%)		**4.05**		Mean C.V. (%)		**7.42**
	NaOH-TP (mg/g)				**NaOH-SRP (mg/g)**				**HCl-P (mg/g)**		
GL-1 (0-10)	0.887	0.796	7.60		0.440	0.373	11.63		0.156	0.196	15.91
GL-3 (0-20)	0.734	0.609	13.16		0.227	0.191	12.32		0.108	0.088	14.27
LL-2 (0-20)	0.418	0.427	1.52		0.111	0.119	4.83		0.112	0.109	1.99
LL-5 (10-30)	0.069	0.066	2.34		0.021	0.021	0.20		0.308	0.248	15.15
RL-1 (36-56)	0.201	0.207	2.02		0.055	0.054	1.29		0.051	0.051	0.52
RL-4 (74-94)	0.115	0.104	7.50		0.044	0.041	4.04		0.304	0.354	10.84
RL-6 (105-115)	0.077	0.067	10.17		0.035	0.033	3.32		0.424	0.428	0.57
RL-8 (265-275)	0.035	0.033	4.05		0.028	0.039	22.89		0.350	0.381	6.17
SS-3 (76-95)	0.128	0.129	0.81		0.035	0.039	8.85		0.018	0.016	11.58
SS-7 (40-60)	4.028	4.196	2.89		2.553	3.033	12.15		0.781	0.791	0.97
	Mean C.V. (%)		**5.21**		Mean C.V. (%)		**8.15**		Mean C.V. (%)		**7.80**
	Total-Fe (mg/g)										
GL-6 (10-30)	14.16	14.34	0.89								
LL-5 (10-30)	10.86	10.71	0.98								
RL-6 (105-115)	10.10	9.77	2.35								
RL-8 (265-275)	12.23	12.10	0.76								
	Mean C.V. (%)		**1.25**								

Loss-On-Ignition **Sobota Slough, Lambert Creek: All Cores**

Depth	Wet (g/cc)	Dry (g/cc)	Dry/Wet	Org/Wet	% Organic	% CaCO3	% Inorg.
(1) 0-20	1.1252	0.1984	0.1764	0.1255	71.16	3.18	25.66
(1) 40-60	1.1217	0.1724	0.1537	0.1332	86.65	4.29	9.06
(1) 75-92	1.0527	0.1745	0.1657	0.1470	88.67	1.88	9.44
(2) 0-20	1.0982	0.2031	0.1850	0.1437	77.70	2.56	19.74
(2) 40-60	1.0845	0.1742	0.1606	0.1429	88.93	2.36	8.71
(2) 80-100	1.0970	0.1706	0.1555	0.1318	84.75	1.93	13.33
(3) 0-16	1.5159	0.7386	0.4872	0.0246	5.06	87.18	7.77
(3) 40-60	1.2071	0.1888	0.1564	0.1306	83.47	2.90	13.63
(3) 76-95	1.0586	0.1696	0.1603	0.1400	87.36	3.39	9.25
(3r) 76-95	1.1130	0.1780	0.1599	0.1399	87.47	3.54	8.98
(4) 0-20	1.1839	0.2623	0.2216	0.1453	65.59	4.39	30.02
(4) 30-50	1.1171	0.2476	0.2216	0.1547	69.78	14.27	15.94
(4) 59-79	1.0887	0.1990	0.1828	0.1516	82.93	2.62	14.45
(5) 0-20	1.0783	0.2314	0.2146	0.1701	79.23	3.67	17.10
(5) 53-73	1.0804	0.2027	0.1876	0.1590	84.78	3.65	11.57
(6) 0-20	1.0477	0.1960	0.1871	0.1671	89.31	2.80	7.90
(6) 52-69	1.0594	0.2030	0.1916	0.1599	83.44	3.51	13.05
(6) 75-96	1.0296	0.1757	0.1706	0.1531	89.71	2.81	7.48
(7) 0-20	1.1912	0.1789	0.1502	0.1122	74.68	2.76	22.56
(7) 40-60	1.0970	0.1080	0.0984	0.0686	69.75	3.30	26.95
(7r) 40-60	1.0952	0.1127	0.1029	0.0685	66.63	2.68	30.69
(7) 80-99	1.1341	0.1219	0.1075	0.0555	51.58	4.27	44.15
(8) 0-20	1.1322	0.1689	0.1492	0.1015	68.05	3.24	28.71
(8) 40-60	1.0918	0.1129	0.1034	0.0539	52.08	3.64	44.28
(8) 80-100	1.1617	0.1061	0.0914	0.0539	59.02	3.36	37.62

