THE LIMNOLOGICAL CHARACTERISTICS OF THE BOW, OLDMAN AND SOUTH SASKATCHEWAN RIVERS (1979 - 82)

PART II

THE PRIMARY PRODUCERS

Prepared by:

S.E.D. Charlton
H.R. Hamilton
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Alberta Environment
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EXECUTIVE SUMMARY

The South Saskatchewan River Basin Study was initiated to address public concerns that water quality was deteriorating among the rivers. The Water Quality Control Branch began the study in 1979: its purpose was to define quantitatively the limnological characteristics of the Bow, Oldman and South Saskatchewan Rivers. This report is the second of two. Report I by Cross, Hamilton and Charlton 1986 presents the water chemistry findings. This report II presents an interpretation of the water quality and relates it to primary producer abundance and productivity. The primary producers of the Bow, Oldman and South Saskatchewan Rivers increase and decrease in response to a myriad of physical, chemical and climatological factors.

Standing crops of both macrophytes and algae are highest in the middle reaches of the rivers and downstream of nutrient additions from sewage treatment plants. Their distribution and abundance are primarily controlled by phosphorus, discharge and temperature. Macrophytes are specifically inhibited by river velocities exceeding 0.40 $m \bullet sec^{-1}$ and phosphorus concentrations of less than 0.010 $mg \bullet L^{-1}$. Algae are also limited by these physical and chemical factors; however, they are much more opportunistic than macrophytes and respond very rapidly despite physical disruption of their communities.

This investigation documented the important role of phosphorus as the primary nutrient responsible for eutrophication of the Bow River. Now it remains to be seen whether or not phosphorus reductions in the Bow River will decrease standing crops of macrophytes and algae within the enriched river zones.

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ACKNOWLEDGEMENTS

This study was planned, financed and conducted by the Water Quality Control Branch (W.Q.C.B.) of the Pollution Control Division. We wish to thank R. Leech for his editorial comments and K. Brennan for manuscript word processing. Finally, we wish to thank the residents of southern Alberta who extended assistance on the often difficult days and granted permission for access to sampling sites.

1.0 INTRODUCTION

The physiology of aquatic plants is similar in many respects to that of terrestrial plants. Aquatic plants absorb various nutrients from their surrounding medium and by photosynthesis, release oxygen and various other metabolic by-products into waters. They are the most important primary producers in the food chain and are essential for aquatic ecosystems. When too numerous, aquatic plants become a nuisance: they interfere with recreational activities; they impede the flow of water in irrigation canals and they affect the appearance, taste, odor and suitability of water for human consumption.

Observations throughout the South Saskatchewan River Basin indicated that aquatic plants were most prolific downstream of Calgary (between Calgary and Carseland), while filamentous algae were more abundant in the middle and lower reaches of the Bow, Oldman and South Saskatchewan rivers (Exner 1977).

Nuisance aquatic plants clogged water intakes and outlets to irrigation districts, resulting in an estimated $1,000,000 in direct costs and lost agricultural production during 1976 (Exner 1977). This study was started in 1978/79 in order to assess the factors controlling the distribution and abundance of aquatic plants throughout the basin.

The most intensive aspects of the study on aquatic plants and role of nutrients and physical variables were carried out by us between 1980 and 1983. The specific aquatic plant communities found here include the microscopic algal assemblage found attached to rocks (epilithic), or freely floating (phytoplankton), and the non-vascular, macroscopic assemblages (hydrophytes, submerged macrophytes) found growing attached to the river bottoms.

1.1 Objectives

The specific objectives of the study were to:

1. define species composition and microhabitat preferences of aquatic plants;
2. determine aquatic plant growth patterns according to season and distribution;
3. establish the relationship between aquatic plant growth and ambient river phosphorus concentrations;
4. define the role of various physical factors (i.e. discharge, temperature, light, velocity) as they affect plant growth; and
5. study the relationship between macrophytes and epilithic algae.

This study was coordinated with the report by Cross *et al*. 1986, and major aspects of the field data were gathered at the same time.

2.0 METHODS AND MATERIALS

2.1 Sampling Sites

Detailed examination of seasonal and annual aquatic plant patterns of development was conducted throughout the South Saskatchewan River Basin. Algae were routinely monitored at six sites on the Bow River (1, 2, 5, 6, 13, 7), three sites on the Oldman River (3, 4, 8) and four sites on the South Saskatchewan River (9, 10, 11, 12) (Figure 1). Macrophytes and algae were also monitored at thirteen sites along the Bow River between Calgary and Carseland, a region supporting nuisance level growths of aquatic plants (Figure 2). Surveys were also conducted over the entire basin to assess the characteristics along the courses of the Bow, Oldman and South Saskatchewan rivers (Figure 1).

Although algae and macrophytes are similar with respect to their metabolic processes, they are very different with respect to their morphological characteristics. Therefore, the methods employed to estimate their relative abundances must also differ. For this study, algal biomass was determined by using chlorophyll a and direct counts. Macrophyte biomass was determined by weighing organic material dried at 105°C for 24-48 hours in the manner used by Westlake (1965).

2.2 Aquatic Plant Standing Crops

Epilithic algal biomass was confirmed by direct counts and by chlorophyll a content of the entire community. Individual cell volumes were not calculated because of the inherent errors and

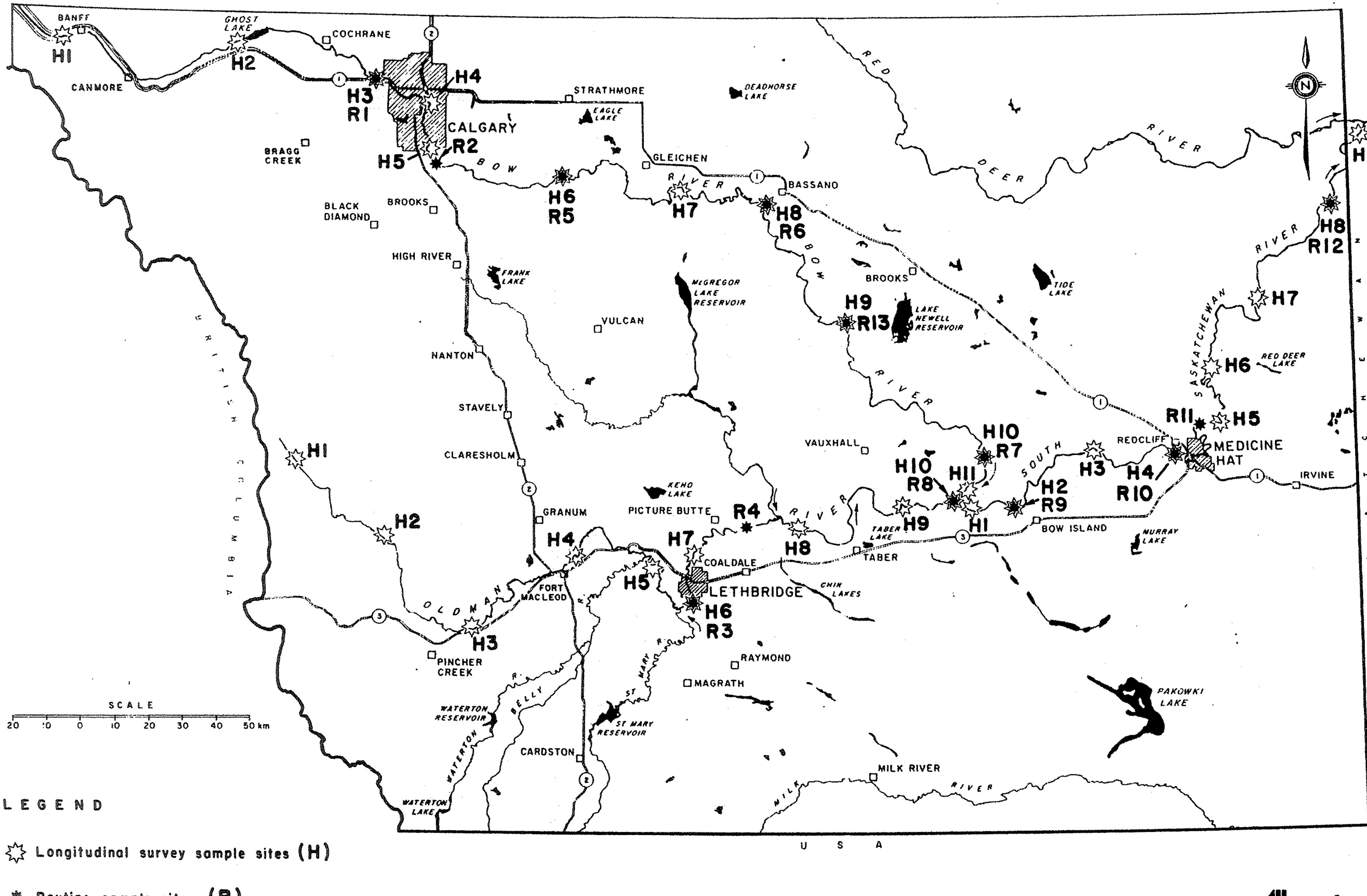

Figure 1. SOUTH SASKATCHEWAN RIVER BASIN

STUDY SAMPLING SITES

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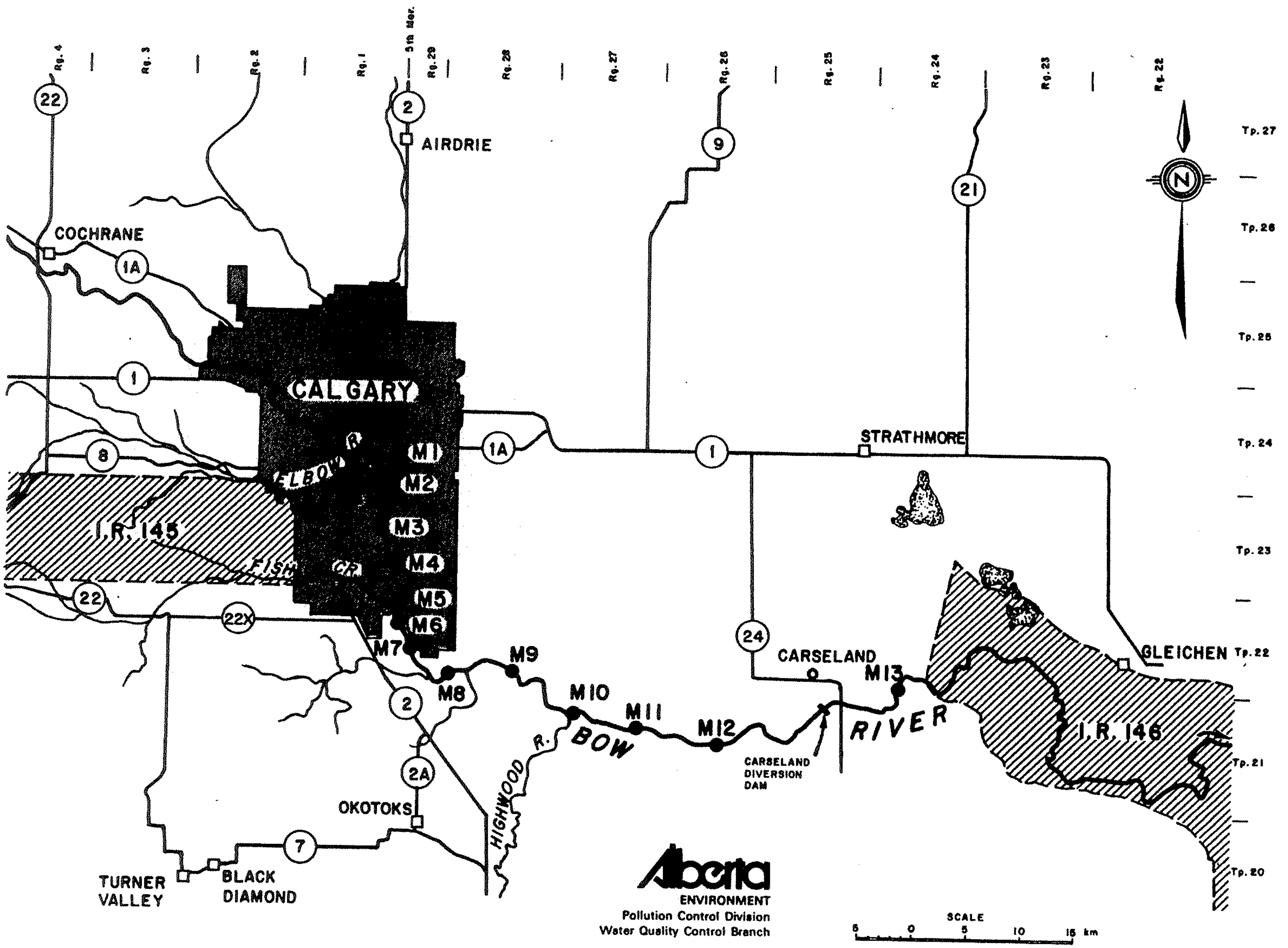

Figure 2. Bonnybrook Study sampling sites.

difficulty associated with defining cell size and shape. Moreover, algal cell sizes frequently vary, not only within species, but also seasonally. Direct counts of cells provide a numerical estimate of population size which is consistent and directly comparable to the literature. Chlorophyll a reflects the quantity of pigment present and therefore, potential for photosynthesis, as it is the pigment directly involved in photosynthesis. The use of this parameter is consistent with the literature.

2.3 Algal Chlorophyll a

Chlorophyll a was utilized as a measure of epilithic standing crop for entire rock surfaces in connection with primary productivity (^{14}C uptake) measurements. Upon termination of the primary productivity incubation period, individual rocks were removed from their incubation chambers and immediately brushed clean to remove the epilithic community. A known volume of slurry (depending upon observed population size) was filtered onto a Whatman GF/C glass fibre filter, covered with anhydrous magnesium carbonate, wrapped in aluminum foil and stored at -4° C until shipped to the University of Alberta, Edmonton, for analysis.

Pigments were extracted into 90% acetone at -4° C for 24 hours in the dark after homogenization, using a Polytron PCU-2-110 homogenizer. The spectrophotometric method and equations of Moss (1967a, 1967b) were used. Normality of the hydrochloric acid did not exceed that recommended by Riemann (1978).

Planktonic algae have also proven to contribute to algal standing crops in lotic systems (Patrick 1961; Swale 1964). Therefore, one litre water samples were collected 15 cm below the water surface as far as possible from the shoreline and also filtered onto glass fibre filters for chlorophyll a determinations.

2.4 Algal Numbers and Species Composition

Algae growing attached to rock (epilithon) were sampled as follows. Duplicate 4 cm^2 areas of substrate were delineated by a template and the area within scraped with a sharp scalpel to remove algae. The community was placed in sterile 30 mL vials, together with 10 mL distilled water and ten drops of Lugol's iodine solution as preservative.

Species composition and algal numbers were determined using the inverted microscope (Biostar A.O.) and sedimentation technique (Lund et al. 1958). Continuous transects were examined under 45x and 100x magnification and the algae identified and counted. A minimum of 200, but more frequently 900-2000, algae were enumerated. To enable diatoms to be identified, subsamples were treated with a mixture of concentrated sulphuric acid, potassium dichromate and hydrogen peroxide to remove organic matter. This was followed by repeated washings in distilled water to remove all traces of acid, slow drying of the cleaned diatom frustules onto coverglasses and mounting in Hyrax. Algae were identified according to Prescott (1961), Patrick and Reimer (1966, 1975), Cleve-Euler (1951-1955) and Hustedt (1930a, 1930b, 1959, 1961-66).

2.5 Macrophyte Standing Crop

Aquatic macrophytes were monitored quantitatively using a quadrat collection technique. Once every two weeks during the period July through mid-September, representative transects from shore to a maximum possible working depth were sampled at right and left bank locations. Quadrats were defined and the plants within the perimeter removed down to a substrate depth of 0.20 m. A net (3 mm mesh) attached to the downstream side of the quadrat was utilized to collect dislodged plant material. All material was washed (in situ) to remove twigs, leaves and non-organic matter. Initially, a m^2 quadrat was employed in 1979/80; however, after 1980, the quadrat size was reduced to .093 m^2 (1 ft^2) because of the large volume of organic material present in most quadrats. In the laboratory, the plant material was given a final wash and oven dried at 105° C for 24-48 hours, then weighed to determine biomass. Sample replication was limited during 1980, at the peak biomass period, by the large quantity of material collected and the problem of rapid decay following collection. Therefore, during 1981, samples over 200 grams were also centrifuged (manual, 12:1 gear ratio spinner) for one minute and weighed on a hanging scale, in order to establish a wet to dry weight conversion factor. Specific wet to dry weight ratios were derived by weighing 100 grams (fresh weight samples) which had been dried at 105° C for 24 hours. The average ratio for the Bow River was 7.1:1 (S.D. = 0.85).

During 1981, sample replication was standardized to six quadrats three paces apart along each transect. SCUBA equipment was used to collect samples to a depth of 1.5 m. Water velocity and depth were recorded for the first and last quadrats of each transect. Water chemistry was also determined at each sample site (i.e. Site M left bank and M right bank). During 1982, seasonal biomass was determined at five locations only. Sampling procedures were the same as those already outlined except for the establishment of a benchmark at each site to ensure subsequent sampling at exact points upstream of previous transect areas. Peak biomass was estimated at all sampling sites (M1-M13) during early September, 1982. During 1983, the same procedures were employed at three sites (M3R, M4R, M6L) to monitor seasonal growth. Peak biomass was estimated for all thirteen sampling locations during September.

2.6 Physical Factors

River velocity was measured at 0.20, 0.60 and 0.80 metre depths, using a Teledyne Gurley Flow Meter. Insolation (surface, subsurface, bottom) was measured with a Protomatic light meter. Bow River discharge data were provided by Water Survey of Canada.

2.7 Algal Primary Productivity (Temporal)

Epilithic and planktonic productivity were measured using the ^{14}C technique. Individual rocks, together with their attached epilithic algae were transferred to 600 mL glass jars and inoculated with 10 μci $NaH^{14}CO_3$, then filled to the top with river water. This procedure limited an air space which has proven to affect ^{14}C availability

(Ilmavirta and Jones 1977). Duplicate dark jars and 12 to 15 light jars were incubated during each sample date. Jars containing only river water and ^{14}C were also incubated to estimate planktonic productivity. All experiments commenced at 10:00 hours and were terminated at 14:00 hours, Mountain Standard Time. At the end of the incubation period the algae were removed from the rocks as described earlier. Subsamples were taken for chlorophyll a analysis before the remaining slurry was preserved with buffered formalin. Each rock was also labelled and retained for surface area determination. Rock surface measurements were done with a planimeter.

Hydrochloric acid was used to acidify 20 mL subsamples of epilithic slurry to pH 2.0. These were then aerated for 30 minutes to remove unincorporated inorganic carbon-14 (Schindler et al. 1972). After aeration, 2 mL subsamples were placed in Aquasol fluor and the incorporated carbon-14 determined, using a Nuclear Chicago Scintillation counter, Model 6800. Corrections for quenching were made. Algal primary productivity was monitored throughout 1980 and 1981 in the South Saskatchewan River Basin.

2.8 Diurnal Epilithic Productivity

The diurnal pattern of ^{14}C uptake was investigated at Site 5 during October 15 and 16, 1981, in order to quantify productivity occurring prior to and following the 10:00 to 14:00 hour routine estimate of ^{14}C uptake. The procedure employed was identical to that already described except that a series of overlapping incubations were performed throughout the twenty-four hour period.

2.9 River Course Surveys

Routine investigation of aquatic plant communities throughout the basin was subject to temporal variation because of the time required for travel between sites. In order to overcome this variation, river course (one day) surveys were conducted by helicopter during early July, 1980/81 and early September, 1980/81, on each of the three rivers. At each of ten sites per river, physical, chemical and biotic samples were collected. Throughout the surveys, macrophyte observations were noted for ground-truthing that followed the helicopter survey. Sample collection and analysis are the same as those outlined already with the exception of epilithon which was derived by collection of five duplicate 4 cm^2 scrapes. Table 1 is a list of parameters determined for each site during the survey.

2.10 Three Site Study

In addition to those studies already described, there was a need to define the biotic and chemical differences between the Bow, Oldman and South Saskatchewan Rivers for an area subject to similar physical and climatological conditions. The confluence of the Oldman and Bow Rivers and the South Saskatchewan River immediately downstream provided a unique location where differences in the biotic and chemical regime are indeed a product of factors other than climate and physical geography (49° 51' 02" N, 111° 41' 48" W). Therefore, during September 30, 1980, primary production, algal standing crop and the physicochemical characteristics of the three rivers were compared quantitatively.

TABLE 1 Parameters determined at each river course survey site

PHYSICAL	CHEMICAL	ALGAL
Depth	pH	Standing Crop
Temperature	Total Alkalinity	Chlorophyll a
Site Description	Turbidity (JTU)	Epilithion
Conductance	DP (dissolved phosphorus)	Phytoplankton
Dissolved Oxygen	OP (ortho phosphorus)	
	DN (dissolved nitrogen)	
	NFR (non-filterable residue)	
	Si (silica)	
	DOC (dissolved organic carbon)	
	DIC (dissolved inorganic carbon)	
	NFFR (fixed non-filterable residue)	
	TP (total phosphorus)	
	TN (total nitrogen)	
	POC (particulate organic carbon)	
	Chloride	

3.0 RESULTS

3.1 Temporal Patterns (Epilithic Algal Numbers, Species Dominants and Percent Composition

3.1.1 The Bow River

Cyanophycean algae were numerically dominant throughout the Bow River, followed by diatoms and green algae during 1980/81. Algal numbers were lowest above Calgary (Site 1) and higher downstream of Calgary (Sites 2, 5, 13) (Figure 3). Cell numbers ranged from 8 x 10^8 cells $\cdot m^{-2}$ at Site 1 (winter, 1980) to 165 x 10^9 cells$\cdot m^{-2}$ at Site 13 (fall, 1980). Table 2 indicates the dominant algal species found for all sites sampled throughout the basin.

Upstream of Calgary (Site 1), algal numbers fluctuated little except from March through to July, 1981. At that time diatoms and blue-green algae were dominant. Diatoms were relatively more abundant at Site 2 and 13 downstream of Calgary than at any other study sites on the Bow River; annual patterns consistently reflected the occurrence of early fall peaks in addition to spring/summer peaks at Sites 2 and 13. Cyanophycean algal numbers fluctuated little annually (Figure 3) except at Site 1 during early 1981 and Site 13 during July/August, 1981. Green algae (Chlorophyta) and diatoms were also relatively more important numerically at Sites 2 and 13.

3.1.2 The Oldman River

The epilithic algal community of the Oldman River was also dominated by blue-green algae and diatoms (Figure 4). They ranged in

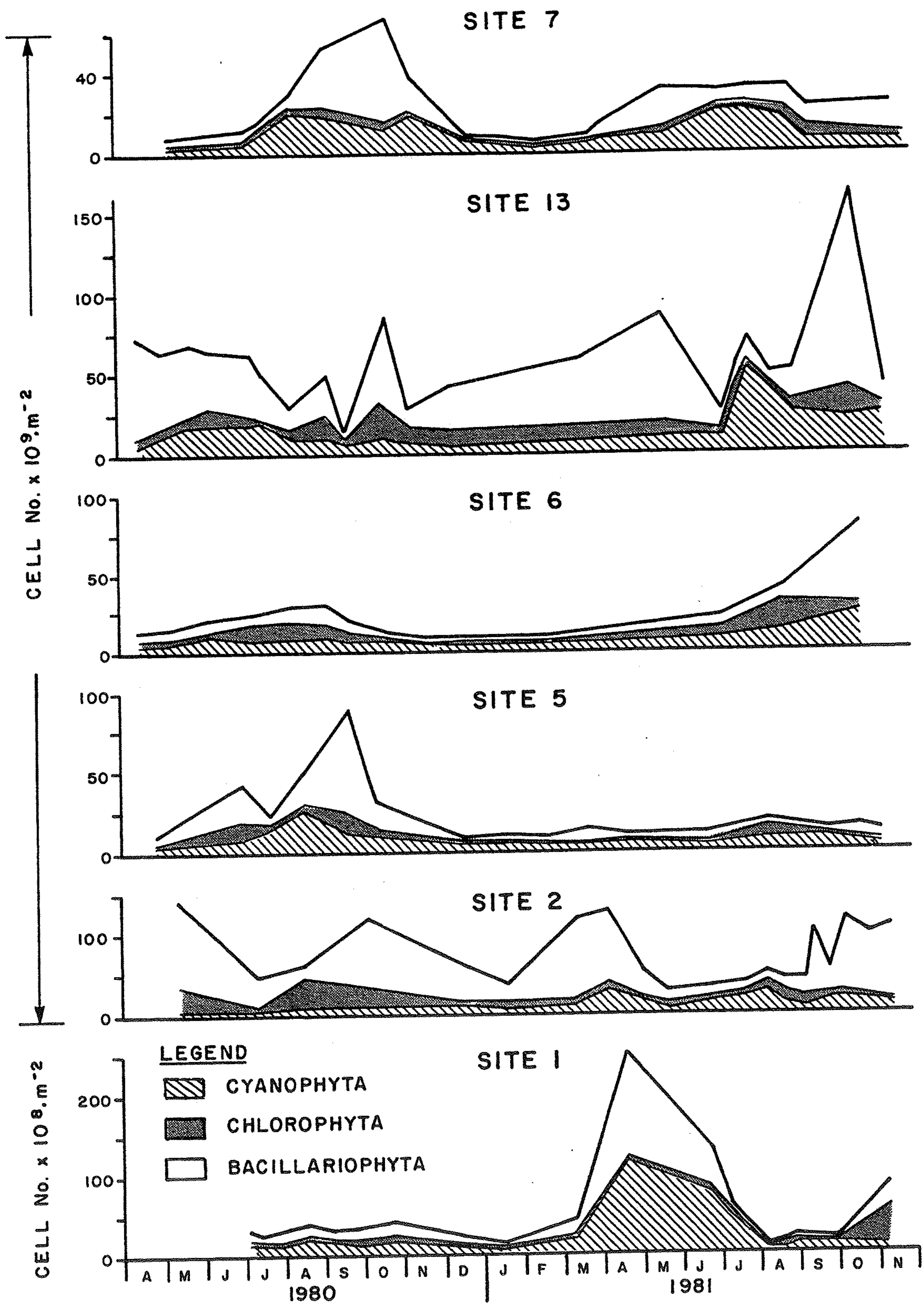

Figure 3. Epilithic algal cell numbers and relative percent composition for the dominant algal divisions occurring in the Bow River (1980/81).