Loss-On-Ignition **Rice Lake, Lambert Creek: All Cores**

Depth	Wet (g/cc)	Dry (g/cc)	Dry/Wet	Org/Wet	% Organic	% CaCO3	% Inorg.
(1) 0-20	1.1641	0.1876	0.1611	0.0999	61.98	5.26	32.76
(1) 36-56	1.1088	0.1525	0.1376	0.1070	77.80	3.05	19.14
(1r) 36-56	1.1604	0.1637	0.1411	0.1122	79.54	3.01	17.44
(1) 72-92	1.0840	0.1741	0.1606	0.0814	50.66	4.41	44.94
(2) 0-20	1.1586	0.1384	0.1195	0.0860	71.98	4.55	23.47
(2) 40-60	1.1049	0.1781	0.1612	0.1012	62.79	4.77	32.44
(2) 80-100	1.1389	0.1083	0.0951	0.0675	70.97	3.79	25.24
(3) 0-20	1.1108	0.1853	0.1668	0.1069	64.11	4.44	31.46
(3) 39-59	1.0943	0.1352	0.1235	0.0753	60.96	3.65	35.39
(3) 78-98	1.1388	0.1437	0.1262	0.0570	45.18	4.38	50.44
(4) 0-20	1.1214	0.2107	0.1879	0.1133	60.32	4.03	35.65
(4) 37-57	1.1206	0.1314	0.1173	0.0885	75.44	3.13	21.44
(4) 74-94	1.0939	0.1340	0.1225	0.0654	53.42	4.09	42.49
(4r) 74-94	1.1159	0.1475	0.1322	0.0679	51.39	4.27	44.34
(5) 0-10	1.1407	0.0889	0.0779	0.0476	61.11	4.01	34.88
(5) 10-30	1.1292	0.1670	0.1479	0.0969	65.51	1.80	32.68
(5) 45-55	1.0834	0.1359	0.1254	0.0851	67.82	3.23	28.96
(5) 65-75	1.1487	0.1345	0.1171	0.0664	56.72	4.48	38.80
(5) 85-95	1.1212	0.1772	0.1581	0.0664	42.01	6.80	51.19
(5) 105-115	1.1039	0.1652	0.1496	0.0631	42.16	10.95	46.89
(5) 125-135	1.1076	0.1696	0.1532	0.0656	42.83	13.40	43.77
(5) 145-155	1.2025	0.2293	0.1907	0.0578	30.32	10.75	58.92
(5) 165-175	1.1559	0.2539	0.2196	0.0876	39.87	16.08	44.05
(5) 185-195	1.1812	0.2683	0.2272	0.0881	38.80	17.56	43.64
(5r) 185-195	1.1419	0.2480	0.2171	0.0847	39.02	17.79	43.19
(5) 205-215	1.1242	0.2060	0.1833	0.0816	44.50	16.76	38.74
(5) 225-235	1.1261	0.2259	0.2006	0.0932	46.45	13.10	40.45
(5) 245-255	1.2071	0.3087	0.2557	0.0759	29.66	29.38	40.96
(5) 265-275	1.2365	0.3525	0.2851	0.0812	28.47	31.86	39.67
(6) 0-10	1.1433	0.0900	0.0787	0.0496	63.05	3.04	33.90
(6) 10-30	1.1786	0.1407	0.1194	0.0754	63.18	3.12	33.70
(6) 45-55	1.0894	0.1819	0.1670	0.1044	62.52	3.31	34.17
(6) 65-75	1.1377	0.1666	0.1465	0.0699	47.72	4.28	48.00
(6) 88-95	1.1437	0.2041	0.1784	0.0725	40.61	8.32	51.06
(6) 105-115	1.1360	0.1853	0.1631	0.0618	37.91	13.60	48.49
(6r) 105-115	1.1640	0.1907	0.1639	0.0626	38.22	13.79	47.99
(6) 125-135	1.1689	0.1739	0.1487	0.0663	44.56	13.24	42.20
(6) 145-155	1.1943	0.2141	0.1793	0.0759	42.32	17.79	39.89
(6) 165-175	1.1754	0.2841	0.2417	0.0879	36.39	18.23	45.39
(6) 185-195	1.1690	0.2916	0.2494	0.0929	37.23	16.73	46.04
(6) 205-215	1.1384	0.2405	0.2112	0.0948	44.89	12.08	43.03
(6) 225-235	1.1422	0.2354	0.2061	0.0963	46.72	13.27	40.01
(6) 245-255	1.2317	0.3329	0.2703	0.0731	27.04	25.84	47.12
(6) 265-275	1.2440	0.3642	0.2928	0.0839	28.65	16.77	54.58
(6) 285-295	1.1293	0.2680	0.2373	0.0998	42.04	16.56	41.39
(6) 305-315	1.1194	0.1536	0.1372	0.0935	68.16	8.20	23.64
(6r) 305-315	1.1271	0.1571	0.1394	0.0941	67.48	8.54	23.97