SPECIES	Bow						Oldman			SSR			
	1	2	5	6	13	7	3	4	8	9	10	11	12
Chlorophyta													
Chlamydomonas ehrenbergii			■										
Cladophora glomerate (L.) Kütz			▼ ■	▼ ■	▼ ■	▼	▼ ■	▼ ■	▼	▼ ■	▼ ■	▼ ■	▼ ■
Geminella mutabiilis (de Breb) Wille		▼											
Pithophora varia Wille	▼							▼		▼	▼ ■	▼ ■	▼
oedognoia (Mont) Wittrock							■	■					
Stigeoclonium namum Kütz	▼ ■	■	▼ ■	▼ ■	▼					▼ ■			▼ ■
lubricum (Dillw.) Kütz					▼								
S. Pachydermum Prescott	■	▼ ■		▼		▼ ■							
S. Subsecundum Kütz	■												
Schizomeris Leibleinii Kütz		▼							■				
Scenedesmus quadricauda (Turp) de Breb				▼ ■	■		▼ ■		▼		▼ ■		
Ulothrix cylindricum Prescott	■												
zonata (Weber & Mohr) Kütz		▼ ■			▼ ■		▼	▼ ■	▼			▼ ■	
aequalis Kütz		▼						▼					
subtlissima Rabenhorst			▼		■								
variablis Kütz									■				

TABLE 2. DOMINANT EPLITHIC SPECIES FOR THE SOUTH SASKATCHEWAN RIVER BASIN 1980/81.

	Bow						Oldman			SSR			
	1	2	5	6	13	7	3	4	8	9	10	11	12
Cyanophyta													
Gleocapsa aeruginosa (Carm.) Kutz	▼												
Phormidium autumnale (As.)Gomont	▼ ■								▼				
tenue (Menegh) Gomont	■	▼ ■	▼ ■	▼ ■	■	▼ ■	▼ ■	▼ ■	■	▼ ■	▼ ■	▼ ■	▼ ■
musicola	■	■	■	▼ ■	▼ ■					▼ ■			
favosum (Bory) Gomont				■									
ambiguum Gomont			▼		▼	▼ ■					■	■	▼ ■
Microcystis aeruginosa Kutz emend Elenkin		▼	■										
Lyngbya-aerugineo-caerula (Kutz) Gomont		▼	▼	▼ ■	▼ ■	▼ ■	▼ ■	▼ ■	▼ ■		■	▼ ■	▼ ■
L. taylorii Drouet & Stickland										▼			
Oscillatoria tenuis C.A. Agardh.		■						▼			▼ ■	▼	▼ ■
tenuis var tergestina (Kutz) Rabenhorst..			▼	▼		▼ ■		▼		■			
Ankistrodesmus falcatus (Corda) Rolff			▼				▼	▼ ■	■	■	■	▼ ■	■
Spirulina laxissima G.S. West			■										
Calothrix brevarticulata West and West							▼ ■	■					
Nostoc commune Vaucher						▼ ■	▼ ■						
Calothrix braunii Bornet and Flahault								▼	■	▼ ■			
epiphytica								■			▼	▼ ■	
Anabaena affinis Lemm.									▼		▼		

▼ Indicates dominant during 1980

■ Indicates dominant during 1981

SPECIES Bacillariophyta	Bow 1	Bow 2	Bow 5	Bow 6	Bow 13	Bow 7	Oldman 3	Oldman 4	Oldman 8	SSR 9	SSR 10	SSR 11	SSR 12
Achnanthes minutissima Kutz			■						▼	▼ ■	■	▼ ■	▼ ■
A. lanceolata Breb			■										
Cyelotella meneghiniana Kutz		■											
Cymbella gracilis (Rabh.) Cl.			■										
C. ventricosa Kutz		▼		■	▼ ■			▼ ■					
Diatoma anceps (Ehr) Grunn.						▼				▼ ■			
D. vulgare Bory	▼												
D. hiemale (Lyngby.) Heiberg	■		▼		■								
Epithemia Sorex Kutz							■	▼ ■	▼ ■				
Fragilaria construens (Ehr) Grun.		▼											
intermedia Grun		■											
Gomphonema olivaceum (Lyngb.) Kutz		▼		▼			▼				▼ ■	■	▼ ■
N. amphibia Grun		▼ ■							▼ ■	■	▼ ■		
N. dissipata (Kutz) Grun			▼							▼			
Nitzchia fonticola Grun	▼			■				▼					
N. holstatica Hust					▼	▼ ■						▼	▼
N. palea (Kutz) W. Sm.		■	▼		▼ ■			■				▼ ■	■
Navicula hungarica Grun	■					■							
N. cryptocephala Kutz		■	▼	▼	■	■	▼ ■	■		▼			
N. viridula Kutz					▼								
Rhicosphenia curvata (Kutz) Grun	■												
Synedra ulna (Nitzsch) Ebr.	■								■	■			
Surirella splendida (Ehr) Kutz			■										
S. ovata Kutz				▼ ■		▼	▼	▼					
Tabellaria fenestrata (Lyngby.) Kutz	▼ ■												

▼ Indicates dominant during 1980

■ Indicates dominant during 1981

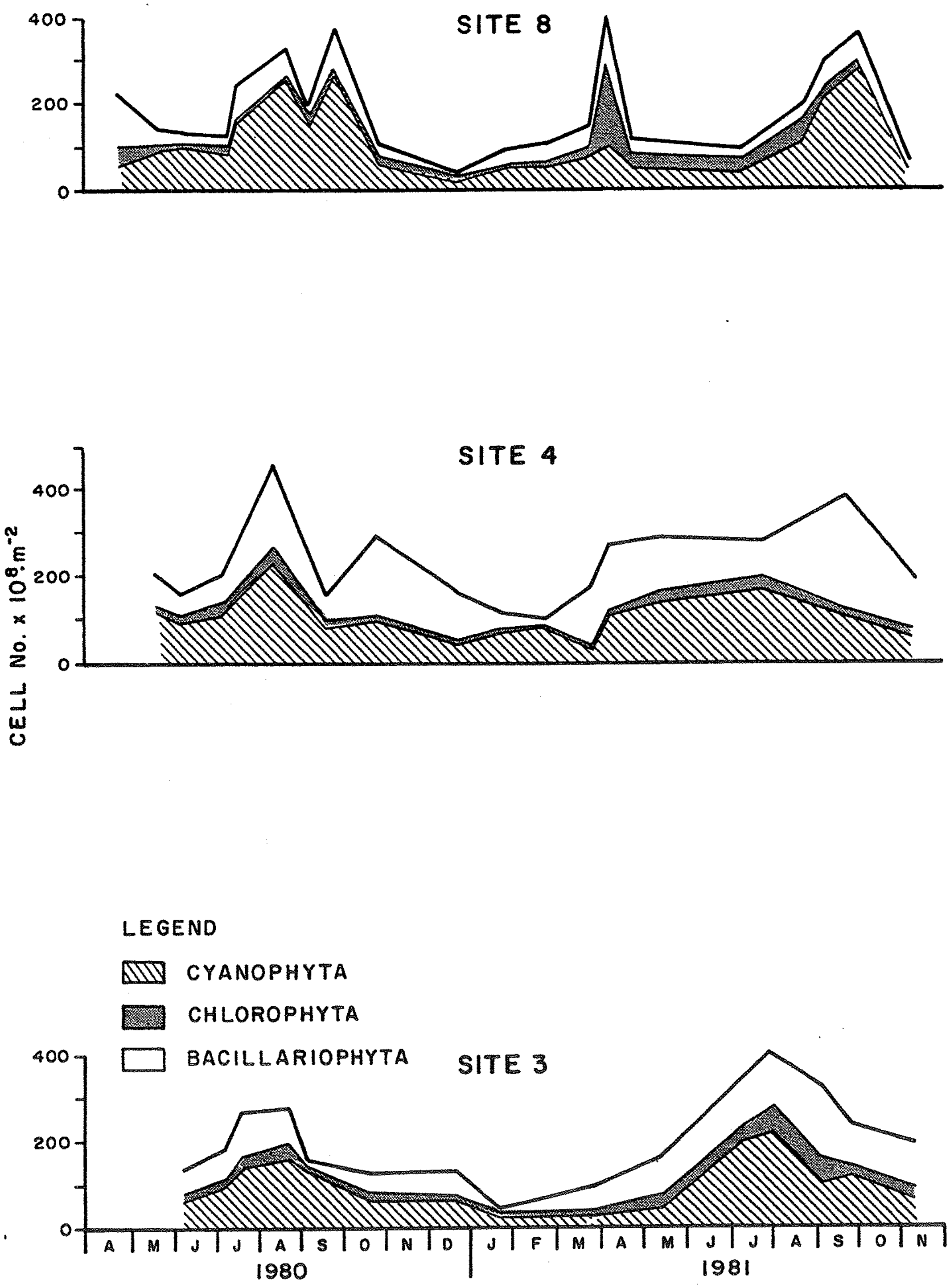

Figure 4. Epilithic algal cell numbers and relative percent composition for the dominant algal divisions occurring in the Oldman River (1980/81).

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numbers from 40 x 10^8 cells•m^{-2} (winter) at Site 3 above Lethbridge to 454 x 10^8 cells•m^{-2} (summer) at Site 4, downstream of Lethbridge. Diatoms were relatively more abundant in the vicinity of Lethbridge, particularly downstream of Lethbridge (Figure 4). Filamentous green algae were found throughout the Oldman River (Table 2) and were relatively more abundant upstream of Lethbridge and at Site 8 near the mouth of the Oldman River. Green algal abundance was higher during the summer of 1981. Cyanophycean algal numbers peaked each year during the summer season (June through early September). Interestingly, *Nostoc commune*, a known nitrogen fixing species, was dominant at Site 3 above Lethbridge.

3.1.3 The South Saskatchewan River

The epilithic algal community of the South Saskatchewan River was also dominated by blue-green algae and diatoms (Figure 5), except at Site 9 where green algae were frequently dominant during 1981. Algal numbers ranged from 70 x 10^8 cells•m^{-2} (winter) at Site 12 to 481 x 10^8 cells•m^{-2} (fall 1981) at Site 9. Epilithic algal numbers generally decreased in a downstream direction. The benthic algal community at Site 9, downstream of the confluence of the Bow and Oldman Rivers was dominated by diatoms during fall and winter (Figure 5). During the early spring/summer period, however, green algae (particularly filamentous forms) were abundant (Table 2).

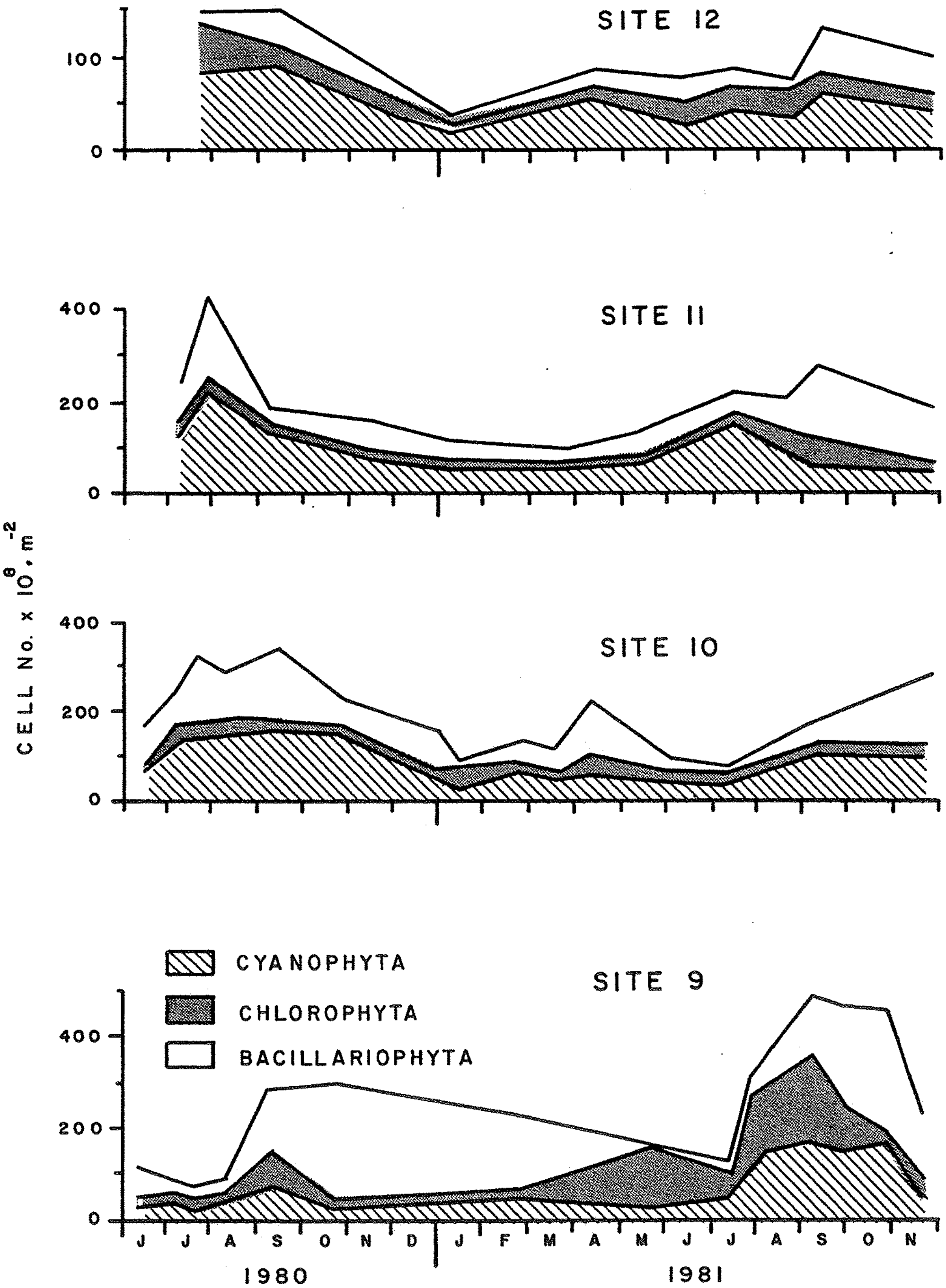

Figure 5. Epilithic algal cell numbers and relative percent composition for the dominant algal divisions occurring in the South Saskatchewan River (1980/81).

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The City of Medicine Hat, located upstream of Site 11, did not appear to influence algal abundance or composition significantly. The relative percent contribution by various algal divisions changed little throughout 1980 and 1981. Planktonic algal contribution to the benthic algal community in the South Saskatchewan River was greater than that observed for either the Bow or the Oldman River. This finding was related to the large slow-flowing nature of the South Saskatchewan River.

3.1.4 Summary

The epilithic algal communities of the South Saskatchewan River Basin are most often numerically dominated by microscopic blue-green algae and diatoms. Diatoms were relatively more abundant downstream of Calgary and Lethbridge. The convergence of the Bow and Oldman Rivers, forming the origin of the South Saskatchewan River at Site 9, supported the largest relative contribution by green algae. Known nitrogen-fixing blue-green algal species were found to occur most frequently in the Oldman and lower Bow River reaches, possibly suggesting a nitrogen-limited lotic environment.

3.2 Temporal Patterns (Epilithic Chlorophyll a)

3.2.1 The Bow River

Epilithic algal chlorophyll a was investigated routinely at thirteen sites throughout the South Saskatchewan River Basin. In the Bow River average standing crops were lowest at Site 1 and high at Sites 2 and 5 located downstream of Calgary. Table 3 illustrates the average benthic algal standing crops for the entire study period by site for the Bow River.

TABLE 3 Seasonal mean and range for benthic algal standing crops in the South Saskatchewan River Basin (1980/81).

LOCATION SITE	mg CHLOROPHYLL $\underline{a}\cdot m^{-2}$ MEAN	RANGE	SEASON HIGHEST	LOWEST
BOW RIVER				
1. Upstream of Calgary	31	11– 42	Sum/80	Spr/80
2. Downstream of Calgary	247	164–439	Fall/80	Sum/80
5. Carseland	296	108–409	Sum/80	Sum/81
6. Downstream of Bassano Dam	127	3–362	Fall/81	Win/80
13. Bow City	69	10–140	Fall/81	Win/80
7. Ronalane Bridge	75	33–114	Sum/80	Win/80
OLDMAN RIVER				
3. Upstream of Lethbridge	47	19– 72	Sum/81	Win/80
4. Downstream of Lethbridge	83	23–165	Sum/80	Win/80
8. Confluence with Bow River	22	13– 40	Fall/81	Win/80
SOUTH SASKATCHEWAN RIVER				
9. Bow Island	36	6– 65	Sum/80	Spr/81
10. Upstream of Medicine Hat	38	16– 67	Sum/80	Sum/81
11. Downstream of Medicine Hat	40	21– 50*	Fall/81	Fall/ Win/80
12. Highway 41	70	9–121	Sum/80	Win/80

* Data absent Spring/80
Spr = Spring - 20 March/19 June
Sum = Summer - 20 June/14 September
Fall = 15 September/01 December
Win = Winter - 02 December/19 March

All available algal standing crop data were used to determine whether or not the abundance of epilithic chlorophyll a was significantly different among sampling stations within each river. Analytical comparisons were derived from unpaired Student's t-tests. Discussion within this report is limited to those sites found to support significantly different epilithic algal biomass.

Epilithic standing crops were significantly lower (P = .01) at Site 1 than at any other Bow River site. Moreover, benthic algal standing crops that ranged from 11 to 42 mg chlorophyll $a \cdot m^{-2}$ (Table 3) did not undergo dramatic seasonal fluctuations as compared with sites located downstream of Calgary (Figure 6).

Epilithic algal standing crops were highest and fluctuated widely at Sites 2, 5 and 6 (Figure 6). Site 2 supported an average 247 mg chlorophyll $a \cdot m^{-2}$ during 1980, the highest values were found during the fall, the lowest in summer. Site 5 supported peak benthic standing crops during the summer (1980) and fall (1981) and averaged 296 mg chlorophyll $a \cdot m^{-2}$. Standing crops at Sites 2 and 5 were not significantly different from each other but were significantly higher (P = .01) than at any other Bow River study site.

Benthic algal standing crops displayed similar trends at Sites 6 and 13 (Figure 6), characterized by a fall maximum and winter minimum. At Site 7, benthic algal standing crops were similarly low during the winter season but highest during the summer seasons and particularly during 1980 (Table 3 and Figure 6).

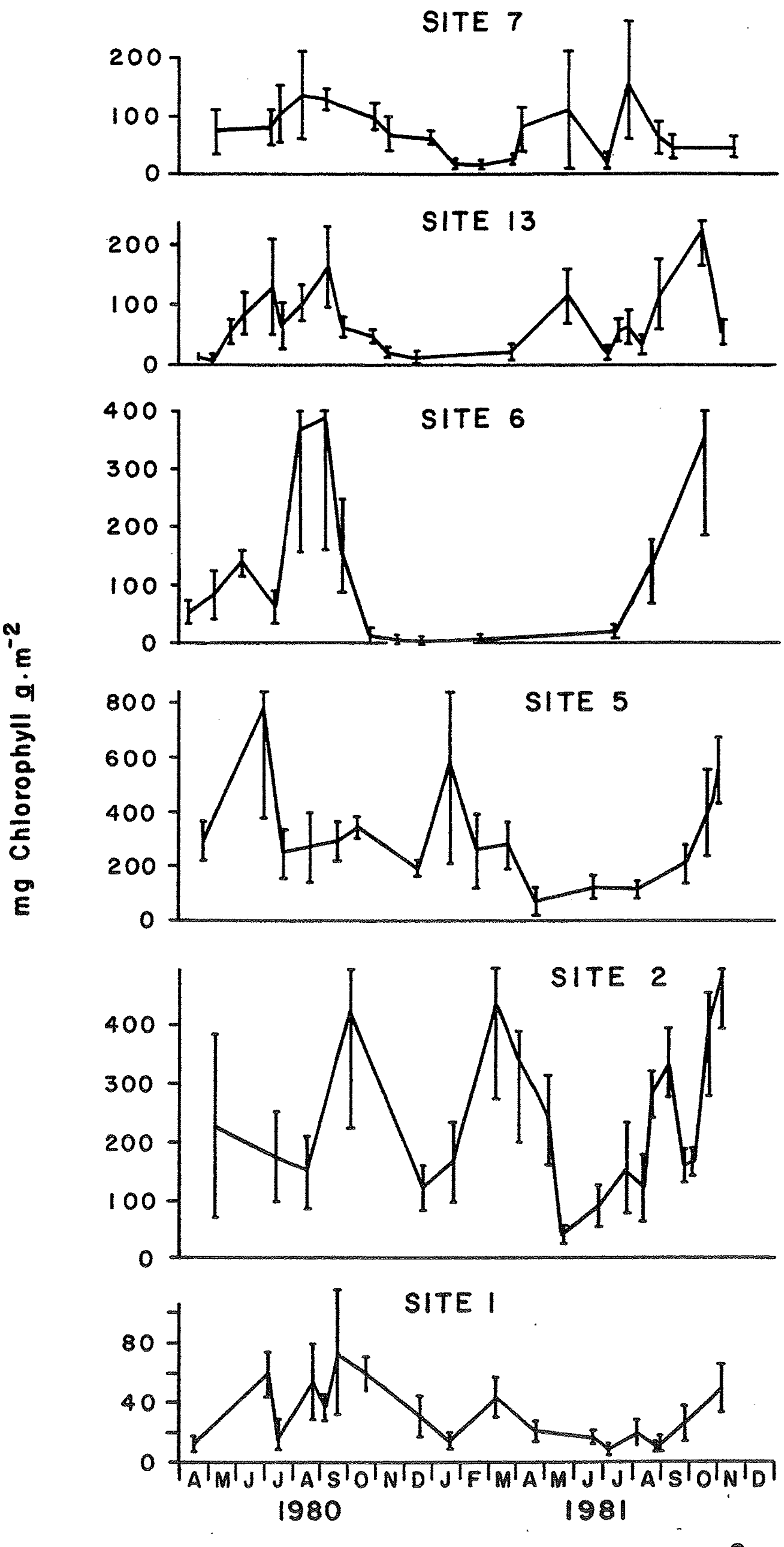

Figure 6 . Mean epilithic algal standing crops (mg Chl $\underline{a} \cdot m^{-2}$) and 95 % confidence limits for the Bow River (1980/81).

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3.2.2 The Oldman River

The seasonality of benthic algal standing crops was compared among three sites on the Oldman River. Table 3 provides mean seasonal chlorophyll a and Figure 7 illustrates the temporal patterns.

Benthic algal standing crops were highest overall in the Oldman River during 1980 reaching 260 mg chlorophyll $a \cdot m^{-2}$ (Figure 7) at Site 4. Moreover, benthic algal standing crops at Site 4 (downstream of Lethbridge) were nearly twice that found to occur at Site 3 (upstream of Lethbridge) when seasonal means were compared (Table 3), but far less than those reported for the Bow River downstream of Calgary. In the Oldman River (sites located near Lethbridge) algal standing crops were consistently highest during the summer and lowest during the winter. Chlorophyll a was also significantly higher at Site 4 ($P = .025$). In the lower reach of the Oldman River, algal standing crops were lowest during the winter and dissimilarly highest during the fall season (Table 3 and Figure 7). Sites 3 upstream of Lethbridge and 8 (lower Oldman River) were not significantly different ($P = .01$) with respect to epilithic standing crops.

3.2.3 The South Saskatchewan River

The seasonality of algal standing crops was compared among four sites on the South Saskatchewan River. Figure 8 and Table 3 present the temporal and seasonal data, respectively.

Maximum algal standing crops were found to occur during the summer at all sites except Site 11 downstream of Medicine Hat where a fall peak was found during 1981. Minimum standing crops occurred

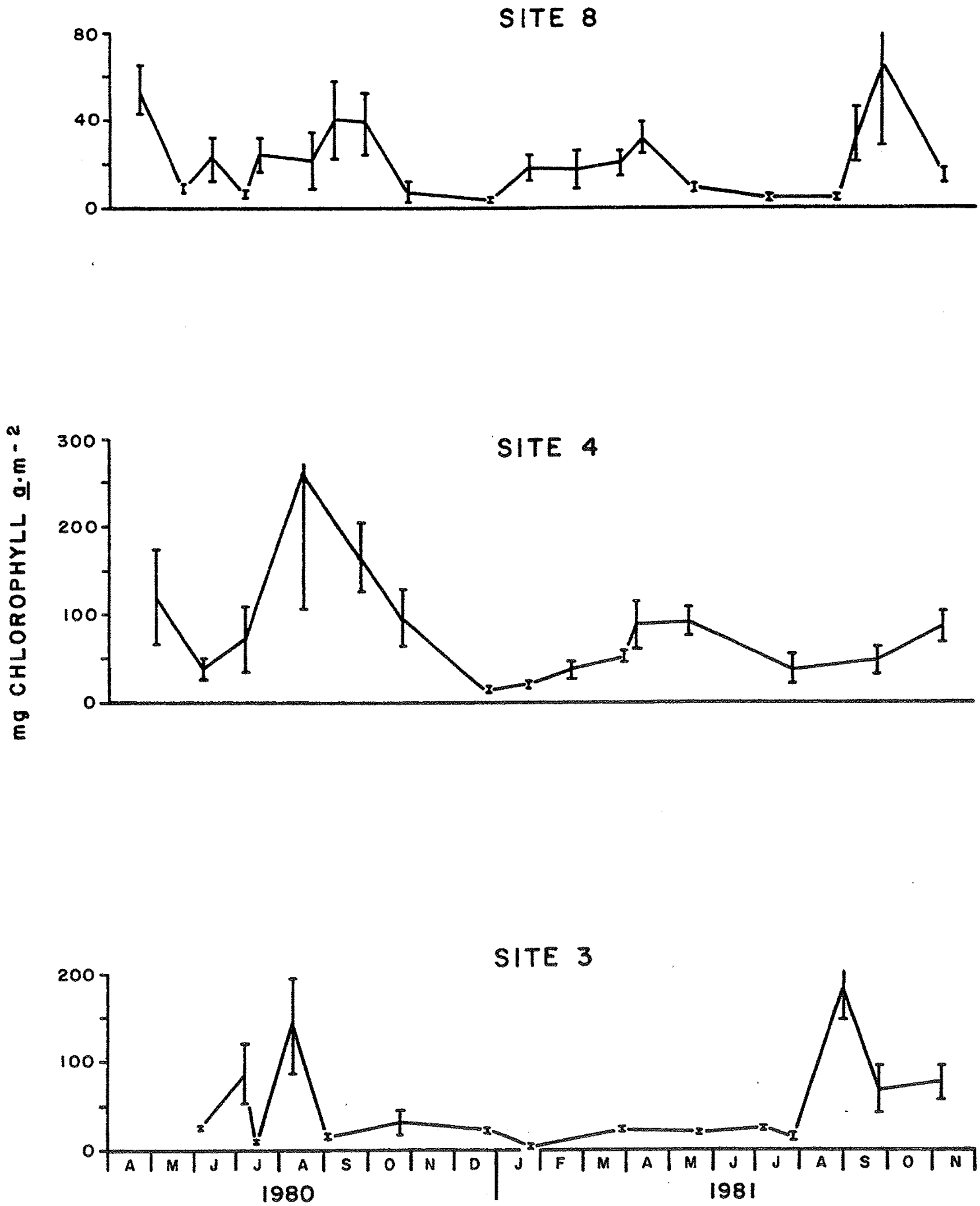

Figure 7. Mean epilithic algal standing crops (mg Chl $g \cdot m^{-2}$) and 95 % confidence limits for the Oldman River (1980/81).

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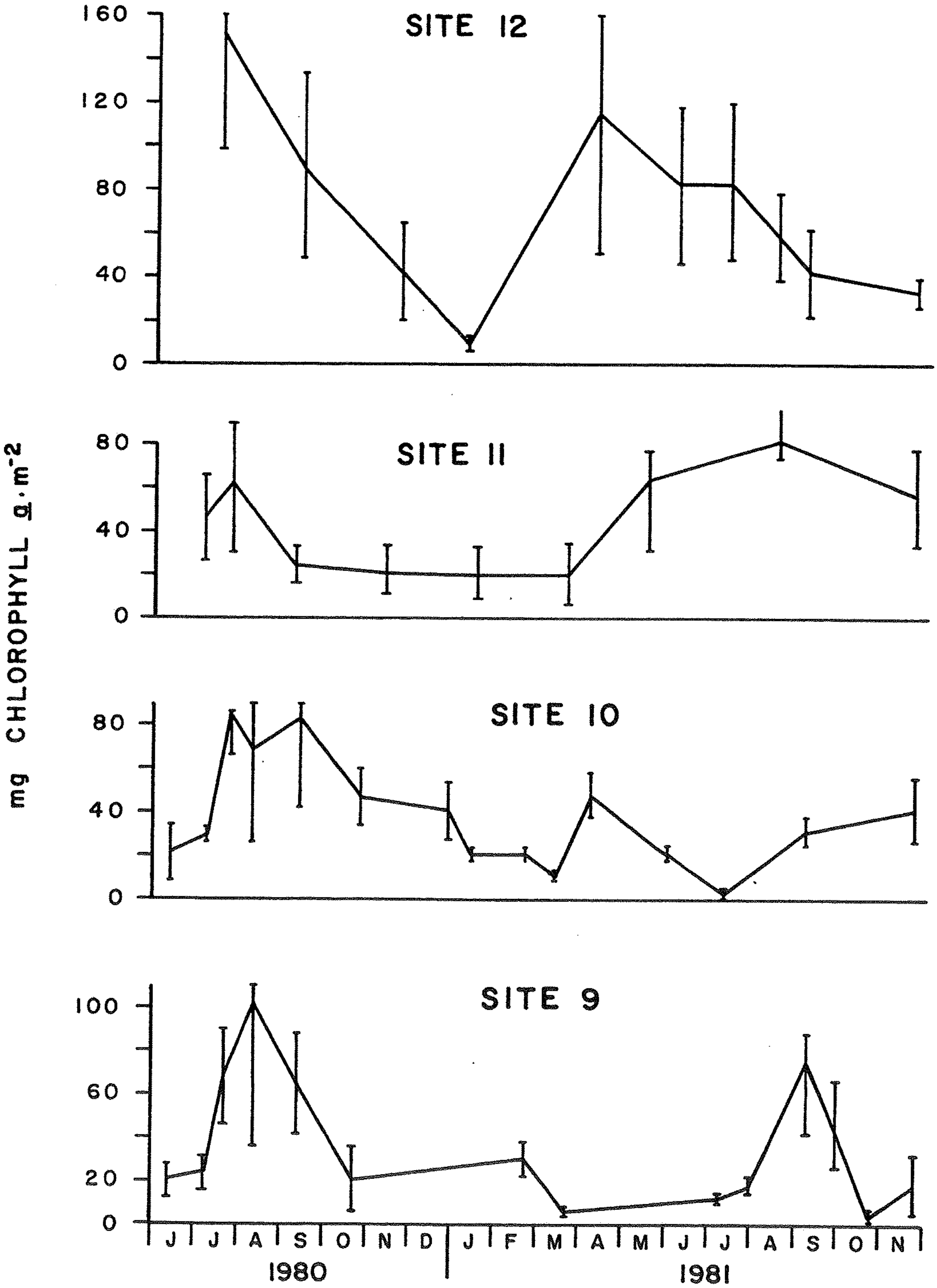

Figure 8. Mean epilithic algal standing crops (mg Chl $g \cdot m^{-2}$) and 95% confidence limits for the South Saskatchewan River (1980/81).

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during the spring/summer 1981 above Medicine Hat, and during the winter below Medicine Hat. The highest recorded standing crop was 152 mg chlorophyll $\underline{a} \bullet m^{-2}$ at Site 12 during July, 1980. Only sites 10 and 12 proved to be significantly different ($P = .05$).

3.3 Temporal Pattern of Primary Productivity

3.3.1 The Bow River

Epilithic algal productivity was monitored routinely in conjunction with estimates of algal standing crop. While there was evidence of higher standing crops during 1980 compared to 1981, the difference with respect to productivity was profound (Figure 9). Uptake of ^{14}C was much lower during 1981. Table 4 presents the mean and range of seasonal production for the Bow River.

Seasonally, ^{14}C uptake ranged from 10 to 78 mg carbon$\bullet m^{-2} \bullet h^{-1}$ at Site 1, with a pronounced maximum during the summer of 1980. Productivity at Site 1 reached 51 mg carbon$\bullet m^{-2} \bullet h^{-1}$ during March, 1981 when a lack of ice cover contributed to the development of an extensive benthic algal community, mainly diatoms and blue-green algae. Statistically significant ($P = .01$) differences were found between Sites 1 and 2 productivity only.

Although primary productivity was monitored at Site 2 during 1980 and winter/early spring 1981, there is evidence to suggest that ^{14}C uptake immediately downstream of Calgary was highest during the fall season; moreover, benthic algae were least productive during summer (Table 4 and Figure 9) when macrophytes were particularly

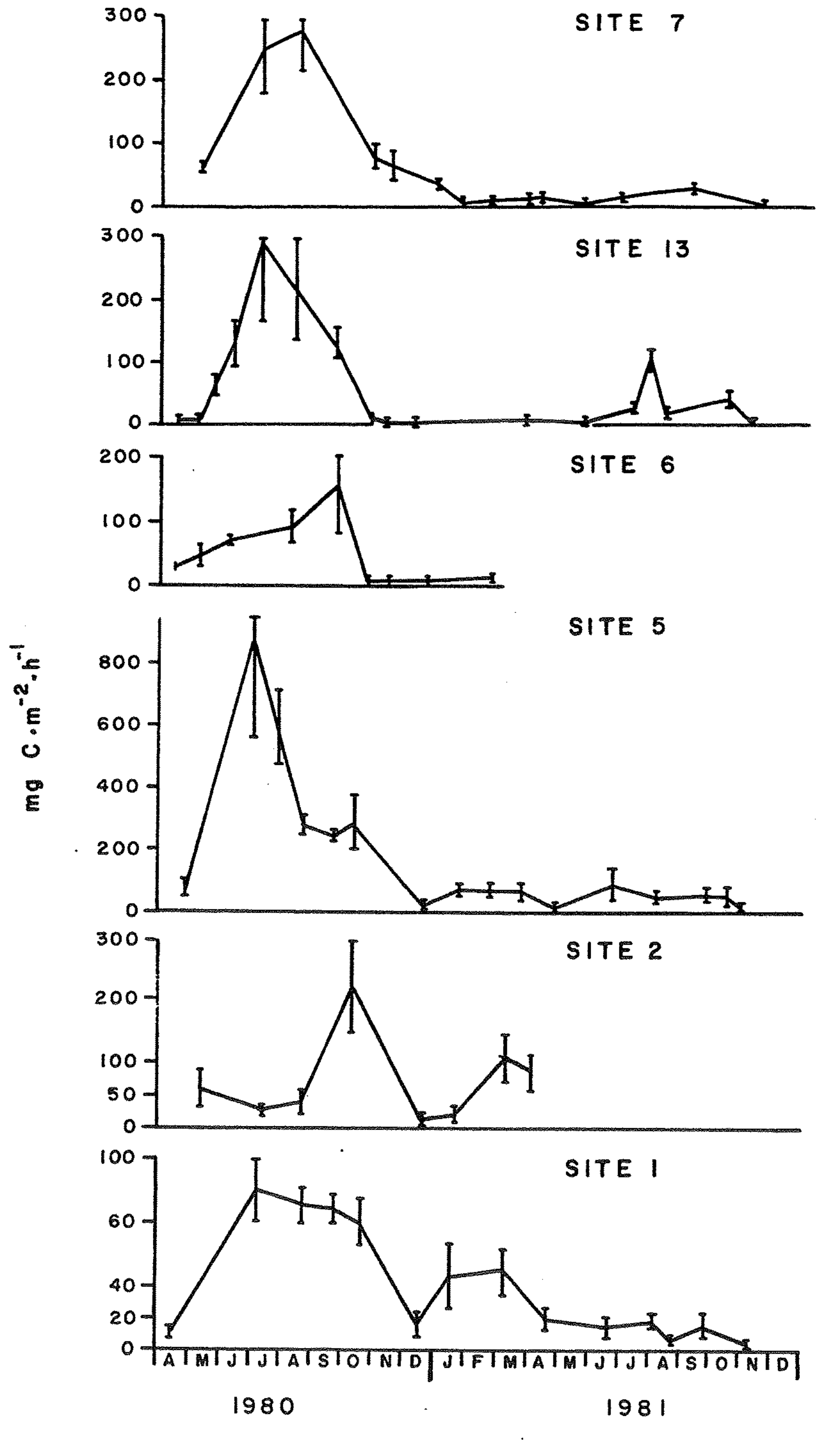

Figure 9. Mean epilithic algal primary productivity (mg Carbon·m^{-2}·h^{-1}) and 95 % confidence limits for the Bow River (1980/81).

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TABLE 4 Mean and range for seasonal benthic primary productivity in the South Saskatchewan River Basin (1980/81)

SITE LOCATION	mg CARBON$\cdot m^{-2} \cdot h^{-1}$ MEAN	RANGE	SEASON HIGHEST	LOWEST
BOW RIVER				
1. Upstream of Calgary	35	10– 78	Sum/80	Fall/81
2. Downstream of Calgary	74	35–228	Fall/80	Sum/80*
5. Carseland	179	38–583	Sum/80	Fall/81
6. Downstream of Bassano Dam	50	5– 92	Sum/80	Win/80*
13. Bow City	63	4–258	Sum/80	Win/80
7. Ronalane Bridge	61	1–266	Sum/80	Fall/81
OLDMAN RIVER				
3. Upstream of Lethbridge	40	1–162	Sum/80	Win/80
4. Downstream of Lethbridge	105	1–394	Sum/80	Fall/81
8. Confluence with Bow	34	1–120	Sum/80	Fall/81
SOUTH SASKATCHEWAN RIVER				
9. Bow Island	83	11–255	Sum/80	Fall/81
10. Upstream of Medicine Hat	57	13–120	Spr/80	Spr/81*
11. Downstream of Medicine Hat	66	57– 81	Sum/80/81	Fall/81*
12. Highway 41	30	12– 41	Sum/81	Win/80*

* Data Incomplete
Spr = Spring – 20 February/19 June
Sum = Summer – 20 June/14 September
Fall – 15 September/1 December
Win = Winter – 2 December/19 March

abundant. Production at Site 5 was highest and ranged seasonally from 38 to 583 mg carbon•m^{-2}•h^{-1} (Table 4). The seasonal pattern of benthic production was similar at Sites 5, 6, 13 and 7. At these sites, ^{14}C uptake was highest during summer and lowest during fall (Sites 5, 7) or winter (Sites 6, 13). The seasonal range of ^{14}C uptake was lowest at Site 6; however, this could be expected to result from the highly variable nature of discharge below the Bassano Dam.

3.3.2 The Oldman River

Productivity was similarly higher in the Oldman River during 1980 than 1981. Table 4 illustrates the seasonal mean and range of benthic algal primary productivity.

Although productivity among the Oldman River sites was not significantly different there was evidence of higher ^{14}C uptake downstream of Lethbridge (Site 4, Figure 10). At Site 4, ^{14}C uptake reached a peak of 421 mg carbon•m^{-2}•h^{-1} during August 15, 1980. The seasonal mean and range of production was also two-fold higher at Site 4 than either Site 3 or Site 8 (Table 4). Similar seasonal patterns evident throughout the Oldman River were characterized by summer maxima, a winter minimum at Site 3 and fall minima at Sites 4 and 8 during 1981.

3.3.3 The South Saskatchewan River

The temporal pattern of benthic algal primary productivity in the South Saskatchewan River is illustrated in Figure 11. Table 4 illustrates the mean and range of seasonal production.

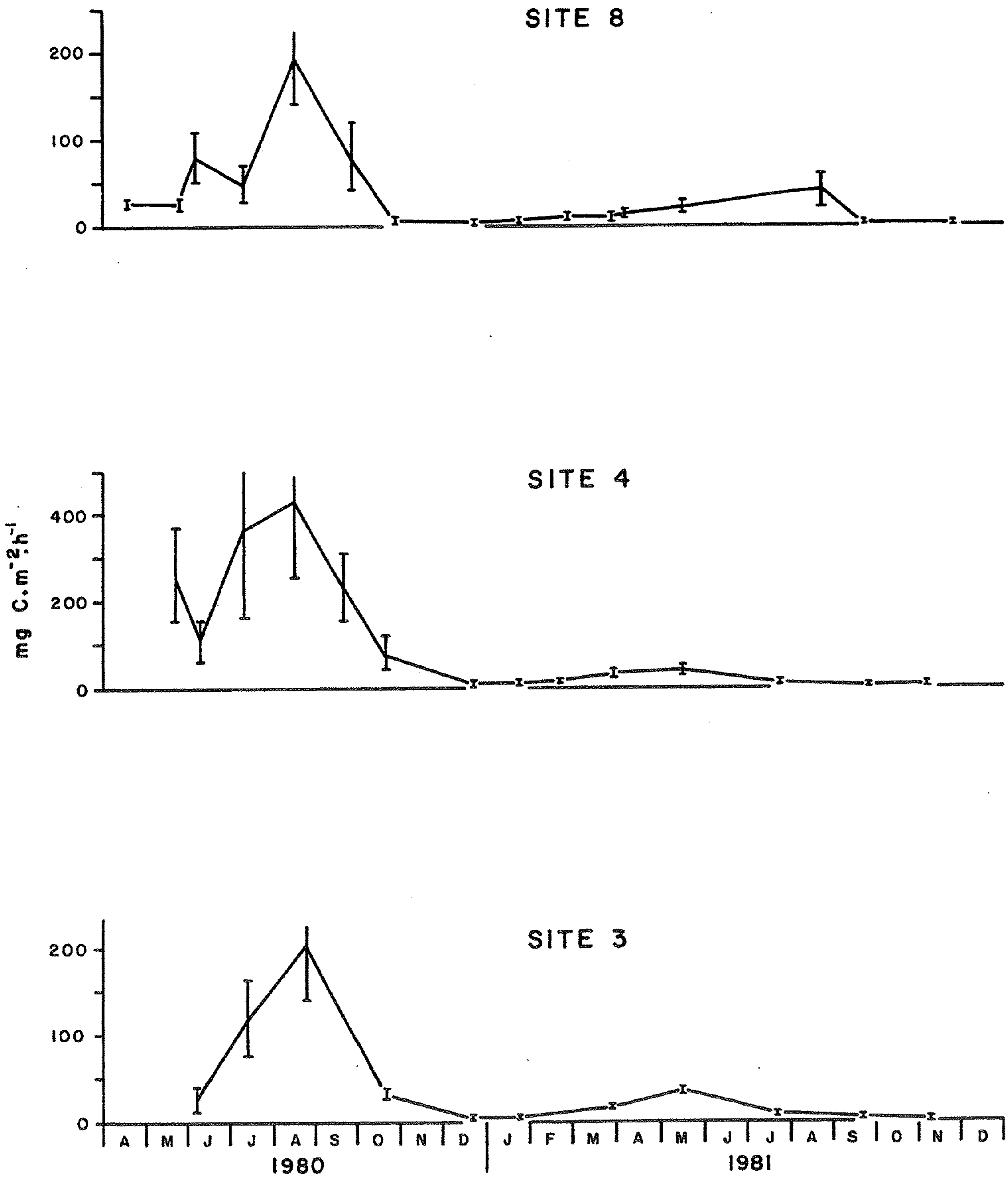

Figure 10. Mean epilithic algal primary productivity (mg Carbon·m^{-2}·h^{-1}) and 95% confidence limits for the Oldman River (1980/81).

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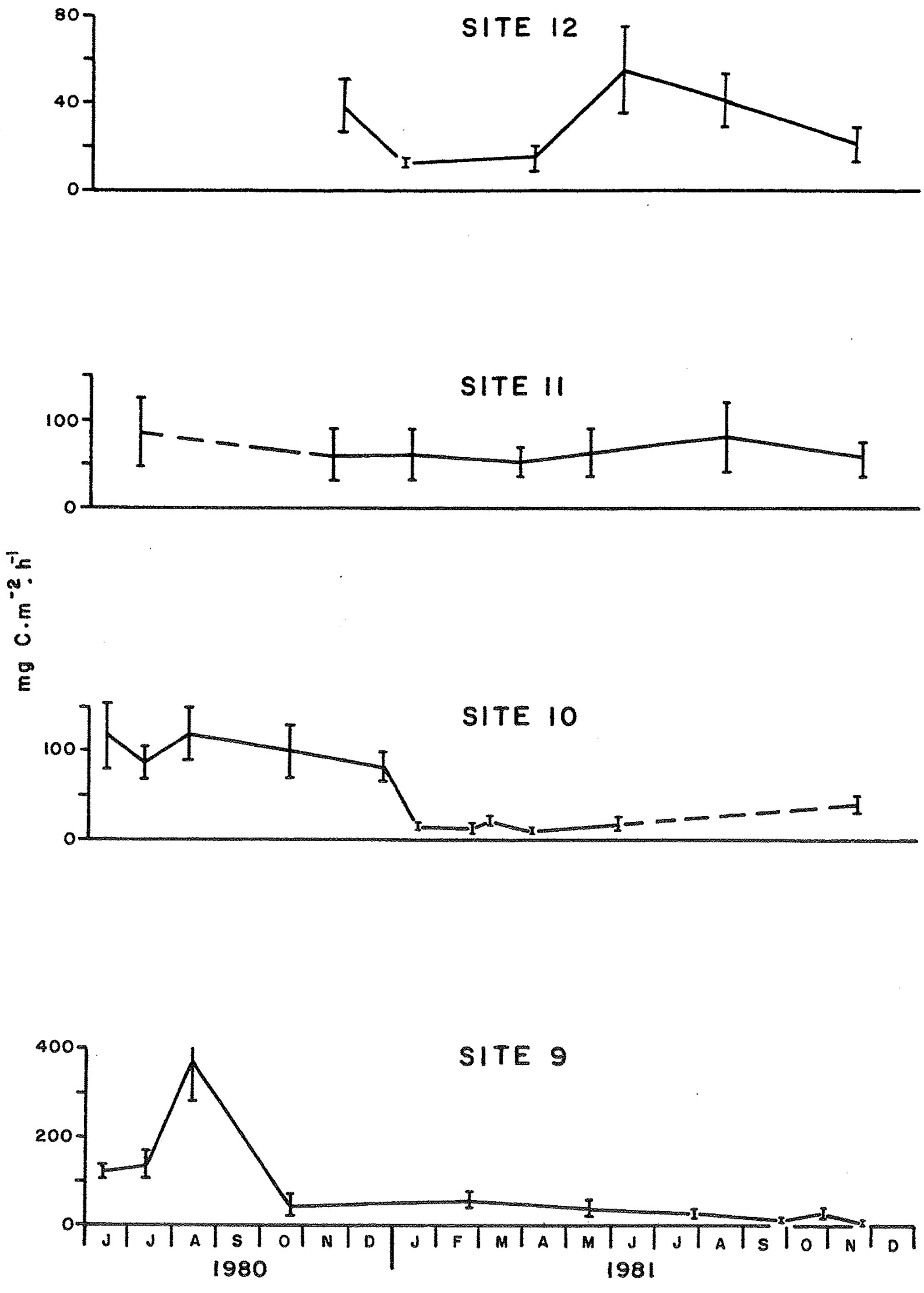

Figure II. Mean epilithic algal primary productivity (mg Carbon · m^{-2} · h^{-1}) and 95% confidence limits for the South Saskatchewan River (1980/81).

Primary productivity averaged highest seasonally at Site 9 and lowest seasonally at Site 12 near the Alberta/Saskatchewan border. Productivity in the South Saskatchewan River was also higher during 1980, as was the case in the Bow and Oldman rivers. Productivity (seasonal) was significantly different (P = .01) between Sites 11 and 12 only. Benthic algal ^{14}C uptake was often higher during the summer in this river except at Site 10 where spring production (1980) was highest (Table 4). The seasons with the lowest productivity included fall at Sites 9 and 11, spring (1981) at Site 10 and winter at Site 12.