Depth	Wet (g/cc)	Dry (g/cc)	Dry/Wet	Org/Wet	% Organic	%CaCO3	% Inorg.
(7) 0-10	1.2257	0.0888	0.0724	0.0472	65.13	4.63	30.24
(7) 10-30	1.1678	0.1176	0.1007	0.0661	65.68	3.49	30.83
(7) 45-55	1.3129	0.1645	0.1253	0.0901	71.94	2.33	25.73
(7) 65-75	1.0986	0.1202	0.1095	0.0632	57.72	4.56	37.73
(7) 80-90	1.1555	0.1546	0.1338	0.0626	46.77	6.74	46.50
(7) 90-100	1.1469	0.1636	0.1427	0.0628	44.04	9.04	46.92
(7) 105-115	1.1613	0.1731	0.1491	0.0592	39.74	14.08	46.18
(7) 125-135	1.1630	0.1829	0.1573	0.0635	40.38	12.43	47.18
(7) 145-155	1.1595	0.1551	0.1337	0.0590	44.13	20.14	35.72
(7) 165-175	1.1408	0.2094	0.1835	0.0775	42.23	23.81	33.95
(7r) 165-175	1.1612	0.2014	0.1735	0.0737	42.46	23.80	33.74
(7) 190-200	1.1731	0.2661	0.2269	0.0822	36.22	25.74	38.05
(7) 205-215	1.1596	0.2595	0.2238	0.0823	36.77	29.24	33.99
(7) 225-235	1.1866	0.2420	0.2040	0.0752	36.88	35.32	27.80
(7) 245-255	1.1886	0.2561	0.2155	0.0693	32.17	40.22	27.61
(7) 265-275	1.2065	0.2739	0.2270	0.0722	31.81	32.31	35.88
(7) 280-290	1.2141	0.3047	0.2510	0.0820	32.66	31.38	35.96
(8) 0-10	1.2435	0.0802	0.0645	0.0414	64.11	5.12	30.76
(8) 10-30	1.2389	0.1361	0.1099	0.0708	64.42	3.62	31.95
(8) 45-55	1.0900	0.1292	0.1185	0.0697	58.86	3.82	37.32
(8) 65-75	1.1290	0.1208	0.1070	0.0608	56.83	3.85	39.32
(8r) 65-75	1.1170	0.1187	0.1062	0.0608	57.26	3.92	38.82
(8) 80-90	1.1217	0.1566	0.1396	0.0619	44.31	5.07	50.62
(8) 105-115	1.1395	0.1639	0.1438	0.0632	43.97	11.04	44.99
(8) 125-135	1.1336	0.1571	0.1386	0.0619	44.63	18.48	36.88
(8) 145-155	1.1593	0.1931	0.1666	0.0693	41.61	20.43	37.96
(8) 165-175	1.1794	0.2513	0.2131	0.0794	37.25	28.23	34.52
(8) 180-190	1.1692	0.2772	0.2371	0.0903	38.07	26.29	35.64
(8) 205-215	1.1664	0.2473	0.2121	0.0748	35.27	31.90	32.83
(8) 225-235	1.2063	0.2724	0.2258	0.0829	36.71	31.48	31.81
(8) 245-255	1.2004	0.2761	0.2301	0.0786	34.16	32.24	33.59
(8) 265-275	1.2095	0.3343	0.2764	0.0870	31.46	41.87	26.67
(8r) 265-275	1.1964	0.3348	0.2799	0.0881	31.49	41.81	26.70
(8) 280-290	1.1948	0.3496	0.2926	0.0842	28.77	51.95	19.27