3.3.4 Summary

Throughout the study area benthic algal productivity, therefore, proved to be maximum during the summer season in the lower Bow River (Sites 5, 6, 13 and 7) and the entire Oldman and South Saskatchewan rivers except for Site 10 (upstream of Medicine Hat). Productivity was higher throughout the basin during 1980 than it was in 1981. 1981 was a high flow year (Cross et al. 1986). Both benthic productivity and algal standing crops were highest below major urban centres on the Bow and Oldman rivers. These values were particularly high downstream of Calgary. Conversely, in the South Saskatchewan River, epilithic productivity was highest (Site 9) upstream of the only urban centre, Medicine Hat. This site, however, represents the combined effects of the Bow and Oldman river waters.

3.4 River Course Helicopter Surveys

Because data derived from the studies on the Bow, Oldman and South Saskatchewan rivers were derived from information obtained on different sampling dates, the data are not directly comparable. In order to overcome this problem and facilitate comparison of the three rivers, river course surveys were conducted during early and late summer of 1980 and 1981. The entire river length within the study area was sampled during one day for quantification of its physicochemical and biotic characteristics.

3.4.1 The Bow River

During July and September of 1980 and 1981, eleven sites were sampled from the Bow River headwaters to its confluence with the Oldman River. Table 5 provides the location and a description of each site. Site numbers assigned during the river course helicopter survey represent locations that are independent of routine study site locations. Figure 1 illustrates the location of these sites.

The Bow River ranges from swiftly-flowing oligotrophic water at its headwaters in the Rocky Mountains to a eutrophic slow-flowing stream in its middle and lower reaches. Moreover, the Bow River is regulated by a series of inflowing rivers, dams and reservoirs which dampen the impact of spring high waters.

Although river course surveys were conducted in early July following the spring high water, and in late August of each year, similar patterns were observed with respect to physicochemical and algal parameters. Detailed interpretation of the river course physicochemical characteristics of the Bow appear in Cross et al., 1986. Figure 12 illustrates the river course values for algal standing crops, dissolved nitrogen (DN) and dissolved phosphorus (DP) in the Bow River.

TABLE 5. A BRIEF DESCRIPTION OF EACH SAMPLING SITE FOR THE BOW RIVER COURSE SURVEYS BY HELICOPTER.

Bow River - Site #	Brief Description
H1	Latitude 51° 10' 00"N, Longitude 115° 39' 25"W. Located immediately upstream of Banff, Alberta at 4500'(1372m) altitude - river banks range from 0 to 1 metre high, the river is swift and riffled. River substrate ranges from flat stone to cobble,with substantial quantities of sediment visible on the river substrate
H2	Latitude 51° 10' 7"N Longitude 114° 52' 40"W Morley, located at 4000'(1220m) altitude - river banks sloped from a height of 5 metres. Flat stone and sediment covered the rocks for a distance of 2 metres from the shoreline out into the river.
H3	Latitude 51° 06' 20"N Longitude 114° 15' 45"W Between Sites 2 and 3 - the river receives water retained by the Ghost Dam, as well as effluent from settling ponds in the vicinity of Cochrane. Algae and macrophytes contributed 80 to 100% sub-strate coverage in the river (visual) in this area. Site 3, at Bowness, is an island in the middle of the river. River site is bounded by steep banks (north) and retention walls (stone) at Bowness Park. Substrate - cobble to flat stone.
H4	Latitude 51° 02' 30"N Longitude 114° 00' 50"W Downstream of the Elbow tributary - at Fort Calgary - flat stone and cobble substrate noticeable, encrusted with fungi and carbonates. River banks steep to a height of 2 metres.
H5	Latitude 50° 53' 50"N Longitude 114° 00' 12"W At Fish Creek Park - cobble, substrate, aquatic mosses. Fontinalis and algae particularly abundant. River shallow and riffled with steep banks to a height of 1.5 metres.
H6	Latitude 50° 48' 50"N Longitude 113° 43' 45"W Below the influences of the Sheep-Highwood Tributaries- macroalgae particularly abundant over cobble. River banks range from 1 to 15 metres in height, with an extensive flood plain utilized for farming (cattle pasture)
H7	Latitude 50° 47' 30"N Longitude 112° 52' 50"W Cluny - river deepens in this region with increasingly steep banks to a height of 5 metres in some areas. River substrate is predominantly cobble and silty mud in the littoral regions. Water is rapid and riffled.
H8	Latitude 50° 44' 52"N Longitude 112° 31' 27"W Below Bassano Dam - subject to highly variable discharges. Substrate ranges from flat stone to cobble and supports substantial growths of macroalgae. This site is a popular fishing area.
H9	Latitude 50° 25' 55"N Longitude 112° 13' 19"W Bow City Bridge - river shallow and macro-algae abundant. Macrophytes abundant, the site of previous fish kills during mid-summer. Cobble dominates the substrate with substantial deposits of silty mud in the littoral region.
H10	Latitude 50° 02' 39"N Longitude 111° 41' 25"W Ronalane Bridge - shallow, swiftly flowing water over cobble. Macroalgae and drifting plant material frequently observed.
H11	Latitude 49° 56' 04"N Longitude 111° 41' 25"W Confluence - water slow flowing over cobble and flat stone. Silty sediment covering the sub-strate, particularly in the littoral zone. Drifting plant material observed often

*H - helicopter longitudinal survey sites.

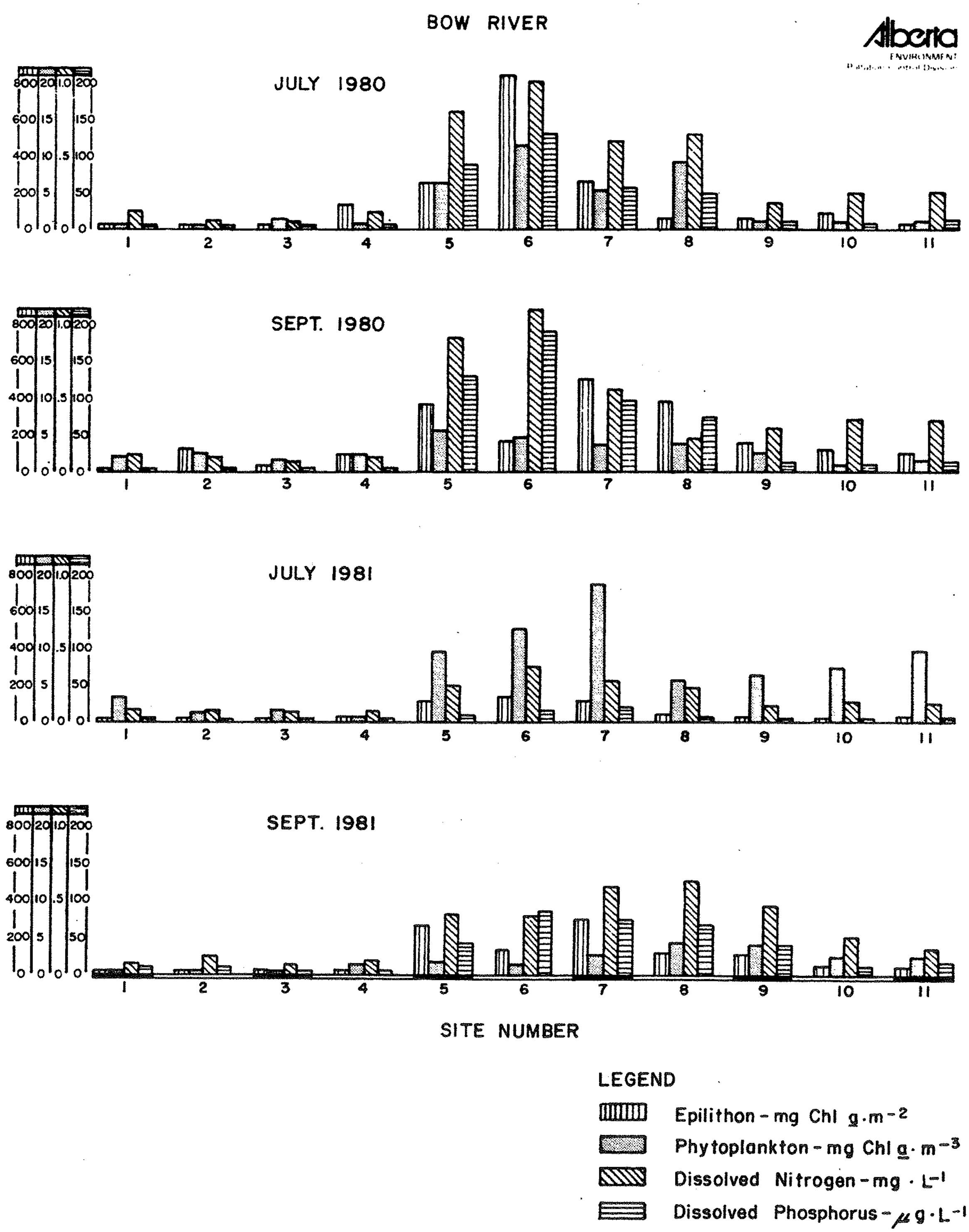

Figure 12. River course variation of algal standing crops, dissolved nitrogen and dissolved phosphorus from the Bow River headwaters (Site 1) to it's confluence with the Oldman River (Site 11).

Algal standing crops (epilithon) were higher during 1980 than 1981 throughout the Bow River; in each year September crops were higher than July crops (Figure 12). The average benthic algal standing crops for the entire river length were 164 mg chlorophyll $\underline{a} \cdot m^{-2}$ (July 1980), 44 mg chlorophyll $\underline{a} \cdot m^{-2}$ (July 1981), 191 mg chlorophyll $\underline{a} \cdot m^{-2}$ (September 1980), and 100 mg chlorophyll $\underline{a} \cdot m^{-2}$ (August 1981). The highest recorded level of epilithic standing crop for the entire Bow River was 833 mg chlorophyll $\underline{a} \cdot m^{-2}$ (July 1980) at Site 6, located below the Highwood River confluence with the Bow. This site frequently supported more algae than any other area of the Bow River. Moreover, the concentrations of essential nutrients (dissolved nitrogen, dissolved phosphorus) were high. During September, 1980, dissolved phosphorus concentrations were 0.190 $mg \cdot L^{-1}$ at Site 6 and dissolved nitrogen values were 1.100 $mg \cdot L^{-1}$. Phytoplankton standing crops were also highest at this site, possibly because of losses from the benthic community.

The river course helicopter survey provided evidence that algal standing crops and nutrients were indeed highest for that reach of the Bow River located between sites downstream of Calgary and Cluny (Site 7). This is the middle reach of the Bow River (Figure 12).

River course one-day surveys of the Bow River provided the unique opportunity for an overview of river conditions devoid of temporal effects. Regression analyses were further employed (SPSS) to define numerically the correlation between algal standing crop and specific nutrients as well as physical variables.

During July and September, 1980, ortho phosphorus accounted for 85% and 35% of the variation in epilithic algal standing crop, respectively (Table 6). During 1981, however, dissolved nitrogen was the primary variable which was highly correlated with benthic algal standing crops. Dissolved nitrogen accounted for 83% and 58% of the variation during July and September, respectively.

Phytoplankton standing crops were highly correlated with nitrate-nitrite nitrogen during July 1980 (r^2 = 93%) and September (r^2 = 70%). However, in 1981, dissolved nitrogen (r^2 = 86%) and silica (r^2 = 63%) were most highly correlated with phytoplankton standing crops.

Both early summer and late summer data from the Bow River river course surveys (1980/81) were combined and subjected to linear regression analysis. This was done in order to define the primary variable most highly correlated with algal standing crops. (The variables are listed in Table 6). Orthophosphorus (OP) was most highly correlated with benthic standing crops, while dissolved inorganic carbon (DIC) in July, and dissolved nitrogen (DN) in August/September, were most highly correlated with phytoplankton. These findings suggest that phosphorus, the principal biotic nutrient, profoundly influences the primary producer standing crop of benthic algae. Phytoplankton (senescent and drifting benthic forms) is less well defined with respect to the relationship between its abundance and nutrients or physical factors.

TABLE 6 Correlations between epilithic and planktonic standing crop (dependent) and various physiochemical variables (independent) for July and August/September river course surveys.

COMMUNITY	EPI July '80	PHY July '80	EPI Sept. '80	PHY Sept. '80	EPI July '81	PHY July '81	EPI Sept. '81	PHY Sept. '81
BOW RIVER								
* Parameter	OP	N	OP	N	DN	DP	DN	Si
Multiple r	.922	.964	.595	.836	.910	.928	.764	.795
(r^2)	85%	93%	35%	70%	83%	86%	58%	63%
OLDMAN RIVER								
* Parameter	pH	Turb	DP	DN	NFR	Si	N	DN
Multiple r	.872	.737	.936	.826	.755	.953	.826	.902
(r^2)	76%	54%	88%	68%	57%	91%	68%	81%
SOUTH SASKATCHEWAN RIVER								
* Parameter	Depth	NFR	NFR	pH	DN	Si	DP	N
Multiple r	.568	.858	.633	.817	.581	.747	.856	.511
(r^2)	32%	74%	40%	67%	34%	56%	75%	26%

COMBINED	EPILITHON BOW	EPILITHON OLDMAN	EPILITHON SSR	PHYTOPLANKTON BOW	PHYTOPLANKTON OLDMAN	PHYTOPLANKTON SSR
(July 1981/82)						
* Parameter	OP	OP	DIC	DIC	Temp	Si
Multiple r	.926	.836	.577	.615	.685	.842
(r^2)	86%	70%	33%	38%	47%	71%
(September 1981/82)						
* Parameter	OP	DP	N	DN	DN	DOC
Multiple r	.634	.729	.599	.775	.832	.728
(r^2)	40%	53%	36%	60%	69%	53%

ALL RIVERS	EPILITHON	PHYTOPLANKTON
(1980)		
* Parameter	DP	DN
Multiple r	.769	.652
(r^2)	59%	43%
(1981)		
* Parameter	DN	NFR
Multiple r	.726	.444
(r^2)	53%	20%

* Parameter most highly correlated with algal standing crop.
EPI = Epilithic, PHY = Planktonic, OP = Orthophosphorus,
N = Nitrate, DN = Dissolved Nitrogen, DP = Dissolved Phosphorus,
NFR = Non-filterable Residue, Si = Silica, DOC = Dissolved
Organic Carbon, DIC = Dissolved Inorganic Carbon

3.4.2 The Oldman River Course Survey

One-day river course surveys were performed on the Oldman River to discern its physicochemical and biotic characteristics during 1980 and 1981. Table 7 presents a general description and the location of each sampling site. The physicochemical characteristics were presented in Cross et al. (1986). Figure 13 illustrates the abundance of algae (epilithic, phytoplankton) as well as nutrients (dissolved nitrogen, dissolved phosphorus).

Algal standing crops for the entire Oldman River length were lower during 1981 than 1980. Moreover, standing crops were lower during July than September for both 1980 and 1981. During 1980, benthic algal standing crop averaged 50 mg chlorophyll $a \cdot m^{-2}$ in July and 150 mg chlorophyll $a \cdot m^{-2}$ in September.

In 1981 benthic algal standing crop averaged 15 mg chlorophyll $a \cdot m^{-2}$ for July and 73 mg chlorophyll $a \cdot m^{-2}$ during early September (Figure 13). Site 7, located downstream of Lethbridge, frequently supported the highest epilithic standing crop and Site 5 supported the lowest. The exception was during July 1980 when Site 1 had the lowest benthic standing crop. Phytoplankton standing crops averaged 2.36 mg chlorophyll $a \cdot m^{-3}$ for all surveys. Standing crops were generally higher within the slow-flowing, deeper reaches of the Oldman River downstream of Site 7.

Linear regression analyses (SPSS) were performed to discern the principal factor most highly correlated with algal standing crops (Table 6). In the Oldman River, pH and dissolved phosphorus were highly correlated with epilithic standing crop during 1980. In 1981 weaker correlations were observed between epilithic standing crop

TABLE 7. DESCRIPTION AND LOCATION OF OLDMAN RIVER COURSE HELICOPTER SURVEY SITES.

OLDMAN RIVER - SITE #	BRIEF DESCRIPTION
H1 -	Latitude 50° 00' 00"N Longitude 114° 31' 15"W East of Mount Tyndall - river rapid and riffled. Algae sparse during July, more abundant during late summer. No evidence of macrophytes. River banks various, with substantial amounts of conifers adjacent to the river. This site is relatively unaffected by human activities.
H2 -	Latitude 49° 47' 50"N Longitude 114° 09' 30"W Below Callum Creek - river rapid over cobble and boulder substrate. Macroalgae abundant, particularly <u>Nostoc sp.</u> River banks steep and subject to slumping - height of 30 metres.
H3 -	Latitude 49° 33' 30"N Longitude 113° 09' 45"W Brocket - steep banks up to 30 metres high, slumping evident. Sand banks and cobble substrate contribute to increasing suspended sediment load in the river. Evidence of cattle farming river use and water removal for irrigation purposes.
H4 -	Latitude 49° 46' 42"N Longitude 113° 19' 40"W Pearce, downstream of Willow Creek - river is shallow over cobble and shore stone. Macroalgae noted downstream of Fort Macleod, perhaps caused by domestic influence.
H5 -	Latitude 49° 45' 50"N Longitude 113° 01' 15"W Coalhurst - Kipp area - cobble substrate covered by sediment. Some evidence of disturbance caused by gravel operations in the vicinity of the river.
H6 -	Latitude 49° 38' 5"N Longitude 112° 51' 55"W Above Lethbridge - river shallow, riffled over cobble and flatstone. River banks steep and subject to slumping.
H7 -	Latitude 49° 47' 03"N Longitude 112° 49' 58"W Diamond City, downstream of Lethbridge, extensive macroalgal development on cobble and flat stone, in the midstream only.
H8 -	Latitude 49° 51' 55"N Longitude 112° 26' 30"W Downstream of Little Bow River - river banks are various from vertical to 4 metres on north bank. Macroalgae patchy over cobble.
H9 -	Latitude 49° 55' 25"N Longitude 112° 57' 05"W Located due north of Purple Springs - the river banks in this area very steep to 50 metres. The river swift over cobble. Macroalgae patchy.
H10 -	Latitude 49° 56' 02"N Longitude 111° 41' 48"W Confluence - water slow flowing, high in suspended sediment. Cobble substrate covered by silty mud. Drifting macroalgae observed.

* H denotes longitudinal helicopter survey sites

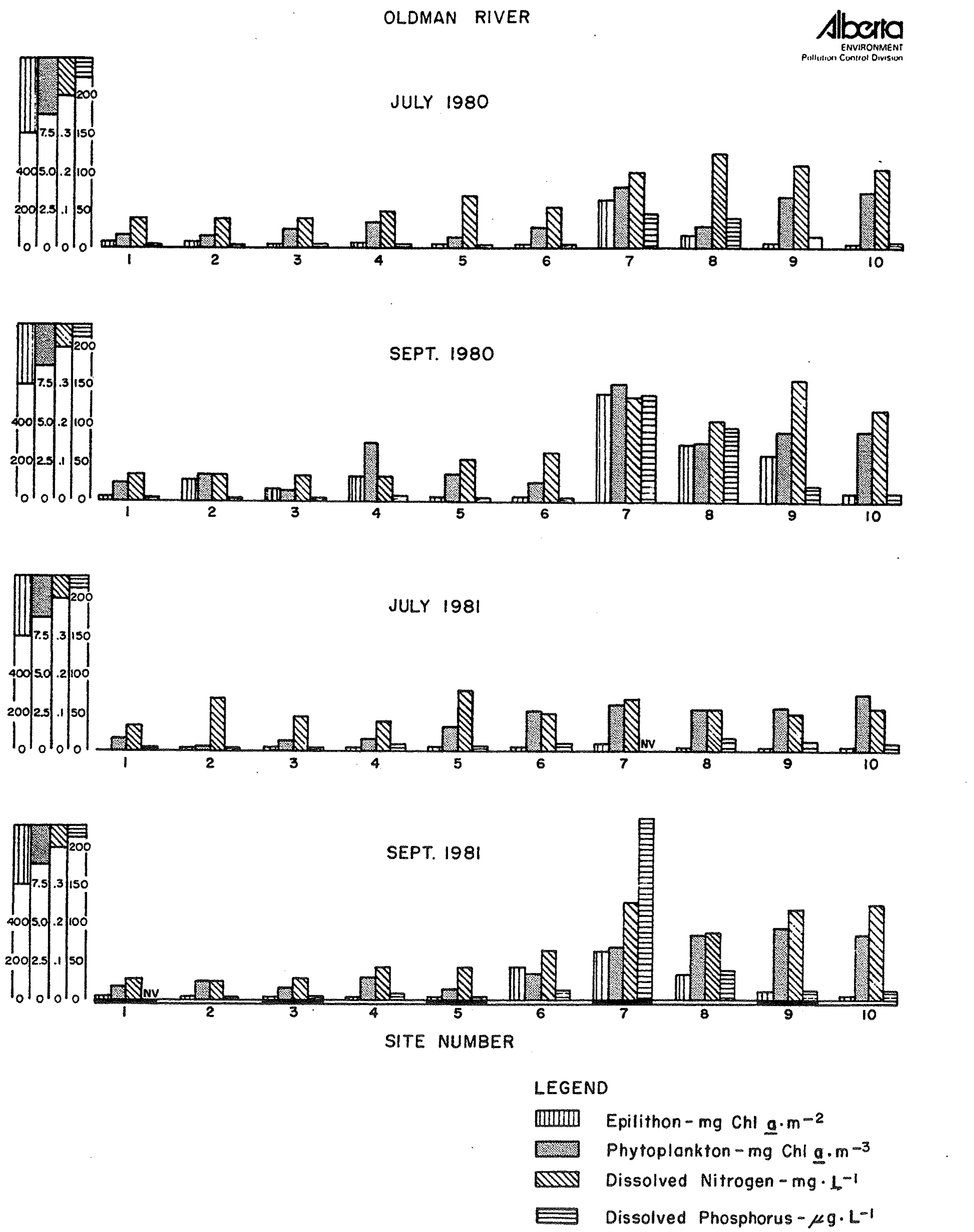

Figure 13. River course variation of algal standing crops, dissolved nitrogen and dissolved phosphorus from the Oldman River headwaters (Site 1) to it's confluence with the Bow and South Saskatchewan Rivers (Site 10).

and non-filterable residue (NFR) and nitrate. Turbidity, dissolved nitrogen and silica correlated best with phytoplankton (Table 6). However, when July data and September data were combined, phosphorus (OP and DP) was most highly correlated with epilithic algal standing crops in similarity to the Bow River (Table 6). Phytoplankton standing crops were most highly correlated with temperature for the July surveys and in similarity to the Bow, with dissolved nitrogen during the September surveys.

3.4.3 The South Saskatchewan River

The South Saskatchewan River was surveyed during 1980 and 1981 and sampled at nine sites from its origin at the confluence of the Bow and Oldman rivers to the confluence of the Red Deer River (Figure 1). This river is generally deeper than the other rivers and meanders slowly through dry prairie. Table 8 provides a description of each sample site.

Epilithic algal standing crops in the South Saskatchewan River were similar to those in the Bow and Oldman Rivers - higher during 1980 than 1981 (Figure 14). Data from surveys indicated that there were higher standing crops in September than there were in July. Benthic algal standing crops averaged 29 mg chlorophyll $\underline{a}\bullet m^{-2}$ in July and 55.4 mg chlorophyll $\underline{a}\bullet m^{-2}$ during September. Epilithic standing crops were lower in the South Saskatchewan River than in the Bow and Oldman Rivers. River course trends were not as evident in the South Saskatchewan River. During July and September of 1980, Site 8 supported the most benthic algae, and in 1981 Site 1 had the highest epilithic standing crop. Moreover, there was a decrease in benthic

TABLE 8: DESCRIPTION AND LOCATION OF SOUTH SASKATCHEWAN RIVER COURSE HELICOPTER SITES.