Loss-On-Ignition **Grass Lake, Lambert Creek: All Cores**

Depth	Wet (g/cc)	Dry (g/cc)	Dry/Wet	Org/Wet	% Organic	% CaCO3	% Inorg.
(1) 0-10	1.1767	0.2739	0.2327	0.0909	39.07	3.10	57.83
(1r) 0-10	1.3357	0.2104	0.1575	0.0861	54.70	3.26	42.05
(1) 10-30	1.1028	0.2499	0.2266	0.1460	64.42	2.08	33.50
(1) 45-55	1.0880	0.1884	0.1732	0.1274	73.53	1.89	24.58
(1) 105-115	1.1373	0.1437	0.1264	0.0744	58.84	2.67	38.49
(1) 125-135	1.1339	0.2087	0.1840	0.0674	36.61	26.00	37.40
(1) 145-155	1.1618	0.1912	0.1646	0.0649	39.45	22.64	37.91
(1) 165-175	1.1482	0.1801	0.1569	0.0652	41.54	21.29	37.17
(2) 0-20	1.1652	0.1898	0.1629	0.1198	73.59	2.17	24.25
(2) 40-60	1.1506	0.1706	0.1483	0.0976	65.82	3.21	30.97
(2) 80-92	1.1218	0.1360	0.1213	0.0688	56.78	3.22	40.00
(3) 0-20	1.4690	0.1080	0.0735	0.0591	80.47	2.79	16.74
(3r) 0-20	1.4682	0.1095	0.0746	0.0579	77.67	2.50	19.83
(3) 40-60	1.1454	0.2184	0.1907	0.1217	63.82	2.51	33.67
(3) 80-97	1.1558	0.1342	0.1161	0.0629	54.13	3.47	42.40
(4) 0-20	1.2422	0.1870	0.1505	0.0997	66.24	2.78	30.98
(4) 33-53	1.1605	0.1605	0.1383	0.0888	64.19	3.24	32.57
(4) 65-85	1.1254	0.1299	0.1154	0.0567	49.17	8.02	42.82
(5) 0-10	1.1741	0.1277	0.1088	0.0820	75.38	2.57	22.05
(5) 10-30	1.1857	0.2152	0.1815	0.1148	63.27	2.67	34.06
(5) 45-55	1.0955	0.1428	0.1303	0.0841	64.56	2.69	32.76
(5) 65-75	1.1477	0.1663	0.1449	0.0608	41.96	25.87	32.17
(5) 85-95	1.1518	0.1941	0.1685	0.0617	36.62	31.20	32.18
(5r) 85-95	1.1151	0.1895	0.1700	0.0622	36.62	31.52	31.87
(5) 105-115	1.1214	0.1699	0.1515	0.0654	43.19	24.84	31.97
(5) 125-135	1.1411	0.1882	0.1649	0.0607	36.81	35.67	27.52
(5) 145-155	1.1901	0.1957	0.1644	0.0817	49.69	19.18	31.12
(5) 162-172	1.1904	0.3100	0.2604	0.0882	33.85	34.82	31.33
(5) 185-195	1.1631	0.2708	0.2329	0.0838	35.99	35.40	28.61
(5) 205-215	1.1539	0.3170	0.2747	0.0782	28.47	47.10	24.43
(5) 225-235	1.2735	0.3583	0.2814	0.0841	29.89	37.62	32.49
(5) 245-255	1.1737	0.3934	0.3351	0.0989	29.49	43.25	27.25
(6) 0-10	1.2530	0.1228	0.0980	0.0732	74.68	3.79	21.53
(6) 10-30	1.1983	0.2059	0.1718	0.1005	58.51	4.12	37.36
(6r) 10-30	1.2352	0.1937	0.1568	0.0912	58.15	4.38	37.47
(6) 45-55	1.1431	0.2033	0.1778	0.1223	68.76	3.10	28.14
(6) 65-75	1.0958	0.1377	0.1257	0.0787	62.64	3.38	33.98
(6) 85-95	1.1799	0.1301	0.1103	0.0583	52.87	10.95	36.18
(6) 105-115	1.1737	0.1727	0.1471	0.0571	38.80	24.91	36.29
(6) 125-135	1.2302	0.1801	0.1464	0.0535	36.52	34.68	28.80
(6) 145-155	1.1325	0.1645	0.1452	0.0610	41.98	25.16	32.87
(6) 160-170	1.1228	0.1555	0.1385	0.0629	45.39	24.84	29.77
(6) 185-195	1.1622	0.1617	0.1391	0.0575	41.36	36.60	22.04
(6) 205-215	1.1582	0.1752	0.1513	0.0555	36.73	45.51	17.76
(6) 225-235	1.2975	0.3420	0.2636	0.0779	29.55	39.33	31.12
(6r) 225-235	1.2380	0.3347	0.2704	0.0757	28.01	40.93	31.07
(6) 245-255	1.1298	0.2735	0.2421	0.0913	37.71	36.97	25.33
(6) 265-275	1.1351	0.2402	0.2117	0.0816	38.57	37.75	23.69
(6) 285-295	1.1293	0.1869	0.1655	0.0762	46.03	29.47	24.50