South Saskatchewan River - Site #	Brief Description
H1 -	Latitude 49° 55' 19"N Longitude 111° 41' 08"W Confluence of the Bow and Oldman Rivers - water riffled to slow flowing over flat stone and cobble.
H2 -	Latitude 49° 54' 15 N" Longitude 111° 28' 17"W Bow Island - current slow, river water high in suspended sediment. Sediment covering littoral cobble and flat stone. Drifting algae noted. Attached algae abundant.
H3 -	Latitude 50° 04' 03"N Longitude 111° 07' 25"W River swift meandering through a wide flood plain used for cattle pasture. River banks increasingly steep to 60 metres. Substrate cobble to boulders and gravel frequently visible.
H4 -	Latitude 50° 04' 03"N Longitude 110° 46' 40"W Above Medicine Hat - *Potamogeton sp.* particularly abundant. Flat stone cobble substrate with littoral deposition of sediment.
H5 -	Latitude 50° 08' 25"N Longitude 110° 34' 48"W Downstream of Medicine Hat - site particularly subject to extensive bank slumping. Fungi noted on the cobble to mud substrate. Macroalgae covered 40-100% of the substrate. Substrate notably high in organic matter, probably caused by domestic effluent from Medicine Hat.
H6 -	Latitude 50° 29' 28"N Longitude 110° 22' 55"W Due west of Red Deer Lake - cobble to sand formed the predominant substrate. River shallow, slow-flowing with patchy macro-algal development on the substrate.
H7 -	Latitude 50° 29' 28"N Longitude 110° 22' 55"W Due west of Hilda - steep solid banks up to 150 metres high. River riffling over boulders and cobble. Macroalgae patchy in this area.
H8 -	Latitude 50° 43' 52"N Longitude 110° 03' 20"W At McNeill - the river banks were gradual sloping up to 50 metres high. Macroalgae particularly abundant, as were clams and fish fry. Current here slow.
H9 -	Latitude 50° 54' 20"N Longitude 110° 05'W Upstream of the South Saskatchewan River confluence with the Red Deer River - river substrate cobble with no evidence of algae or macrophytes during July. Abundant *Nostoc sp.* during late August. River banks various and flood plain was used for cattle pasture.

* H Denotes longitudinal helicopter survey sites.

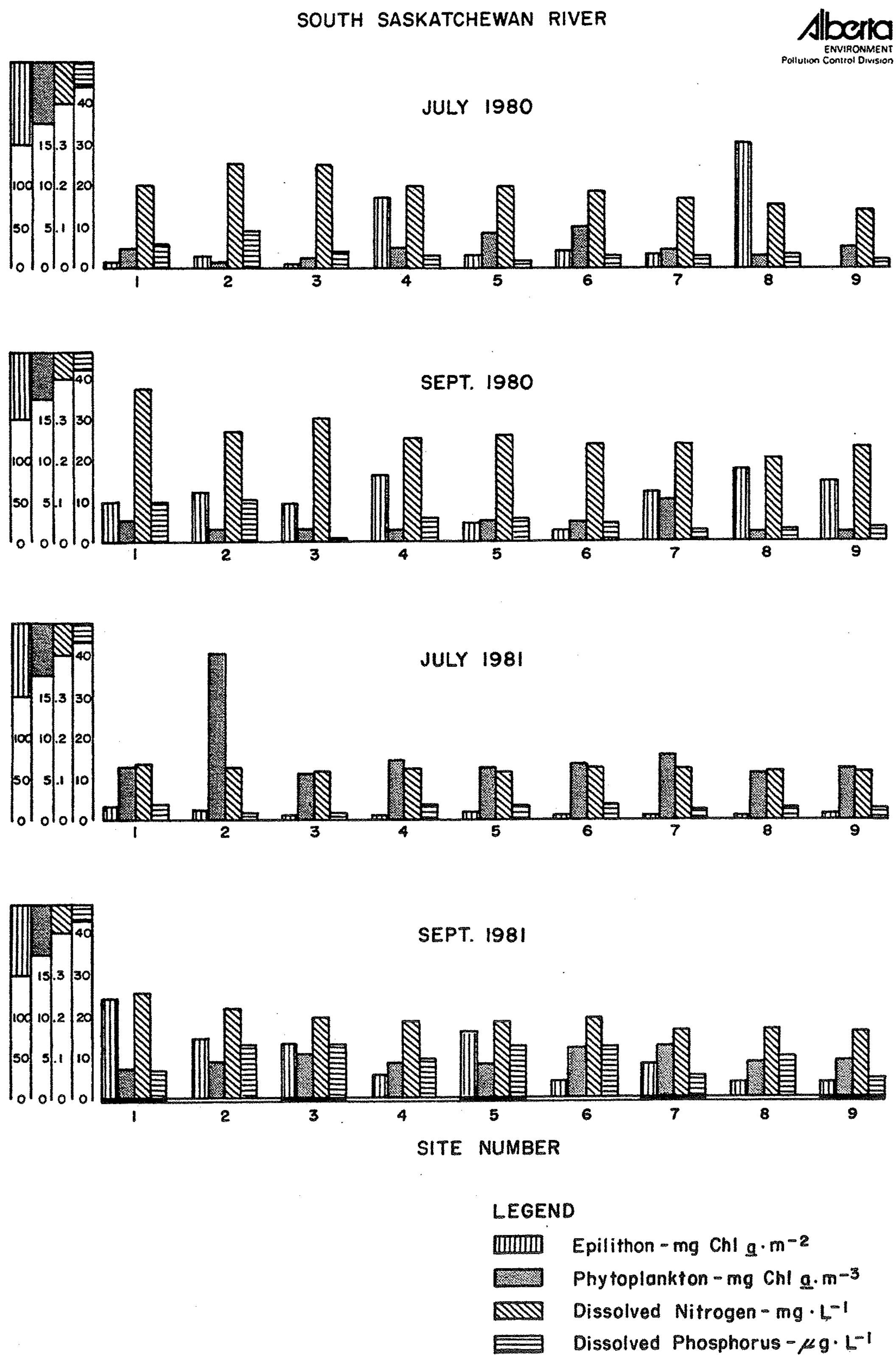

Figure 14. River course variation of algal standing crops, dissolved nitrogen and dissolved phosphorus from the origin of the South Saskatchewan River (Site 1) to it's confluence with the Red Deer River (Site 9).

standing crops in a downstream direction during 1981. Site 5 located downstream of Medicine Hat supported lower standing crops than Site 4 except during September, 1981.

Linear regression analyses (SPSS) were performed on data acquired during river course surveys of the South Saskatchewan River. Epilithic algal standing crops were most highly correlated with depth and non-filterable residue (NFR) during 1980, and with dissolved nitrogen and dissolved phosphorus during 1981 (Table 6). Phytoplankton standing crops correlated with a different parameter during each survey. Combined July data and September data indicated a high correlation between benthic standing crop and dissolved inorganic carbon (DIC) in July, and nitrate nitrogen in September. Phytoplankton standing crops were highly correlated statistically with silica levels during July and dissolved organic carbon (DOC) during September.

3.4.4 Summary

The river course helicopter survey data of the three rivers confirmed that epilithic algal standing crops were highly correlated with phosphorus and nitrogen, particularly in the Bow and Oldman rivers. Moreover higher standing crops occurred downstream of urban centres, specifically Calgary and Lethbridge. The origin of the South Saskatchewan River represents the convergence of waters from the Bow and Oldman Rivers. The convergence of these waters produced a chemical regime which stimulated algal growth. Therefore, standing crops were higher just below the convergence than those observed further downstream.

Annual survey data from the three rivers were combined to discern the primary variables that were highly correlated with algal standing crops for the South Saskatchewan River Basin. Linear regression analysis indicated that during 1980, epilithon was most highly correlated with dissolved phosphorus, and that phytoplankton was most highly correlated with dissolved nitrogen (Table 6). During 1981, dissolved nitrogen and non-filterable residue were the variables having the highest correlation with algal standing crop. Hence phosphorus and nitrogen were the variables that were most commonly correlated with benthic algal standing crop in the South Saskatchewan River Basin.

3.5 Phytoplankton Standing Crops and Productivity

3.5.1 The Bow River

Phytoplankton standing crops and productivity (^{14}C uptake) fluctuated widely throughout the Bow River. As they rarely paralleled each other, it is suggested that phytoplankton in the river may not be actively growing. In fact, microscopic examination of this community indicated the presence of predominantly senescent benthic forms. Other confirmation is that seasonal phytoplankton standing crops in the Bow River were low ranging from 1 to 21 mg chlorophyll $\underline{a}\bullet m^{-3}$ (Figure 15). The data in Table 9 indicate the mean standing crop and production for the Bow River during the 1980/81 investigative period.

Phytoplankton standing crops were seasonally higher at Site 13 and productivity was higher at Site 7. Phytoplankton standing crops at Site 13 were highest during the spring and summer, 1981.

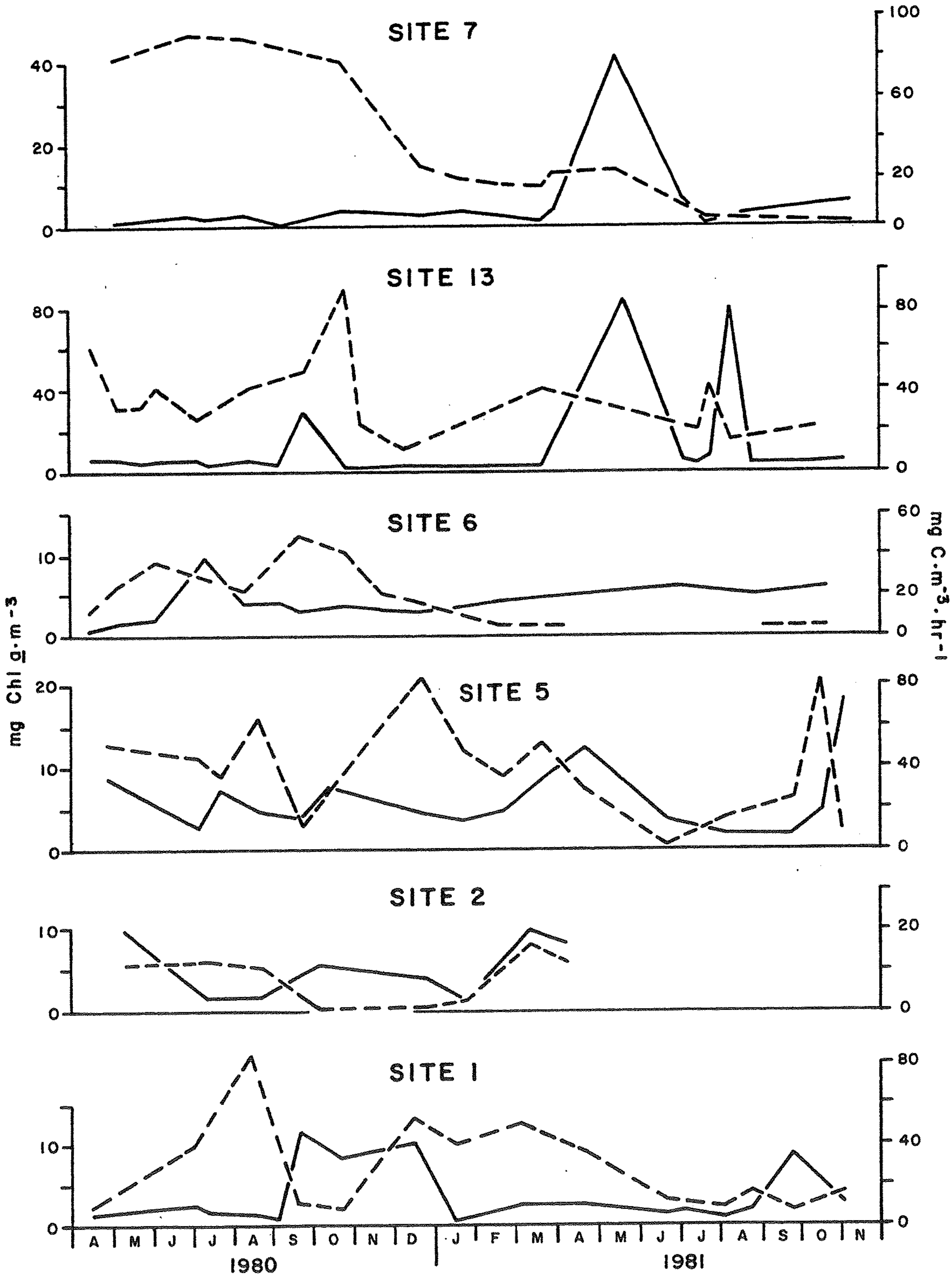

Figure 15. (—) Planktonic algal standing crop estimates (mg Chlorophyll $\underline{a} \cdot m^{-3}$) and (--) primary productivity (mg Carbon$\cdot m^{-3} \cdot h^{-1}$) for the Bow River (1980/81).

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TABLE 9 Seasonal mean and range of South Saskatchewan River Basin phytoplankton standing crop (chlorophyll a•m^{-3}) and productivity (mg carbon•m^{-3}•h^{-1}), 1980 and 1981.

SITE/ LOCATION	STANDING CROP MEAN	STANDING CROP RANGE	PRODUCTIVITY MEAN	PRODUCTIVITY RANGE
	mg chlorophyll a•m^{-3}		mg Carbon•m^{-3}•h^{-1}	
BOW RIVER				
1. Upstream of Calgary	3	1- 10	28	9- 48
2. Downstream of Calgary	4	1- 8	9	1- 12
5. Carseland	6	3- 9	38	8- 56
6. Downstream Bassano Dam	4	1- 6	27	11- 42
13. Bow City	13	2-21	31	11- 54
7. Ronalane Bridge	5	1-16	41	2- 93
OLDMAN RIVER				
3. Upstream of Lethbridge	3	1- 4	31	7- 90
4. Downstream of Lethbridge	7	2-12	38	15- 70
8. Confluence with Bow	3	2- 5	37	9- 46
SOUTH SASKATCHEWAN RIVER				
9. Bow Island	6	2- 26	48	18-165
10. Upstream of Medicine Hat	3	2- 6	22	11- 48
11. Downstream of Medicine Hat	3	2- 3	28	21- 41
12. Highway 41	4	1- 14	25	2- 40

Phytoplankton ^{14}C uptake was highest during spring and summer, 1980. High productivity and low standing crops in the lower reach of the Bow River suggested higher planktonic efficiency in this reach, perhaps caused by the meandering, slow-flowing nature of the river. Average planktonic standing crops were the same for Site 2 and 6; however, productivity was much higher at Site 6 (Table 9). Therefore, phytoplankton populations downstream of Calgary (Site 2) consisted mainly of senescent algae while those that occurred further downstream were actively growing.

3.5.2 The Oldman River

In the Oldman River phytoplankton standing crops and productivity were more closely related than they were in the Bow River. Table 9 presents the seasonal means and ranges for standing crop and productivity in the Oldman River for 1980 and 1981.

Phytoplankton standing crops were highest during the summer and spring seasons of 1980 and 1981, respectively, at Site 3 (Figure 16). Phytoplankton ^{14}C uptake at Site 3 was highest during the fall/winter of 1980. Both standing crop and productivity (seasonal mean) were highest downstream of Lethbridge at Site 4 (Table 9). Values were higher during 1980 than they were in 1981. In 1980 the averages were 12.3 mg chlorophyll $\underline{a} \bullet m^{-3}$ and 69.8 mg carbon$\bullet m^{-3} \bullet h^{-1}$ during the fall (Sept. 15 - Dec. 1) season. At Site 8, phytoplankton standing crops for 1980 and 1981 had the same seasonal mean of 3 mg chlorophyll $\underline{a} \bullet m^{-3}$. However, ^{14}C uptake was higher (Table 9). Phytoplankton production at Site 8 was highest during the spring seasons of both 1980 and 1981 (Figure 16). The highest phytoplankton standing crop at Site 8 also occurred during spring, 1981 (Figure 16).

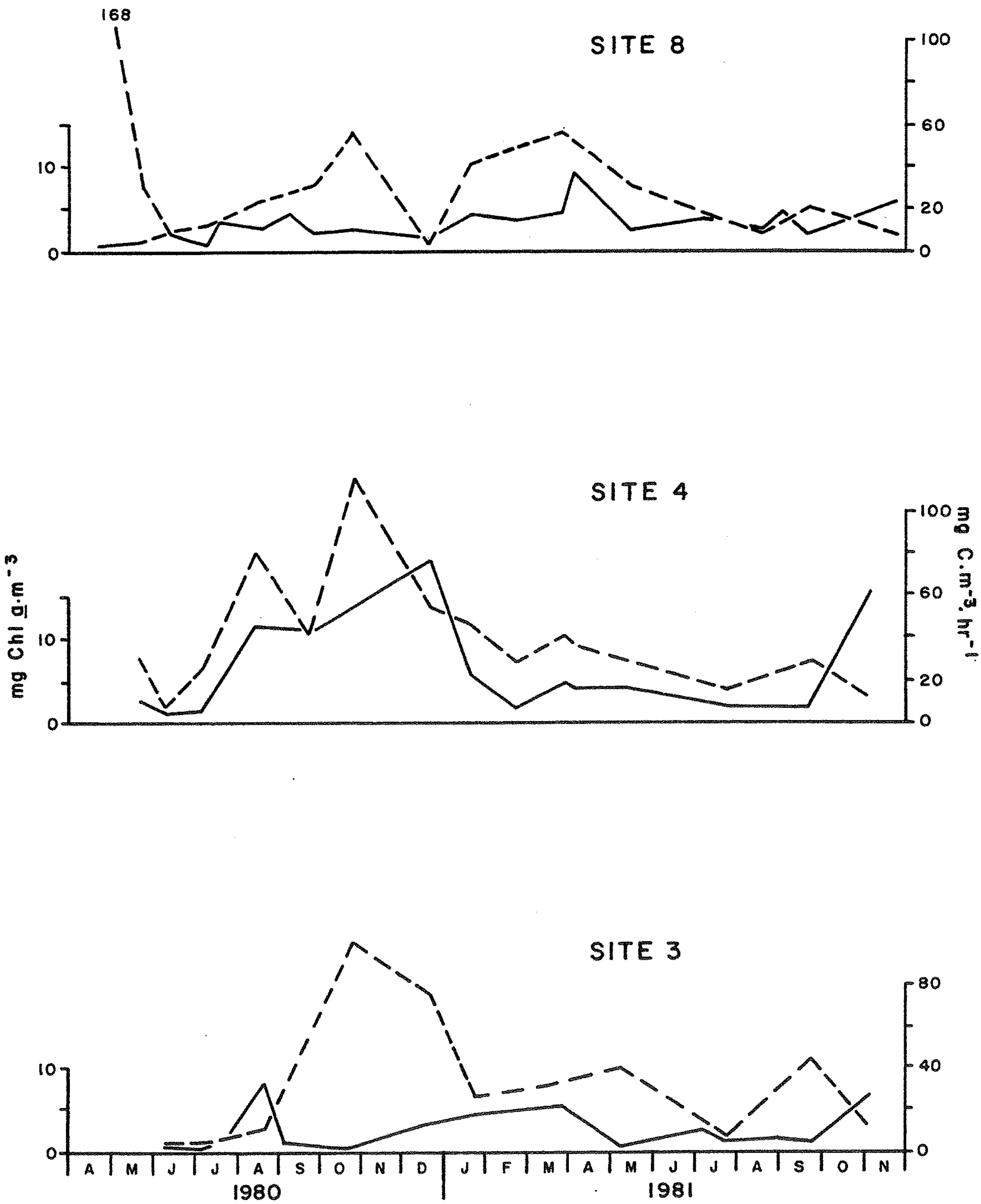

Figure 16. (—) Planktonic algal standing crop estimates (mg Chlorophyll a·m^{-3}) and (--) primary productivity (mg Carbon·m^{-3}·h^{-1}) for the Oldman River (1980/81).

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3.5.3 The South Saskatchewan River

Phytoplankton standing crops and productivity were frequently higher at the origin of the South Saskatchewan River (Site 9) than other sites downstream (Figure 17). The seasonal mean standing crop at Site 9 was 6 mg chlorophyll a•m^{-3} and productivity averaged 48 mg carbon•m^{-3}•h^{-1}. Table 9 presents mean seasonal values for all sites within the South Saskatchewan River.

At Site 10, located upstream of Medicine Hat, standing crop peaked during the fall of 1980 and summer of 1981 (Figure 17). Phytoplankton ^{14}C uptake reached a maximum of 48 mg carbon•m^{-3}•h^{-1} during the fall season (Sept. 15 - Dec. 1) of 1980. Although mean seasonal standing crops were the same for Sites 10 and 11, productivity was higher downstream of Medicine Hat (Site 11). Moreover the temporal variation of ^{14}C uptake and chlorophyll a showed little change. At Site 12, phytoplankton standing crop and productivity both peaked during the winter season (Dec. 2 - Mar. 19) and reached an average of 14 mg chlorophyll a•m^{-3} and 40 mg carbon•m^{-3} h^{-1}, respectively.

3.6 Comparison of the Rivers Within the Same Locale

The myriad of factors which control primary producers in the South Saskatchewan River Basin are indeed complex. Elimination of data variation attributed to temporal, climatic and topographic local factors was possible only at the confluence of the Bow and Oldman Rivers (Lat. 49°, 51', 02" N; Long. 111°, 41' 48" W).

Substrates in the three rivers at this location were similar as was local riparian (river bank) vegetation, soil and climate. As

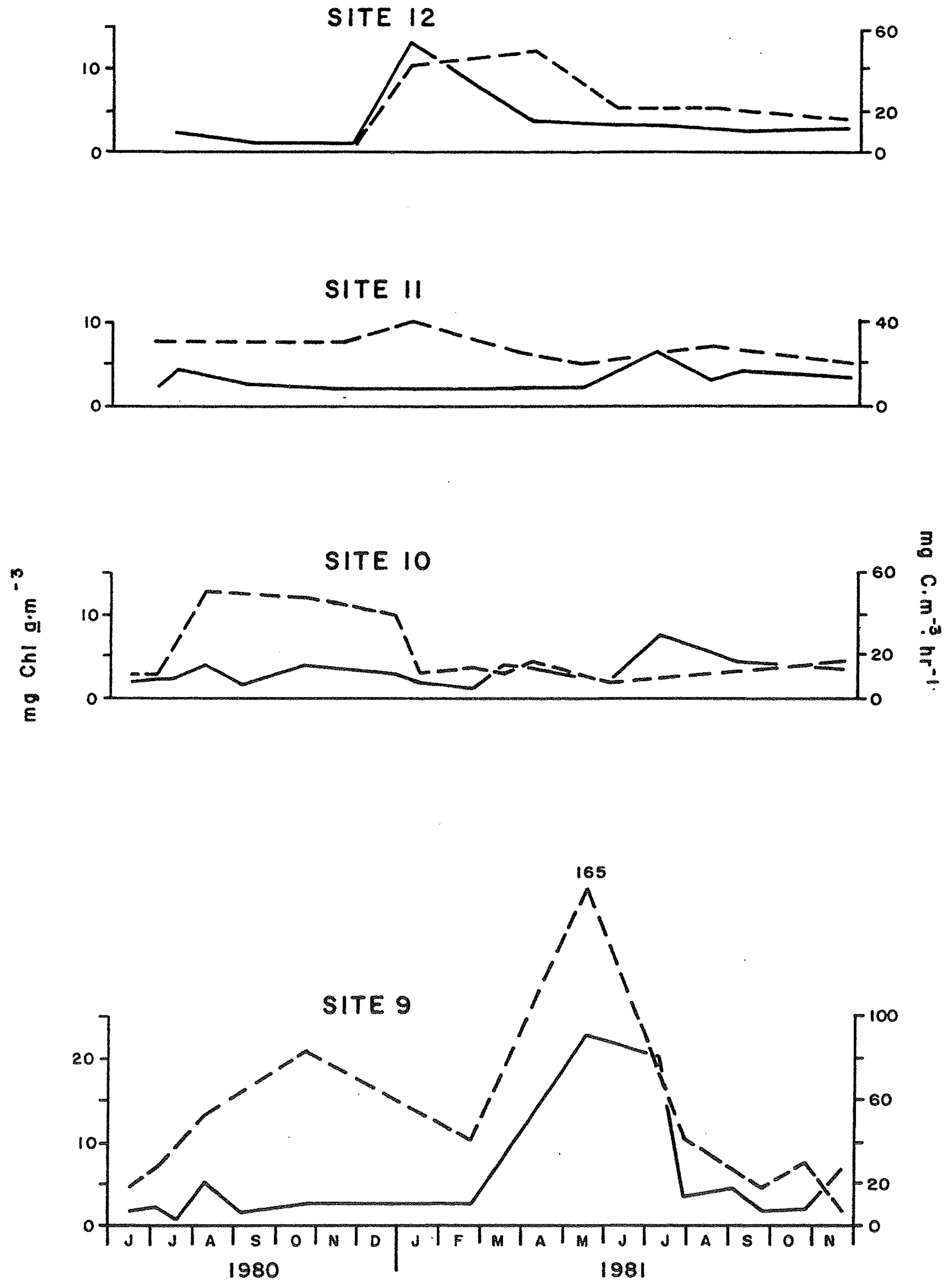

Figure 17. (—) Planktonic algal standing crop estimates (mg Chlorophyll a · m^{-3}) and (--) primary productivity (mg Carbon · m^{-3} · h^{-1}) for the South Saskatchewan River (1980/81).

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soil is fine grained clayey-sand, the river banks are particularly subject to erosion and slumping. Water samples were collected immediately upstream of the confluence of the Bow and Oldman rivers, and downstream from the origin of the South Saskatchewan River. Water samples were collected at mid-stream, and biota were collected along transects across each river. Table 10 indicates the biotic and physico chemical characteristics of the three rivers during the morning of September 30, 1980. These sites were at the confluence of the Bow and Oldman rivers and immediately downstream in the South Saskatchewan River.