Depth	Wet (g/cc)	Dry (g/cc)	Dry/Wet	Org/Wet	% Organic	% CaCO3	% Inorg.
(1) 0-20	1.1148	0.2278	0.2044	0.1113	54.47	3.25	42.28
(1) 37-57	1.1160	0.1394	0.1249	0.0638	51.08	3.93	44.99
(1) 74-94	1.1213	0.1372	0.1224	0.0645	52.68	9.78	37.54
(2) 0-20	1.1506	0.1217	0.1058	0.0778	73.56	3.15	23.28
(2r) 0-20	1.2181	0.1543	0.1267	0.0835	65.89	4.08	30.03
(2) 40-60	1.1304	0.2093	0.1851	0.1052	56.82	4.19	38.99
(2) 80-99	1.1293	0.1124	0.0995	0.0443	44.48	13.65	41.87
(3) 0-20	0.9913	0.1912	0.1929	0.1275	66.10	2.72	31.18
(3) 35-55	1.1425	0.1258	0.1101	0.0627	56.99	3.92	39.09
(3) 70-88	1.1051	0.1264	0.1144	0.0581	50.81	9.54	39.65
(4) 0-20	1.0810	0.2400	0.2220	0.1444	65.06	3.20	31.74
(4) 35-55	1.1771	0.1408	0.1197	0.0683	57.06	4.86	38.08
(4) 70-90	1.1033	0.1512	0.1371	0.0637	46.45	16.67	36.88
(5) 0-10	1.1483	0.2507	0.2183	0.1244	56.99	3.17	39.84
(5) 10-30	1.1429	0.1727	0.1511	0.0763	50.52	4.44	45.03
(5r) 10-30	1.1352	0.1718	0.1513	0.0767	50.70	4.94	44.36
(5) 45-55	1.1219	0.1243	0.1108	0.0645	58.24	7.49	34.27
(5) 65-75	1.1059	0.1500	0.1356	0.0674	49.72	17.90	32.38
(5) 85-95	1.1483	0.1904	0.1658	0.0689	41.58	25.04	33.37
(5) 105-115	1.2037	0.3407	0.2831	0.0880	31.08	43.18	25.74
(5) 125-135	2.1200	1.7373	0.8195	0.0125	1.53	13.40	85.07
(5) 145-155	1.2220	0.3186	0.2607	0.0780	29.92	23.74	46.35
(5) 185-195	1.1959	0.2292	0.1916	0.1144	59.73	4.06	36.21
(5) 205-215	1.3575	0.4704	0.3465	0.0478	13.78	2.39	83.83
(5) 225-235	2.0936	1.7331	0.8278	0.0056	0.67	2.53	96.80
(5) 245-255	1.9759	1.6394	0.8297	0.0020	0.24	2.91	96.86
(5r) 245-255	1.9099	1.5901	0.8326	0.0021	0.26	2.91	96.83
(6) 0-10	1.2602	0.4005	0.3178	0.1081	34.03	3.69	62.28
(6) 10-30	1.1128	0.1687	0.1516	0.0787	51.93	3.41	44.66
(6) 45-55	1.1061	0.1451	0.1311	0.0710	54.15	5.10	40.75
(6) 65-75	1.1282	0.2808	0.2489	0.0946	38.01	18.24	43.75
(6) 85-92	1.3502	0.5754	0.4262	0.0750	17.59	11.67	70.75
(6) 105-115	1.1595	0.3255	0.2808	0.1020	36.34	26.59	37.06
(6) 125-135	1.8310	1.5327	0.8371	0.0043	0.51	3.91	95.57
(6) 145-155	2.0073	1.7076	0.8507	0.0026	0.31	3.14	96.54
(6) 165-175	1.9500	1.6755	0.8593	0.0030	0.35	4.43	95.22

Appendix D: Phosphorus Fractions & Iron (mg/g dry sediment)