As the Bow and Oldman rivers converge, they form the origin of the South Saskatchewan River. The concentration of most nutrients, with the exception of nitrate-nitrite nitrogen and reactive silica, were higher in the Bow River than in the Oldman River. The concentrations of dissolved phosphorus, dissolved nitrogen and chloride in the Bow River were diluted by the Oldman River water. Values for temperature, ortho phosphorus, total inorganic phosphorus, nitrate-nitrite nitrogen, particulate nitrogen, particulate organic carbon, dissolved inorganic carbon and reactive silica were the same or higher in the South Saskatchewan River as in the Oldman River. The Oldman River water was more turbid, because of the presence of suspended sediment, than the Bow River. The combined effect of these rivers however, yielded an even higher turbidity value for the South Saskatchewan River (Table 10). Raised turbidity may also be related to inputs that occurred between the Bow, Oldman and South Saskatchewan River sampling sites.

TABLE 10 The physicochemical and biotic characteristics of the Bow, Oldman and South Saskatchewan Rivers at their confluence (Sept. 30, 1980)

	RIVERS		
	BOW	OLDMAN	S. SASK
Specific Conductance (mmhos cm^{-2})	373.0	429.0	425.0
Turbidity (J.T.U.)	3.9	6.8	9.2
pH (pH units)	8.00	8.15	8.05
Total Alkalinity (meq"L^{-1})	1.95	2.42	2.33
Temperature (°C)	13.3	13.2	13.2
Total phosphorus as P	0.021	0.062	0.058
Dissolved phosphorus	0.010	0.027	0.033
Dissolved inorganic phosphorus	0.003	0.016	0.010
Ortho phosphorus	0.003	0.003	0.004
Total inorganic phosphorus	0.010	0.031	0.044
Nitrate/nitrite nitrogen	0.07	0.01	0.01
Dissolved Nitrogen	0.35	0.38	0.20
Particulate Nitrogen	0.14	0.15	0.24
Particulate Organic Carbon	0.67	0.91	1.2
Dissolved Inorganic Carbon	26.0	32.0	32.0
Chloride (Dissolved)	4.1	4.2	4.0
Reactive silica	0.4	0.2	0.6
<u>Chlorophyll</u>			
Planktonic (mg"m^{-3})	5.6 % 2.7	18.9 % 5.8	12.9 % 3.2
Epilithic (mg"m^{-2})	122.5 % 103	39.3 % 27	148.3 % 116
<u>Primary Productivity</u>			
Planktonic (mg carbon"m^{-3}"h^{-1})	62.8	31.3	94.3
Epilithic (mg carbon"m^{-2}"h^{-1})	123.8 % 56	78.5 % 41	214.7 % 44
<u>Photosynthetic Index</u>			
Planktonic (mg C"mg chl a"m^{-3}"h^{-1})	11.21	1.66	7.31
Epilithic (mg C"mg chl a"m^{-2}"h^{-1})	1.01	2.00	1.45
Depth (cm)	40.0	40.0	40.0
Insolation (MJ"m^{-2}"h^{-1})	1.02	1.02	1.02
Discharge (m^3"s^{-1})	40.5	47.8	92.4

* All values above mg•L^{-1} units except otherwise noted.

Planktonic algal standing crops were found to be highest in the Oldman River, possibly because of its slow meandering nature and the presence of numerous quiet water areas. Epilithic standing crops were lowest in the Oldman River, however, possibly because of sediment accumulation over the rock substrate. The South Saskatchewan River also had the highest epilithic algal standing crop and the highest productivity. Therefore, it appears that the synergistic effects of Bow and Oldman river waters stimulated epilithic algal growth and development at the origin of the South Saskatchewan River.

The algal photosynthetic index (efficiency) for the study date was highest in the Bow River phytoplankton community and highest in the Oldman epilithic community. This means that the Oldman River supported an actively growing epilithic community of small (low chlorophyll a content) cells which were very efficient.

3.7 Diurnal Productivity (The Bow River)

Primary producer productivity varied not only seasonally but daily in response to the increase and decrease of sunlight. The diurnal variation of chemical parameters in the Bow River was presented in Cross et al. (1986). Figure 18 presents the diurnal variation of productivity, pH, temperature and bicarbonate alkalinity for the Bow River during the period October 15 and 16, 1981, at Site 5 (Carseland).

Epilithic primary productivity on October 15-16 was highest during the period 10:00 through 14:00 hours Mountain Standard Time (Figure 18). Thereafter ^{14}C uptake declined to a minimum for the

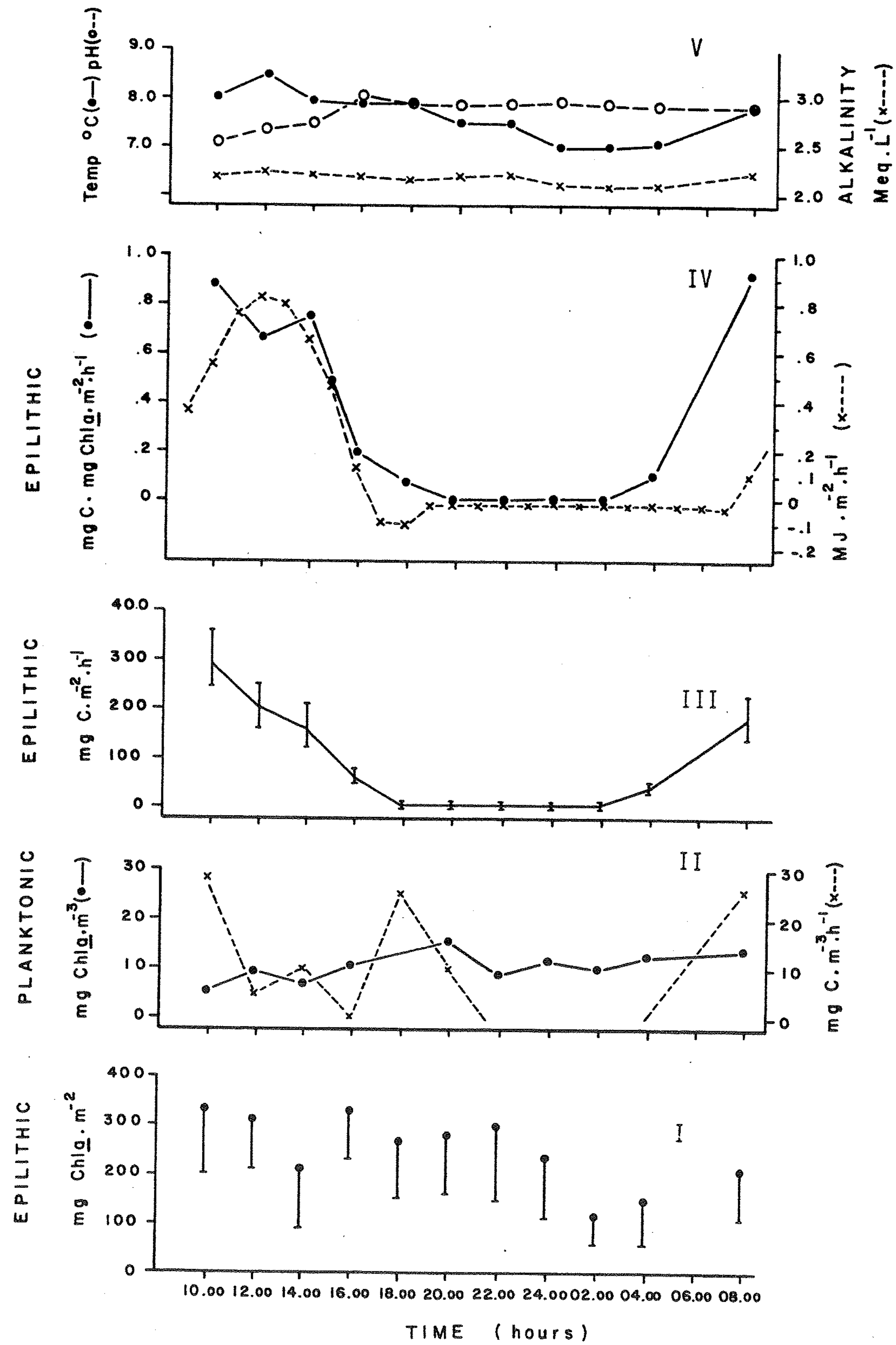

Figure 18. Diurnal variation measurements at Site R5 of :
I. Epilithic Chlorophyll a
II. Planktonic Chlorophyll a
III. Epilithic primary productivity
IV. Epilithic photosynthetic efficiency
V. pH, temperature, and bicarbonate alkalinity

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dark period (18:00-02:00 hours). After 02:00 hours, productivity steadily increased to a midday maximum. Table 11 indicates the mean hourly rate of epilithic algal productivity.

Routine investigation of ^{14}C uptake was conducted hourly between 10:00 and 14:00 hours; therefore, the diurnal study provided some indication of the daily rate of ^{14}C uptake in relation to the entire 24 hour period. This investigation provided evidence for lower rates of ^{14}C uptake prior to and following routine studies (10:00-14:00 hours). Production occurring outside the 10:00 through 14:00 hour period amounted to an additional 55% (Table 11). During the dark period 20:00 through 04:00 hours, ^{14}C uptake represented less than 1% of the rate observed for 10:00 through 14:00 hours. Daily production for the Bow River during, October 15-16 was 432 mg carbon•m^{-2}•day^{-1}.

Mean hourly benthic algal productivity was highest during the period from 10:00 to 12:00 hours, then photosynthetic efficiency fell at 12:00 hours. This midday suppression coincided with the period of maximum net radiation (Figure 18).

Phytoplankton primary production peaked at 08:00, 10:00 and 18:00 hours, while standing crops (drift) were highest during the early evening (20:00 hours) (Figure 18). Bicarbonate alkalinity and pH changed little during the 24 hour period. Temperature peaked during midday.

3.8 Algal Standing Crop Heterogeneity

During the diurnal study, epilithic algal standing crop heterogeneity among 38 separate rocks was compared. Standing crop ranged from 43.6 to 581.1 mg chlorophyll a•m^{-2} with a mean of 255.1 mg

TABLE 11 Epilithic ^{14}carbon uptake rates prior to and following a routine 10:00-14:00 hour incubation at Site 5 during October 15 and 16, 1981.

TIME	EPILITHIC ^{14}CARBON UPTAKE mg carbon$\cdot m^{-2} \cdot h^{-1}$	PERCENTAGE OF 10:00-14:00 HR. RATE
10:00-14:00	274.5	100 (4 hours)
14:00-20:00	112.3	41 (6 hours)
20:00-04:00	2.1	1 (8 hours)
04:00-10:00	36.0	13 (6 hours)

chlorophyll a•m^{-2}. Figure 18 presents the standing crop of each incubation series and the 95% confidence limit of the 9-12 rocks assayed during each successive incubation. Confidence limits were lower during the dark period when it was not possible to observe the rocks during collection. This deliberate lack of bias yielded a lower standing crop estimate.

For many reasons, it was also necessary to determine the sample size which yielded an adequate estimate of epilithic algal standing crop. Routine studies had consisted of 12 to 15 separate samples. It was not known however, how the standard error of this estimate compared for various sample sizes. Therefore, the standard error of the mean standing crops was calculated (S.E. = 14.2; n = 88) and compared to the standard error for increasing sample sizes. Table 12 depicts the results.

The standard error associated with 88 individual samples was nearly equal to that determined for 42 samples. Thus 42 samples would have yielded an adequate estimate of epilithic standing crop. Unfortunately it is not feasible to collect routinely 42 samples of standing crop. Routine assays of 12 to 15 samples were, however, feasible. Routine estimates of algal standing crop were found to represent a standard error approaching 35%.

Data gathered during this investigation confirmed the very patchy nature of epilithic algal standing crops in lotic systems such as the Bow River. Because of the high degree of variation, and the myriad of ecological factors which influence algal standing crop distribution and abundance, caution must be employed when interpreting and predicting from the data.

TABLE 12 The standard errors associated with various sample sizes for estimating attached algal standing crop in the Bow River, 1981

SAMPLE SIZE	S.E.
12	35.7
15	31.3
30	19.8
40	15.6
42	14.9
50	12.4
70	7.2

3.9 Macrophyte Species Composition

The distribution of aquatic submerged macrophytes range from extremely prolific (near Calgary) to patchy, or sparse, throughout the remainder of the South Saskatchewan River Basin. With the exception of downstream Calgary, the preferred macrophyte habitat was primarily quiet water areas where stream current is minimal, i.e., backwaters having silty substrate. Downstream of Calgary macrophytes occur in coarse gravel and cobble substrate in regions subjected to active currents. The dominant species found in the Bow River (1980) were *Zannichellia palustris*, *Potamogeton vaginatus*, *P. crispus* and *P. pectinatus*. In addition, *P. richardsonii* was observed only in Bassano Dam.

Figure 19 illustrates the general micro-distribution of macrophytes observed in the Bow River. *Z. palustris* was located in nearshore regions on mud/gravel substrate. *P. pectinatus* occurred in the deeper region where large cobble occurred. *P. vaginatus* was dominant in the midstream among large cobble substrate. *P. crispus* was found in a wider range of habitats and more frequently in areas sheltered from current effects. Bow River regions lacking *P. vaginatus* were frequently devoid of any macrophyte growth, i.e., in mid-channel. *P. vaginatus* was generally dominant between sites M2 and M8 while *P. pectinatus* dominated between M9 and M12 during 1982 and 1983.

3.9.1 Macrophyte Growth Cycle

Submerged macrophytes in the Bow River are perennial. Growth during early May originated principally from rhizomes located in the

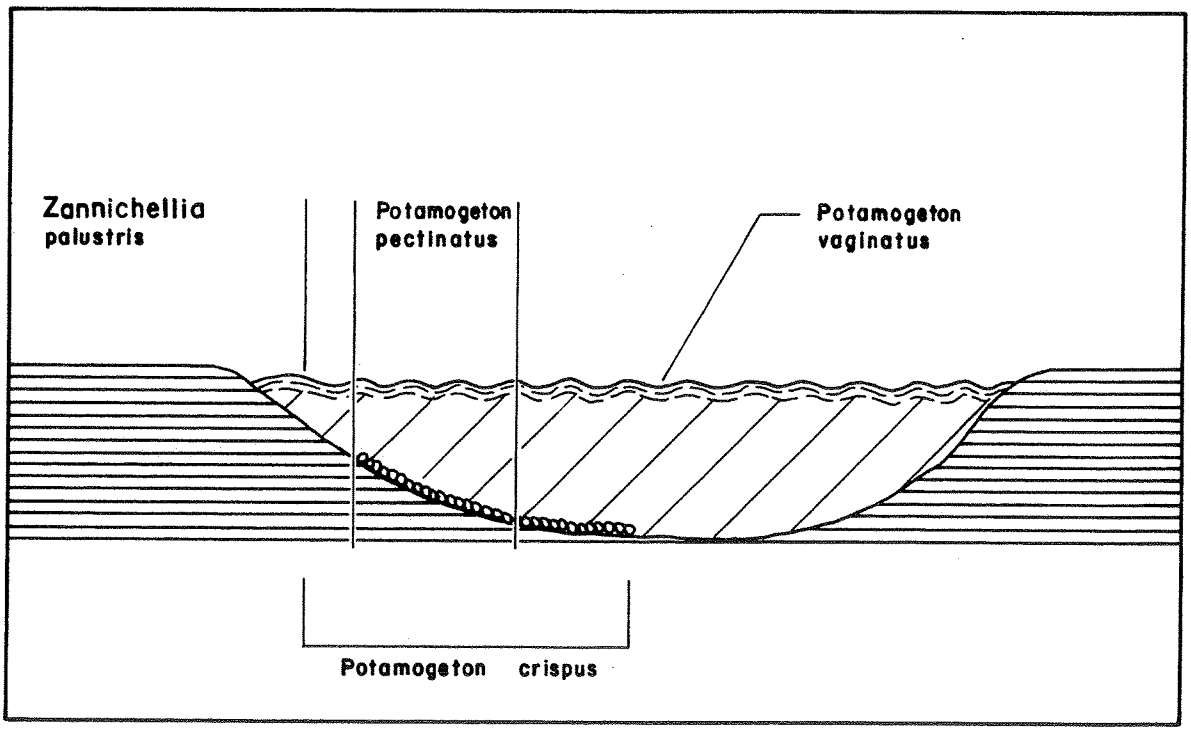

Figure 19. The micro-distribution of dominant macrophyte species in the Bow River downstream of Calgary.

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river substrate and continued until June when the mountain melt and resulting high river discharges normally scour away much of the photosynthetic plant tissue, and probably some substrate rhizomes. Immediately following the June high waters, macrophytes again grow and produce a peak biomass in late August or September of most years.

3.9.2 Benthic Algal/Macrophyte Biomass Ratios

Macrophyte and benthic algal biomass ratios were compared for 1981 and 1982. Data were collected at stations M1 (R and L) through M12 (R and L) (Table 13). Macrophyte dry weight was compared to benthic algal biomass by converting the chlorophyll a ($mg \bullet m^{-2}$) to dry weight (mg chlorophyll $a \bullet m^{-2}$ x 50)(Marker 1976). The ratios ranged from zero to a maximum of 28 at M5R during early July of 1981. Benthic algal biomass was far less than that found for macrophytes and the ratio was usually less than 0.05 during August and September. Benthic algae were generally more abundant at the far downstream sites during the spring and late fall seasons. Where macrophytes are abundant, they appear to hold a competitive advantage over benthic algae during July and August.

3.9.3 Macrophyte and Algal Standing Crops

During 1980, preliminary investigations were conducted to discern the distribution and quantity of submerged macrophytes occurring in the Bow River between Calgary and Carseland. In 1980, macrophyte biomass exceeded 1000 $gm \bullet m^{-2}$ (dry wt.) at Site M3R immediately downstream of Bonnybrook, and Site M6R immediately downstream of

TABLE 13 The ratios of benthic algal to macrophyte biomass for the Bow River (1981/82)

M1	M2		M3		M4		M5		M6		M7		M8		M9		M11		M12		SAMPLING DATES
Mid	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	
0	0	1.9	0	1.56	.43	7.73	5.58	.45	1.55	.27	1.37	.51	0	.39	1.46	.84	0	0	0	0	81.04.30 to 81.05.15
0	0	.39	.29	.06	.50	.35	.91	1.23	4.18	1.57	0.33	.63	-	-	-	-	0	0	-	0	81.05.16 to 81.05.22
0	-		-	-	-	-	-	-	4.63	1.42	.39	.20	0	1.39	3.16	0	-	0	-	-	81.05.23 to 81.06.24
0	0	24.34	0	1.7	2.5	3.5	3.18	1.20	-	-	-	-	-	-	-	-	-	-	-	-	81.06.25 to 81.07.02
0	0	0	.07	.16	1.32	8.33	.19	28.0	3.58	8.0	.47	.38	0	0	-	-	-	-	-	-	81.07.03 to 81.07.16
0	-		-	-	-	-	-	-	4.46	.99	.24	.28	0	0	0	0	0	0	0	0	81.07.17 to 81.07.22
0	0	.14	0	0	.05	.14	.10	.09	.23	.10	.04	.04	-	-	-	-	-	-	-	-	81.07.23 to 81.08.14
0	0	.51	0	.10	.08	.37	.25	.12	.08	.04	-	-	0	.21	.25	.16	.16	0	.14	0	81.08.15 to 81.08.25
.53			-	-	-	-	.04	-	-	-	.03	.02	.04	.13	.20	.36	.73	.02	1.25	.07	81.08.26 to 81.08.28
0	0	.14	0	.05	.02	.03	.01	.072	.03	.01	.02	.04	.02	.07	.09	.30	-	-	-	-	81.08.29 to 81.09.18
.154	0	.03	0	.01	.012	.02	-	.023	.02	.02	-	-	-	-	-	-	.06	.06	.04	.06	81.09.19 to 81.09.24
0			-	-	-	-	.02	-	-	-	.02	.04	-	0	.09	0	.05	.10	.03	.06	81.09.25 to 81.09.30
0		-	0	.01	.06	.03	.07	.12	.05	.01	.04	.01	.33	0	.17	0	.20	.25	.29	.27	81.10.01 to 81.10.16
0	-	-	0	.05	.06	.13		0.5	.06	0	.22	.06	-	-	-	-	-	-	-	-	81.10.17 to 81.11.17
					.06	.03			.05												82.07.20 to 82.08.01
					.01	.02			.03												82.08.01 to 82.08.31
					.03	.02			.03												82.09.01 to 82.09.30

Ratios: A:M = Algal $g \cdot m^{-2}$ dry wt:Macrophyte $g \cdot m^{-2}$ dry wt
Mid = Midstream
L = Left side
R = Right side

Fish Creek sewage treatment plant effluents. Conversely, the left bank Sites at M3L and M6L supported a significantly lower biomass (164 - 800 $g \cdot m^{-2}$ dry wt).

Little or no growth occurred during the summer of 1981 at Site M1, M2L, M3L, M10 and M13 (Figure 20). At the remaining sampling points, a distinct seasonal pattern was apparent. During May, plant growth was apparent at most locations, but average densities were less than 10 $g \cdot m^{-2}$ dry wt. By mid-July macrophyte growth was again apparent at M3L, M3R, M5L, M7R and M11L, where densities at all sites were less than 150 $g \cdot m^{-2}$ dry wt. For most sites, particularly those downstream of M7, greatest macrophyte biomass accumulation occurred after mid-August. Macrophyte populations peaked at most sites during mid to late September, after which time densities rapidly declined.

Macrophytes contributed the greater proportion of primary producer instantaneous biomass because of their perennial nature; benthic algae on the other hand grow rapidly, senesce, detach and are swept downstream in a period of time ranging from a few days to two or three weeks. Primary producer growth rates were estimated by subtraction using the following formula.

$$\text{Growth Rate} = \frac{\text{Biomass } T_2 - \text{Biomass } T_1}{N}$$

where T = Time
N = Number of days between sampling dates.

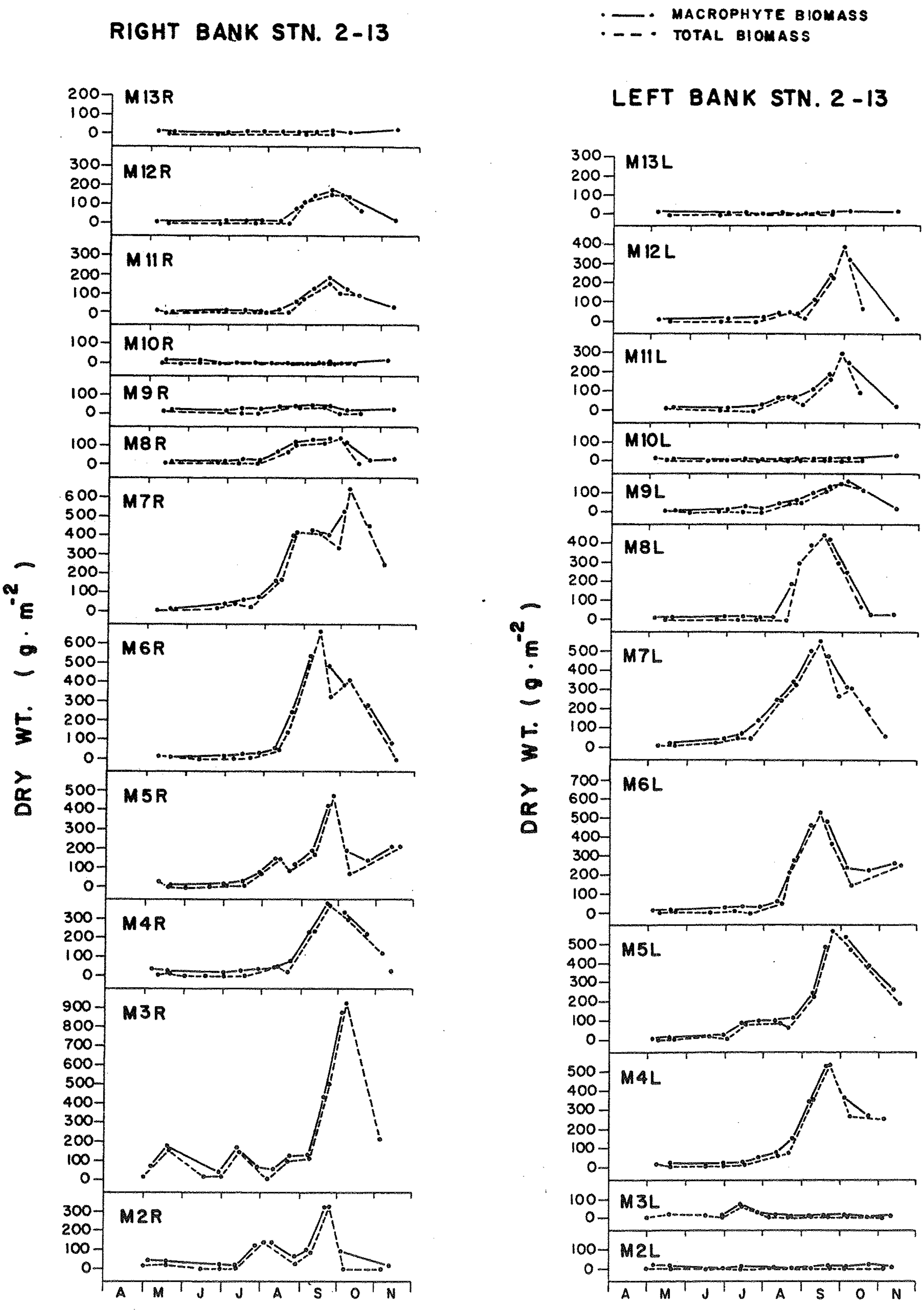

Figure 20. The seasonal variation of macrophyte and macrophyte + algal (total) biomass for 1981 in the Bow River.