Lake	Core	Top	Base	NaOH-TP	NaOH-SRP	HCl-P	NaOH-ORP	Residual-P	Total-P	Total-Fe
	No.	(cm)	(cm)		(NAI-P)	(Apatite-P)	(Hydr. Org-P)	(Organic-P)		
GL	1	0	10	0.8866	0.4396	0.1564	0.4471	0.4295	1.4725	
GL	1	10	30	0.8048	0.3769	0.1825	0.4280	0.5333	1.5206	
GL	1	105	115	0.2523	0.1307	0.3246	0.1216	0.3859	0.9627	
GL	1	145	155	0.0692	0.0396	0.4225	0.0296	0.2347	0.7264	
GL	2	0	20	0.5976	0.1326	0.0697	0.4650	0.5317	1.1990	
GL	2	40	60	0.5371	0.3871	0.1847	0.1500	0.4920	1.2137	
GL	2	80	92	0.8015	0.6596	0.4436	0.1418	0.3158	1.5609	
GL	3	0	20	0.7342	0.2273	0.1077	0.5069	0.2937	1.1355	
GL	3	40	60	2.4228	2.0319	0.4041	0.3909	0.2968	3.1237	
GL	3	80	97	0.3743	0.3084	0.8572	0.0659	0.4171	1.6486	
GL	4	0	20	0.4991	0.1652	0.1233	0.3339	0.3422	0.9646	
GL	4	33	53	1.4766	1.3282	0.4164	0.1484	0.2496	2.1426	
GL	4	65	85	0.2556	0.2133	0.9178	0.0423	0.2475	1.4209	
GL	5	0	10	0.8089	0.3304	0.2039	0.4785	0.5861	1.5989	7.37
GL	5	10	30	0.3509	0.0982	0.1059	0.2527	0.4690	0.9258	9.44
GL	5	65	75						0.8987	
GL	5	105	115	0.0708	0.0385	0.4157	0.0323	0.2094	0.6959	18.00
GL	5	145	155						0.7047	
GL	5	185	195	0.0612	0.0256	0.3908	0.0356	0.1396	0.5917	12.60
GL	5	225	235	0.0440	0.0185	0.3894	0.0256	0.1907	0.6241	14.81
GL	6	0	10	1.0988	0.5133	0.3895	0.5855	0.5687	2.0570	15.87
GL	6	10	30	0.6020	0.2736	0.2230	0.3284	0.4931	1.3181	14.16
GL	6	65	75						1.0383	
GL	6	105	115	0.0802	0.0406	0.6230	0.0396	0.2100	0.9132	19.60
GL	6	145	155						0.7254	
GL	6	185	195	0.0618	0.0341	0.4113	0.0277	0.1958	0.6689	16.60
GL	6	225	235						0.6184	
GL	6	265	275	0.0614	0.0245	0.4134	0.0369	0.1694	0.6442	12.41
GL	1R	0	10	0.7962	0.3728	0.1960	0.4235	0.5189	1.5112	
GL	3R	0	20	0.6092	0.1909	0.0879	0.4183	0.4506	1.1477	
GL	6R	10	30						1.3855	14.34
GL	6R	225	235						0.8497	
LL	1	0	20	0.1018	0.0269	0.1500	0.0749	0.2524	0.5042	
LL	1	37	57	0.0547	0.0197	0.4241	0.0350	0.3592	0.8380	

Appendix D: Phosphorus Fractions & Iron (mg/g dry sediment)