Multiple, stepwise regression analysis was performed on the 1981 data in order to define the relative importance of physical factors (depth, velocity, temperature, non-filterable residue) in relation to macrophyte growth rate. All data were log transformed with zero and negative growth rates deleted from the data base. The first six independent variables accounted for only 28% of the macrophyte growth rate variance. Depth was the primary variable, followed by dissolved phosphorus, velocity, nitrate, non-filterable residue and temperature.

Because of the apparent significance of variables other than phosphorus, the 1982 and 1983 field studies were modified to clearly define the role of physical variables on macrophyte growth and development. Biomass accumulation in relation to light (P.A.R. insolation), velocity and depth were monitored at Sites M3R, (Figure 21), M4R (Figure 22) and M6L (Figure 23).

During 1982 macrophyte growth started during July at Sites M3R and M6L and during August at Site M4R. Biomass accumulated to a peak during mid-September at all sites. Macrophyte biomass was highest at Site M3R, and there it frequently exceeding 1000 $g \bullet m^{-2}$ (dry wt) during September 1982 (Figure 21). At Site M6L macrophyte biomass reached 1500 $g \bullet m^{-2}$ (dry wt) also during September 1982. Biomass accumulation was higher as sites having a longer period of growth.

During 1983 macrophyte growth started earlier (during June) and peaked earlier (Figures 21, 22 and 23). Again, the biomass was highest at sites M3R and M6L where the time period for biomass accumulation was longer (Figures 21, 23). Figure 24 depicts the relationship between macrophyte growth rate, light, depth and streamflow velocity. Growth rates were highest at velocities between

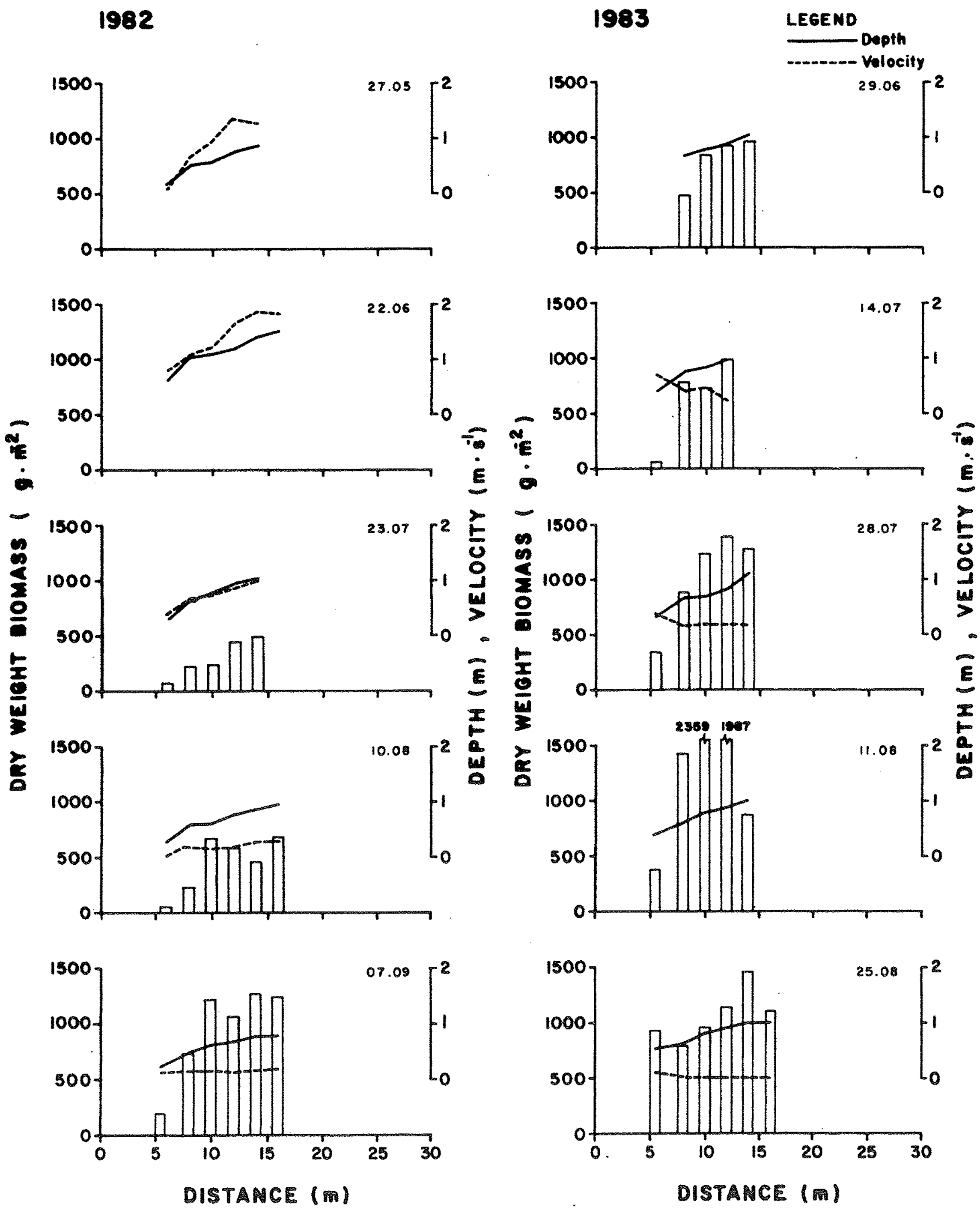

Figure 21. Macrophyte biomass in relation to depth and velocity at Site M3R, downstream of Calgary.

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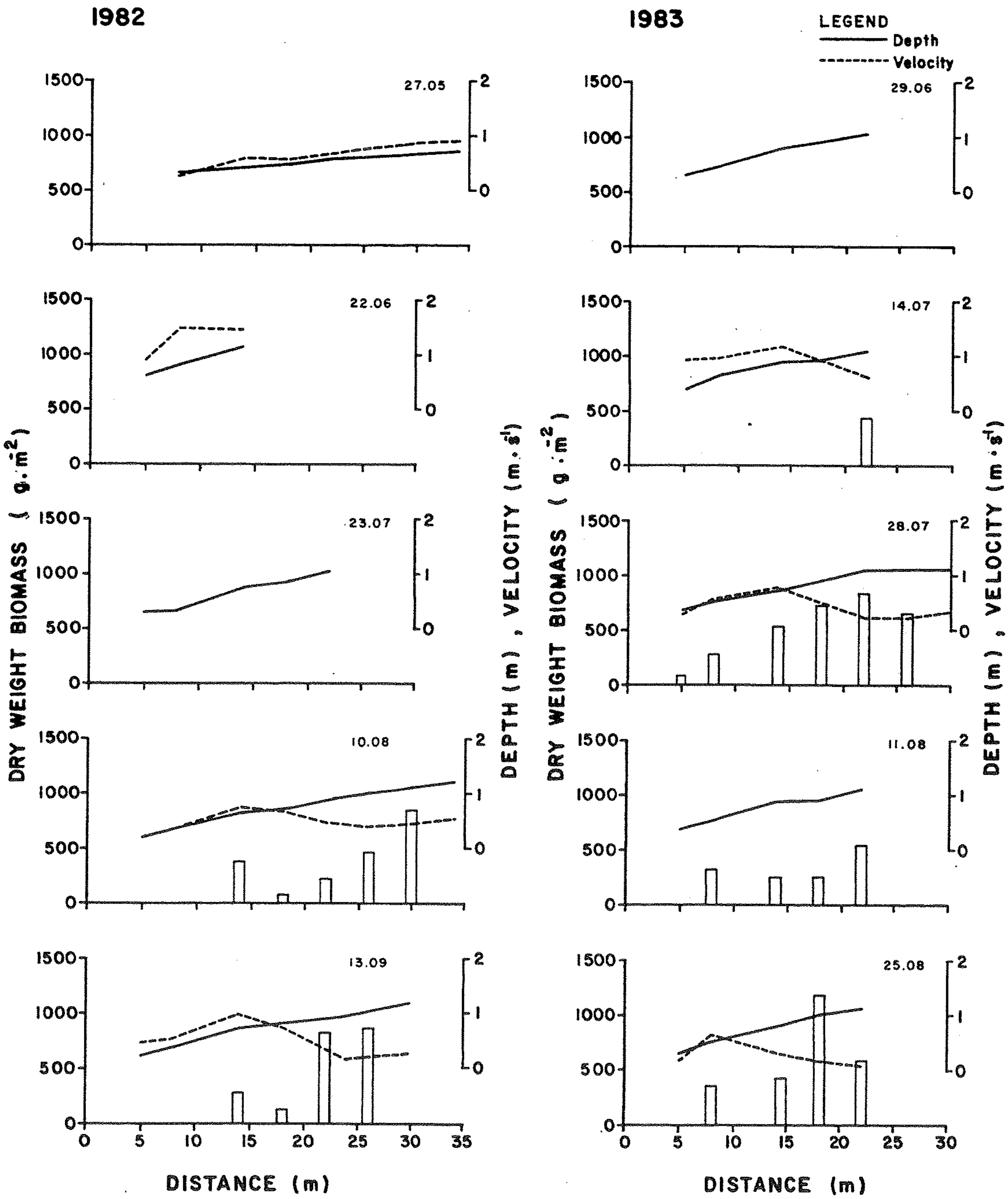

Figure 22. Biomass accumulation in relation to velocity at Site M4R.

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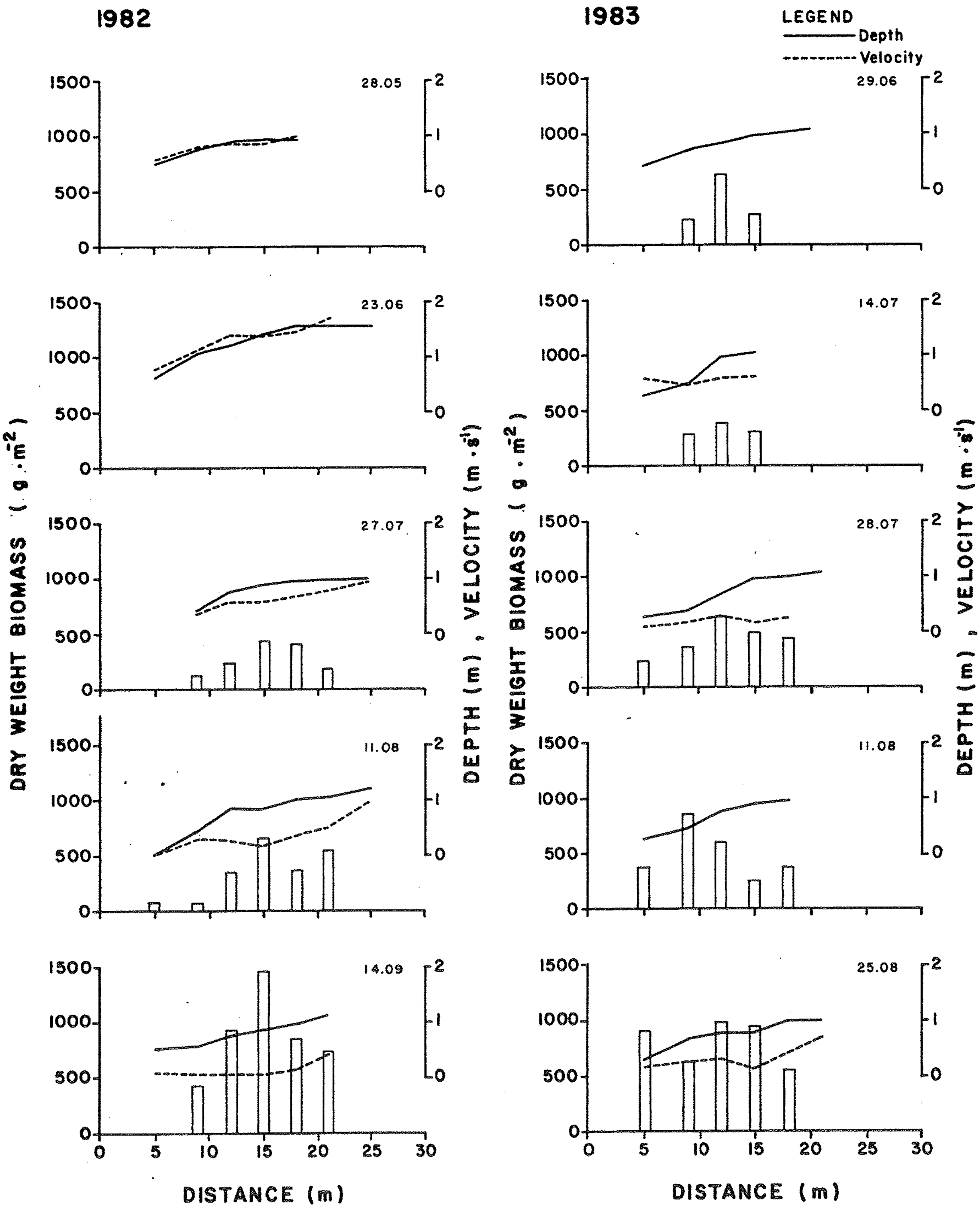

Figure 23. Macrophyte biomass in relation to depth and velocity for M6L downstream of Calgary.

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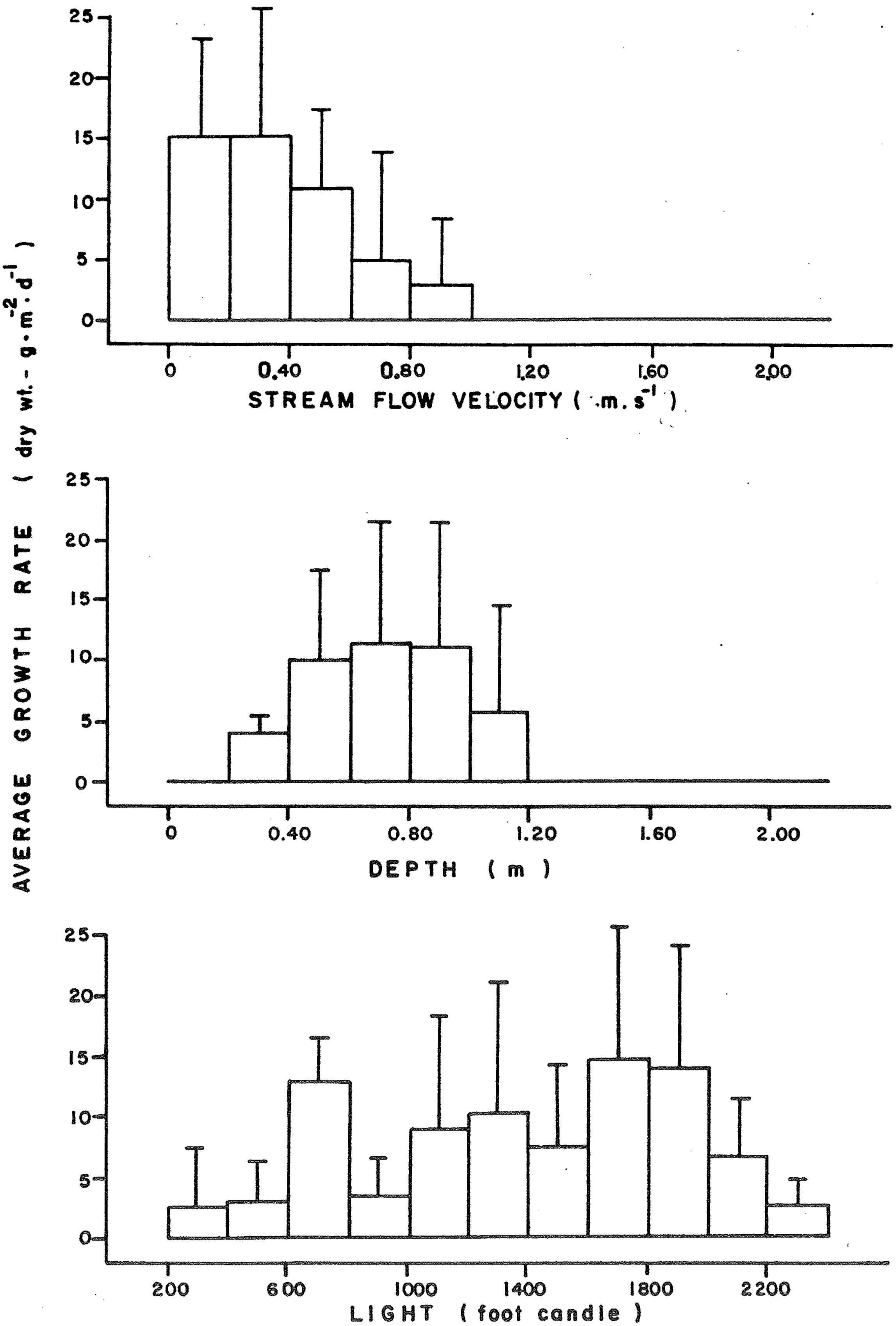

Figure 24. Relationship between physical variables and macrophyte growth rates for Bow River below Calgary.

zero and 0.40 $m \bullet s^{-1}$ with no growth occurring at velocities in excess of 1.00 $m \bullet s^{-1}$. The optimum depth for submerged macrophyte biomass accumulation was 0.40 through 1.00 m. The optimum amount of light for growth of Bow River macrophytes was 600 to 2000 footcandles (Figure 24).

Since physical factors proved to exert a profound influence on macrophyte biomass accumulation, Bow River discharge and velocity were compared for 1978 through 1983. Figures 25 and 26 depict the mean and maximum weekly discharge and mean velocity values for the open water periods.

With the exception of 1979 and 1983, mean weekly discharge during the mountain melt exceeded 250 $m^3 \bullet s^{-1}$ (Figure 25), or an average cross section velocity of 1.8 $m \bullet s^{-1}$ (Figure 26). During 1979 and 1983, average discharge remained at less than 170 $m^3 \bullet s^{-1}$ with an averaged cross section velocity of 1.4 $m \bullet s^{-1}$. Macrophyte biomass was lower during the years in which velocities exceeded 1.8 $m \bullet s^{-1}$ and higher during the years when velocities fell below 1.4 $m \bullet s^{-1}$. These data indicate that river velocities between 1.8 $m \bullet s^{-1}$ and 1.4 $m \bullet s^{-1}$ represent a critical range beyond which macrophyte tissue is scoured. River velocity is a critical factor influencing the abundance and distribution of macrophytes in the Bow River downstream of Calgary.

3.9.4 Temperature and Macrophyte Development

Although the specific effect of Bow River temperature was not examined in detail, it appeared that warming in May may stimulate vegetative growth of submerged macrophytes. During May, river

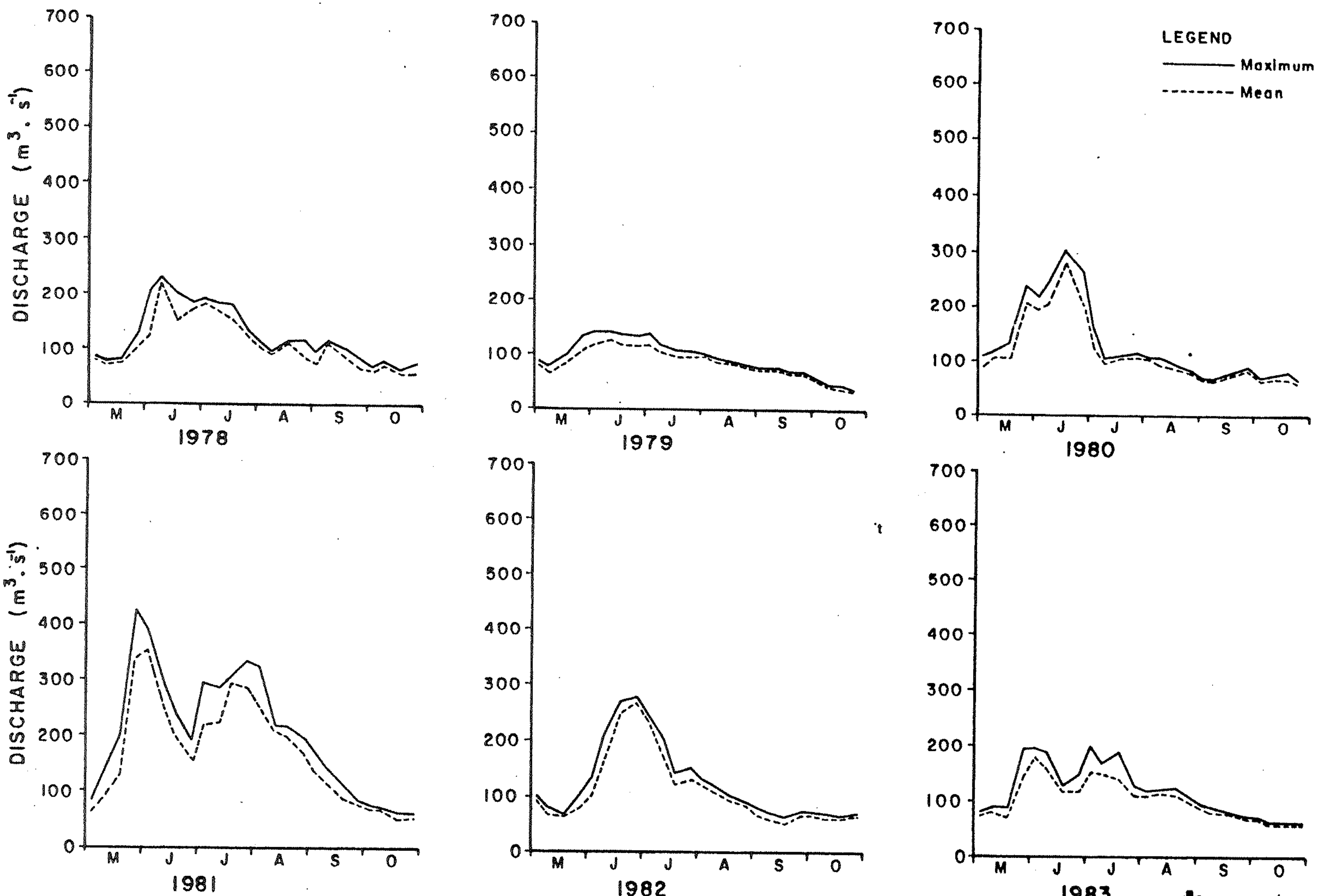

Figure 25. Mean weekly discharges for the Bow River at Calgary, 1978-83.