Lake	Core	Top	Base	NaOH-TP	NaOH-SRP	HCl-P	NaOH-ORP	Residual-P	Total-P	Total-Fe
LL	1	74	94	0.0520	0.0238	0.3703	0.0282	0.3203	0.7426	
LL	2	0	20	0.4177	0.1113	0.1117	0.3064	0.4903	1.0196	
LL	2	40	60	0.1858	0.0474	0.2609	0.1384	0.3747	0.8214	
LL	2	80	99	0.0553	0.0236	0.3573	0.0317	0.2660	0.6786	
LL	3	0	20	0.0807	0.0207	0.0944	0.0601	0.3245	0.4996	
LL	3	35	55	0.0668	0.0209	0.2361	0.0459	0.3547	0.6577	
LL	3	70	88	0.0607	0.0231	0.3370	0.0376	0.3280	0.7257	
LL	4	0	20	0.1634	0.0419	0.0888	0.1215	0.3651	0.6174	
LL	4	35	55	0.1526	0.0261	0.2562	0.1265	0.3073	0.7161	
LL	4	70	90	0.0547	0.0194	0.3162	0.0353	0.2540	0.6250	
LL	5	0	10	0.2925	0.1857	0.3811	0.1068	0.3347	1.0083	11.19
LL	5	10	30	0.0685	0.0207	0.3078	0.0478	0.2248	0.6011	10.86
LL	5	65	75						0.9392	
LL	5	105	115	0.0402	0.0213	0.3287	0.0189	0.1226	0.4915	6.46
LL	5	145	155						0.6048	
LL	5	185	195	0.0314	0.0110	0.1459	0.0204	0.2114	0.3887	7.47
LL	5	225	235	0.0116	0.0044	0.1466	0.0072	0.0085	0.1667	1.92
LL	6	0	10	0.1876	0.0995	0.1716	0.0881	0.0278	0.3870	8.77
LL	6	10	30	0.1208	0.0486	0.1746	0.0722	0.3289	0.6243	8.21
LL	6	65	75						0.6062	
LL	6	105	115	0.0388	0.0158	0.3893	0.0230	0.1521	0.5802	8.20
LL	6	145	155	0.0126	0.0040	0.1977	0.0087	0.0420	0.2524	2.04
LL	2R	0	20	0.4268	0.1192	0.1086	0.3076	0.5786	1.1139	
LL	5R	10	30	0.0663	0.0207	0.2482	0.0455	0.3857	0.7002	10.71
RL	1	0	20	0.5344	0.1276	0.0869	0.4068	0.6623	1.2836	
RL	1	36	56	0.2010	0.0547	0.0511	0.1463	0.5526	0.8047	
RL	1	72	92	0.1374	0.0485	0.1572	0.0889	0.4308	0.7253	
RL	2	0	20	0.5495	0.1852	0.0519	0.3643	0.3698	0.9712	
RL	2	40	60	0.2647	0.0667	0.0996	0.1979	0.5803	0.9446	
RL	2	80	100	0.6274	0.4661	0.2890	0.1613	0.7535	1.6700	
RL	3	0	20	0.5105	0.2530	0.2063	0.2575	0.5713	1.2881	
RL	3	39	59	3.9211	3.1936	0.7404	0.7275	0.3000	4.9614	
RL	3	78	98	0.6238	0.5248	0.6001	0.0990	0.3634	1.5873	
RL	4	0	20	0.4101	0.0686	0.0579	0.3415	0.5572	1.0252	
RL	4	37	57	0.1631	0.0468	0.1047	0.1163	0.5667	0.8345	

Appendix D: Phosphorus Fractions & Iron (mg/g dry sediment)

Lake	Core	Top	Base	NaOH-TP	NaOH-SRP	HCl-P	NaOH-ORP	Residual-P	Total-P	Total-Fe
RL	4	74	94	0.1152	0.0436	0.3039	0.0716	0.3604	0.7795	
RL	5	0	10	1.4505	0.9719	0.8861	0.4786	0.5315	2.8681	22.70
RL	5	10	30	0.2786	0.0946	0.1054	0.1840	0.4519	0.8359	9.57
RL	5	45	55						1.3666	
RL	5	65	75						1.0534	
RL	5	105	115	0.0823	0.0352	0.3958	0.0471	0.3636	0.8417	12.25
RL	5	145	155						0.6160	
RL	5	185	195	0.0510	0.0234	0.4456	0.0276	0.0949	0.5916	9.68
RL	5	225	235						0.7408	
RL	5	265	275	0.0457	0.0239	0.4648	0.0219	0.1784	0.6889	18.50
RL	6	0	10	1.1226	0.6582	0.3768	0.4644	0.7760	2.2753	20.60
RL	6	10	30	0.7572	0.5375	0.2834	0.2197	0.4287	1.4693	14.93
RL	6	65	75						1.1134	
RL	6	105	115	0.0772	0.0351	0.4241	0.0422	0.2847	0.7860	10.10
RL	6	145	155						0.6623	
RL	6	185	195	0.0483	0.0208	0.3747	0.0275	0.1612	0.5843	8.58
RL	6	225	235						0.5826	
RL	6	265	275	0.0464	0.0261	0.4827	0.0203	0.1024	0.6315	23.70
RL	6	305	315						0.4190	
RL	7	0	10	0.6582	0.2850	0.1628	0.3732	0.3956	1.2166	15.41
RL	7	10	30	0.4031	0.1371	0.1284	0.2660	0.4869	1.0184	9.68
RL	7	65	75						0.8103	
RL	7	105	115	0.0806	0.0358	0.4755	0.0448	0.3108	0.8669	10.26
RL	7	145	155						0.7388	
RL	7	190	200	0.0601	0.0520	0.3877	0.0081	0.1445	0.5923	7.76
RL	7	225	235						0.5903	
RL	7	265	275	0.0566	0.0462	0.3994	0.0103	0.2305	0.6865	10.07
RL	8	0	10	0.6320	0.4687	0.1843	0.1633	0.3938	1.2101	12.96
RL	8	10	30	0.3411	0.2136	0.1217	0.1275	0.4488	0.9116	12.91
RL	8	65	75						1.5207	
RL	8	105	115	0.0646	0.0527	0.4265	0.0119	0.3857	0.8768	11.69
RL	8	145	155						0.6675	
RL	8	180	190	0.0465	0.0469	0.3534	**-0.0005**	0.1879	0.5878	8.46
RL	8	225	235						0.6304	
RL	8	265	275	0.0353	0.0284	0.3496	0.0069	0.2765	0.6614	12.23

Appendix D: Phosphorus Fractions & Iron (mg/g dry sediment)

Lake	Core	Top	Base	NaOH-TP	NaOH-SRP	HCl-P	NaOH-ORP	Residual-P	Total-P	Total-Fe
RL	1R	36	56	0.2068	0.0538	0.0508	0.1531	0.5212	0.7788	
RL	4R	74	94	0.1036	0.0412	0.3543	0.0624	0.2934	0.7514	
RL	5R	185	195						0.8595	
RL	6R	105	115	0.0669	0.0335	0.4276	0.0334	0.3250	0.8195	9.77
RL	6R	305	315						0.4526	
RL	8R	265	275	0.0334	0.0394	0.3815	**-0.0061**	0.1549	0.5697	12.10
SS	1	0	20	0.4329	0.1582	0.1652	0.2747	0.4379	1.0359	
SS	1	40	60	0.1865	0.0381	0.0286	0.1484	0.4058	0.6209	
SS	1	75	92	0.1392	0.0371	0.0213	0.1021	0.3802	0.5407	
SS	2	0	20	0.2939	0.0580	0.0412	0.2360	0.5216	0.8567	
SS	2	40	60	0.1558	0.0398	0.0207	0.1160	0.3832	0.5597	
SS	2	80	100	0.1235	0.0360	0.0247	0.0876	0.3682	0.5164	
SS	3	0	16	0.0579	0.0372	0.1164	0.0207	0.1058	0.2801	
SS	3	40	60	0.1690	0.0388	0.1150	0.1302	0.3114	0.5954	
SS	3	76	95	0.1277	0.0346	0.0183	0.0931	0.4206	0.5666	
SS	4	0	20	0.9178	0.5047	0.2858	0.4131	0.5411	1.7446	
SS	4	30	50	0.5500	0.2508	0.1777	0.2993	0.6832	1.4110	
SS	4	59	79	0.2372	0.0467	0.0644	0.1905	0.5259	0.8275	
SS	5	0	20	0.3124	0.0372	0.0447	0.2753	0.4561	0.8133	
SS	5	53	73	0.1143	0.0092	0.0144	0.1051	0.2496	0.3783	
SS	6	0	20	0.1144	0.0236	0.0146	0.0908	0.2755	0.4046	
SS	6	52	69	0.1372	0.0193	0.0204	0.1179	0.3217	0.4793	
SS	6	75	96	0.1298	0.0273	0.0197	0.1026	0.3915	0.5410	
SS	7	0	20	1.3111	0.9602	0.3507	0.3509	0.4836	2.1454	
SS	7	40	60	4.0284	2.5533	0.7806	1.4751	0.1712	4.9802	
SS	7	80	100	2.0403	1.5962	1.3046	0.4442	0.8063	4.1512	
SS	8	0	20	4.9129	4.1164	1.3742	0.7965	**-0.1655**	6.1216	
SS	8	40	60	0.6959	0.5692	0.8217	0.1267	0.3031	1.8207	
SS	8	80	99	1.7331	1.3810	1.4947	0.3521	0.4129	3.6407	
SS	3R	76	95	0.1292	0.0392	0.0155	0.0900	0.3581	0.5028	
SS	7R	40	60	4.1964	3.0334	0.7914	1.1630	**-0.0047**	4.9831	