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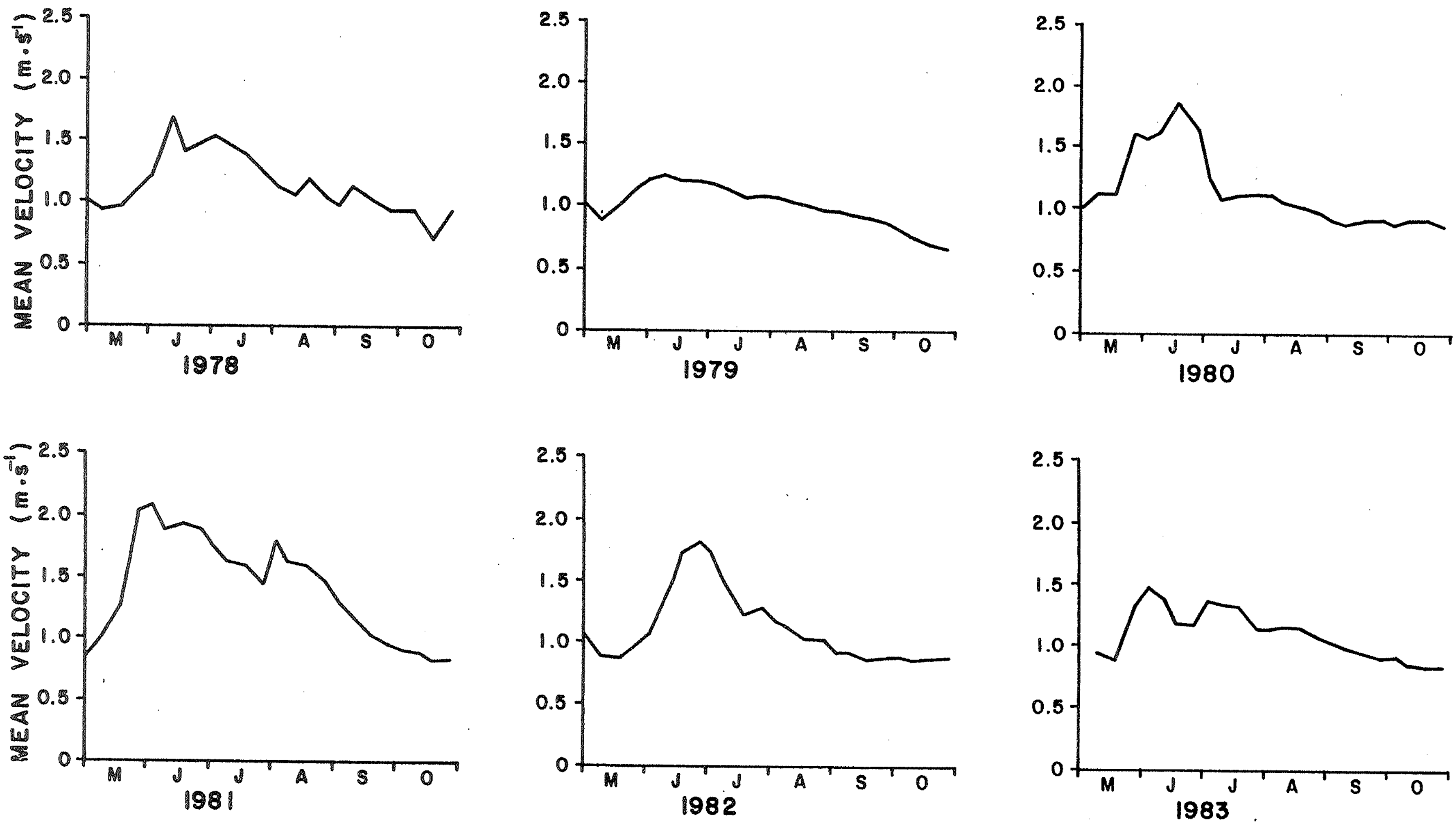

Figure 26. Mean weekly velocities for the Bow River at Calgary, 1978 - 83.

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temperatures generally range from 3 to 10° C with the exception of 1981 when temperatures were 8 to 10° C (Figure 27). Moreover, Bow River temperatures steadily increased and peaked on average at less than 18° C during late July or August. An exception occurred during 1981 when temperatures remained above 15° C until late September. The growth period was probably extended at that time. The average for September ranged from 11 to 13° C.

3.9.5 Bow River Course Trends (Chemical and Biotic)

3.9.5.1 Chemical (Dissolved Phosphorus)

During 1981 dissolved phosphorus (DP) concentrations were monitored for both left and right bank stations in conjunction with the biotic studies. Figure 28 depicts the average concentrations detected. Dissolved phosphorus was consistently low at Site M1 upstream of the Bonnybrook sewage treatment plant. At Site M2R dissolved phosphorus concentrations were raised by inputs from sewage treatment plant effluent. However, dissolved phosphorus values decreased between Sites M2R and M5R because of dilution and uptake. Inputs of Fish Creek sewage treatment plant effluent again raised the concentration of dissolved phosphorus at Site M6R. The concentration of dissolved phosphorus continually increased in a downstream direction at left bank stations as sewage treatment plant effluent was diffused into the entire river. Complete mixing had occurred between Sites M8 and M9 (Figure 28). Low dissolved phosphorus values at Site M10R reflected the dilution effect caused by the Highwood River water. The same general dissolved phosphorus river course pattern was exhibited during 1982, when overall average concentrations tended to be higher as a result of reduced river discharge (Cross *et al*. 1986).

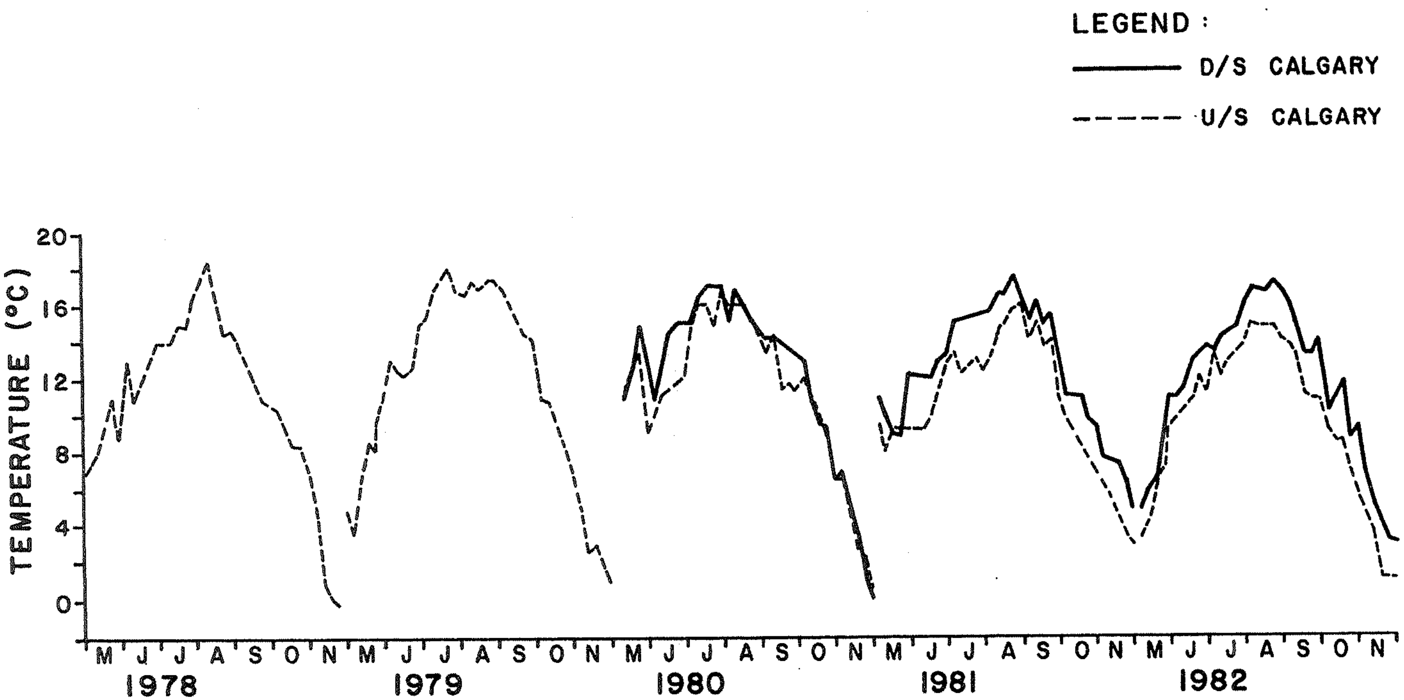

Figure 27. Mean weekly river temperatures in the Bow River upstream and downstream of Calgary.

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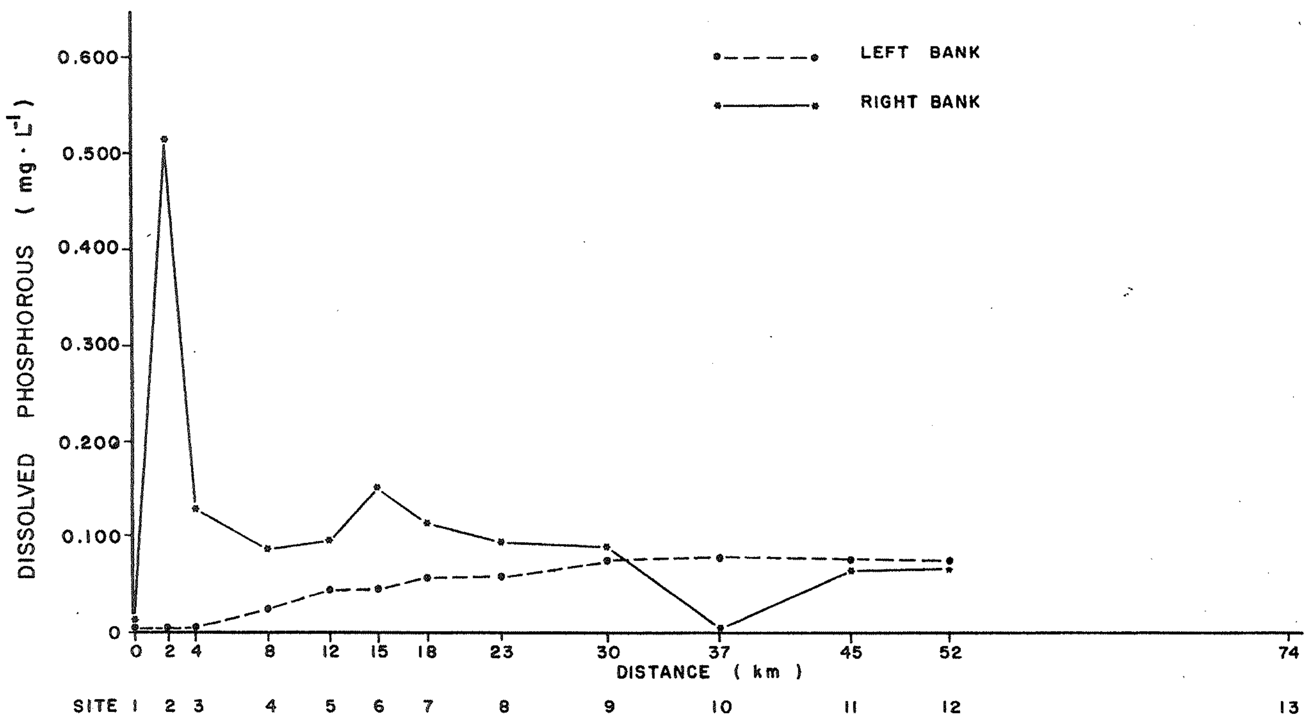

Figure 28. Ambient dissolved phosphorus concentrations for left and right bank stations in the Bow River downstream of Calgary (1981).

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3.9.5.2 Biotic (Peak Macrophyte Standing Crop)

As there was an observed phosphorus gradient between left and right bank locations and with downstream distance, the abundance of aquatic macrophytes was evaluated for similar trends. It was hypothesized that if a cause and effect relationship did exist between phosphorus and weed growth, then the average ambient phosphorus concentration at a particular river location should be correlated with peak macrophyte abundance. The peak, or terminal, biomass achieved in late August or early September was selected as the pertinent biomass parameter for two reasons. First, since macrophyte biomass accumulated over the entire growing season, (unlike benthic algae which has a rapid turnover rate), maximum biomass achieved is an integrator of growth conditions throughout the entire summer. Second, by specifically sampling the most prolific growth zones at each site the possible over-riding influence of physical control of growth was eliminated. In this section of the river spatial and temporal patterns in peak macrophyte biomass were tested statistically first. These patterns were then related to corresponding phosphorus concentrations.

A comparison of plant densities at the right and left bank sampling sites using paired Student's t-tests (Table 14), generally indicated bank to bank differences for sites closest to Calgary and, therefore, in the mixing zone of the effluent from the two Calgary sewage treatment plants. The Bonnybrook plant discharged upstream of Site M2 and the Fish Creek plant discharged between Sites

TABLE 14 Results of paired T-Tests comparing peak macrophyte biomass between right and left banks.

SITE	1981	1982	1983
M2	+	+	+
M3	+	+	+
M4	+	+	
M5	+	+	+
M6		+	+
M7		+	
M8	+		
M9	+		
M10			
M11			
M12		+	

M5 and M6. Downstream of Site M7, the macrophyte biomass tended to be similar along both sides of the river. Chemical data indicated complete mixing of the water system downstream of Site M9.

Analysis of variance followed by the Student-Newman-Keuls *a posteriori* test for significant difference between sample means was utilized to test for river course trends in peak biomass (Figure 29). The vertical lines indicate groups with common means. Only non-overlapping groups are significantly different ($P = 0.05$). A maximum downstream gradient in biomass was apparent along both banks in 1981. In the subsequent two years less variation existed between sampling locations.

For right bank sites in 1981, maximum densities occurred downstream of Bonnybrook and Fish Creek sewage treatment plants, while a progressive decrease was evident with distance below the city. The one anomaly to this pattern was the first right bank site immediately below the Bonnybrook sewage treatment plant effluent release. At this site, dry weights were lower than at the next downstream site, and at the sites downstream of the Fish Creek sewage treatment plant. In 1982 the gradient in right bank densities observed in 1981 was largely eliminated. Compared to other sites, plant densities in 1983 were significantly greater for right bank sites downstream of the two sewage treatment plant discharges.

Sites M2L and M3L experienced little or no macrophyte growth in any of the three years. During 1981 plant growth at the furthest downstream locations was reduced relative to sites closer to Calgary. This pattern was not apparent in the subsequent years when, with the exception of M2L and M3L, left bank densities were similar.

FIGURE 29 Analysis of Macrophyte Biomass Variance at Right Bank and Left Bank Stations downstream of Calgary (Student-Newman-Keuls procedure). Peak mean biomass in $g \cdot m^{-2}$

RIGHT BANK

1981

BIOMASS	SITE	GROUP			
0	M10	│			
0.06	M9	│			
0.13	M11	│	│		
0.18	M8	│	│		
0.25	M12	│	│		
0.43	M2		│		
0.45	M5		│		
0.47	M4		│		
0.80	M6			│	
0.97	M7			│	
1.23	M3				│

1982

BIOMASS	SITE	GROUP			
0.30	M12	│			
0.61	M11	│	│		
0.75	M10	│	│	│	
0.83	M5	│	│	│	
0.88	M8	│	│	│	
1.13	M9	│	│	│	
1.22	M4	│	│	│	│
1.27	M7	│	│	│	│
1.42	M3		│	│	│
1.62	M2			│	│
1.87	M6				│

1983

BIOMASS	SITE	GROUP			
0.63	M12	│			
0.81	M10	│			
0.85	M11	│			
0.88	M5	│			
1.07	M9	│			
1.17	M8	│			
1.47	M4	│	│		
1.62	M3	│	│		
2.16	M7		│	│	
2.52	M6			│	
3.18	M2				│

LEFT BANK

1981

BIOMASS	SITE	GROUP	
0	M2	│	
0	M10	│	
0.07	M3	│	
0.17	M9	│	
0.19	M11	│	
0.21	M12	│	
0.73	M4		│
0.76	M8		│
0.76	M7		│
0.78	M5		│
0.79	M6		│

1982

BIOMASS	SITE	GROUP		
0	M2	│		
0	M3	│		
0.57	M10		│	
0.62	M12		│	
0.67	M4		│	
0.67	M11		│	
0.68	M9		│	
0.72	M7		│	
0.96	M8		│	│
1.02	M6		│	│
1.22	M5			│

1983

BIOMASS	SITE	GROUP		
0	M2	│		
0	M3	│		
0.63	M9		│	
0.66	M12		│	
0.73	M6		│	
0.75	M10		│	
0.87	M5		│	
0.93	M4		│	
1.02	M11		│	
1.08	M7		│	
1.61	M8			│

Between year comparisons for each site (Table 15) indicate for right bank locations 1981 standing crops tended to be significantly less than corresponding densities for 1982 and 1983. Only at M2R, M7R and M12R was there a significant difference between 1982 and 1983. At left bank sites upstream of M7 and at Site M12R, there was no significant variation between any of the three years. The 1981 biomass was significantly less than that for the other two years for most downstream sites. Variation between 1982 and 1983 occurred only at Sites M7L and M8L.

Spatial patterns in plant density existed within the mixing zone, and there is also year to year variation. How these patterns related to average phosphorus concentrations in the surrounding water is presented in Figure 30. At sites that had extremely low average dissolved phosphorus concentrations, less than 0.005 $mg \bullet L^{-1}$, macrophyte biomass was considered essentially to be zero.

High macrophyte densities can occur at ambient dissolved phosphorus concentrations greater than 0.010 $mg \bullet L^{-1}$. Maximum plant densities in 1982 and 1983 were similar. However, ambient phosphorus concentrations were significantly less in 1983, following implementation of phosphorus removal at the two Calgary sewage treatment plants. The greatest variation in plant biomass between sites occurred in 1981, when there were low standing crops even at dissolved phosphorus concentrations ranging between 0.060 and 0.090 $mg \bullet L^{-1}$.

TABLE 15 Results of paired T-Tests comparing peak macrophyte biomass between years.

	LEFT BANK			RIGHT BANK		
SITE	1981/82	1981/83	1982/83	1981/82	1981/83	1982/83
M2				+	+	+
M3						
M4					+	
M5						
M6				+	+	
M7		+	+		+	+
M8		+	+	+	+	
M9	+	+		+	+	
M10	+	+		+	+	
M11	+	+			+	
M12					+	+

\+ - Statistically Significant

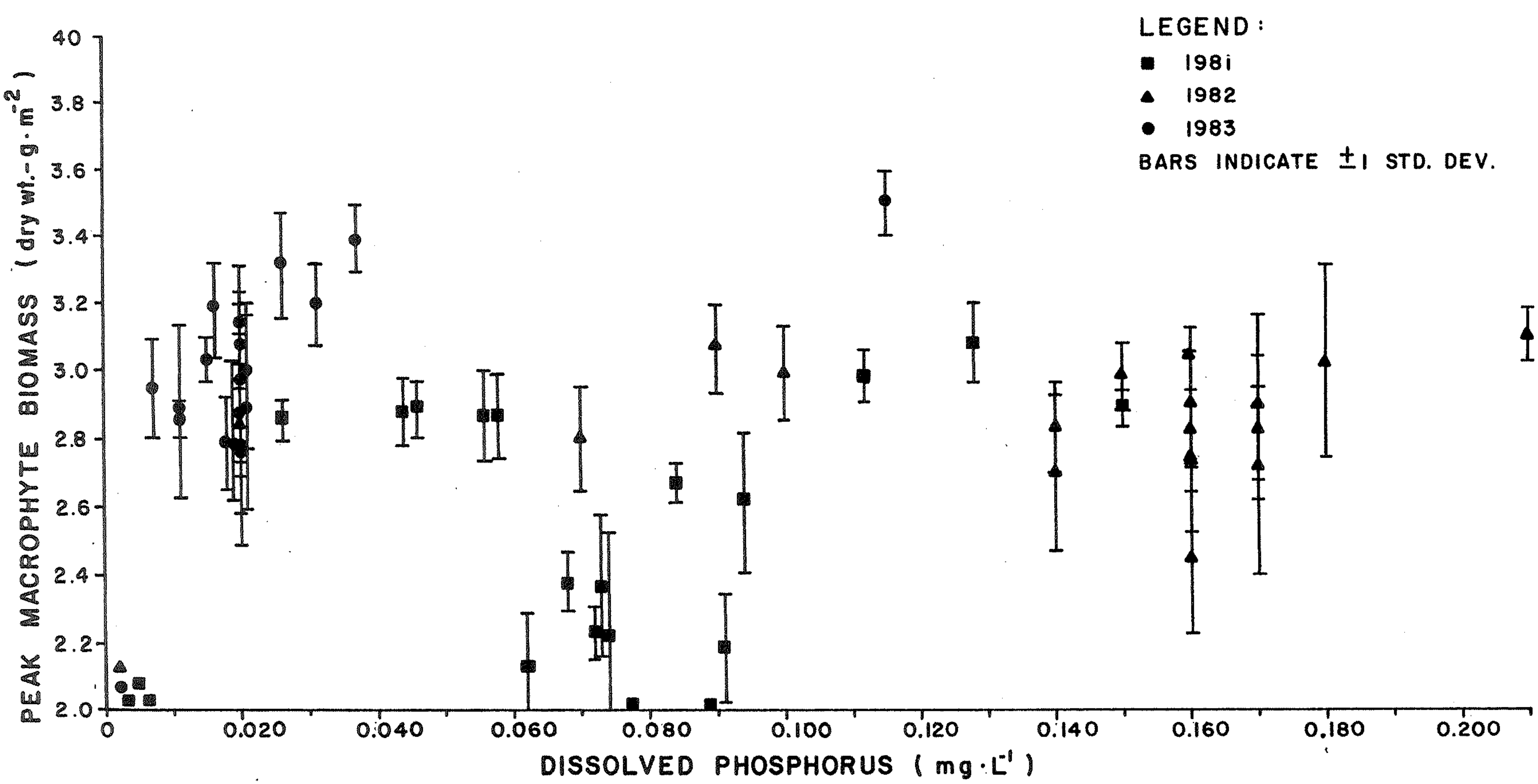

Figure 30. Macrophyte biomass (peak) in relation to ambient DP in the Bow River 1981 - 82.

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4.0 CLUSTER ANALYSIS

A multivariate analysis program entitled Clustan (Wishart 1975) was employed for both cluster and principal components analysis (PCA) of the extensive database acquired for the South Saskatchewan River Basin. Mean seasonal values for each variable were utilized to group (cluster) biological and chemical data. Cluster analysis included data for the seven periods from spring 1980 through fall 1981, inclusive.

Cluster analysis permitted grouping of river sampling station data based upon similarities among sites. Principal component analysis was then utilized to distinguish the variables which were most important for defining each cluster. This procedure included the calculation of a correlation matrix from which eigenvalues and eigenvectors were derived. The proportion of the total variance in the data can be explained by each eigenvector which was derived from the eigenvalue.

The following parameters were utilized: dissolved phosphorus, dissolved nitrogen, non-filterable residue, particulate organic carbon, pH, silica, epilithic chlorophyll _a_, ^{14}C uptake rate, number of Cyanophyta, Chlorophyta, Bacillariophyta, net radiation, temperature and discharge. Table 16 presents the site and seasonal components of each cluster in addition to the mean values for each variable contained in the clustered data. Figure 31 presents the distribution of the clusters in relation to the geographic location of each site. Sites located downstream of Site 5 on the Bow River, and the entire Oldman and South Saskatchewan River, were similar biologically and chemically within each season during fall, summer and

TABLE 16 Site, season and mean values associated with each cluster component for the South Saskatchewan River Basin 1980/81.

CHEMICAL, BIOLOGICAL AND PHYSICAL VARIABLES

GROUP CLUSTER	CHL a	PRO	DP	DN	NFR	POC	pH
1 (n = 12)	38	56	.038	.43	448	3.0	5.7
2 (n = 18)	96	144	.024	.29	17	.51	2.3
3 (n = 25)	44	31	.067	.66	26	.86	6.6
4 (n = 18)	71	48	.050	.67	21	.90	3.8
5 (n = 9)	283	99	.176	1.3	16	.85	11

GROUP CLUSTER	SI	DISC	LITE	TEMP	CYANO	CHLOR	BACI
1 (n = 12)	2.9	278	5.2	9.2	7.8	2.6	5.7
2 (n = 18)	1.5	115	5.4	19	15	6.5	7.1
3 (n = 25)	3.0	109	3.0	6.0	4.9	1.3	11
4 (n = 18)	.73	58	1.7	7.8	10	3.1	21
5 (n = 9)	3.1	91	3.7	7.4	7.7	11	41

CLUSTER GROUPING

CLUSTER	SITE	SEASON
1	3	P80, P81, W81
	4	P80, P81
	8	P80, P81
	9	P80
	10	P80, P81
	11	P81
	12	P81

CLUSTER	SITE	SEASON
2	3	S80, S81
	4	S80, S81
	8	S80, S81
	9	S80, S81
	10	S80
	11	S80, S81
	12	S81
	5	S80
	6	S80
	13	S80, S81
	7	S80, S81

CLUSTER	SITE	SEASON
3	3	F80, F81
	4	W81
	8	W81
	9	P81, W81
	10	W81
	11	W81
	12	W81
	1	P81, S80, S81 F80, F81, W81
	5	P81, S81
	6	P80, W81
	13	P80, P81, W81
	7	P80, P81, W81

CLUSTER	SITE	SEASON
4	4	F80, F81
	8	F80, F81
	9	F80, F81
	10	F80, F81
	11	F80, F81
	12	F80, F81
	6	F80, F81
	13	F80, F81
	7	F80, F81

CLUSTER	SITE	SEASON
5	2	P80, P81, S80, F80, W81
	5	P80, F80, F81, W81

P - Spring
S - Summer
F - Fall
W - Winter

Units are in $mg{\bullet}L^{-1}$ except: CHL a ($mg{\bullet}m^{-2}$), PRO ($mg{\bullet}m^{-2}{\bullet}h^{-1}$), pH (pH units), DISC ($m^3{\bullet}s^{-1}$) LITE ($MJ{\bullet}m^{-2}$), TEMP (°C), CYANO, CHLOR, BACI (cells x $10^9{\bullet}m^{-2}$)

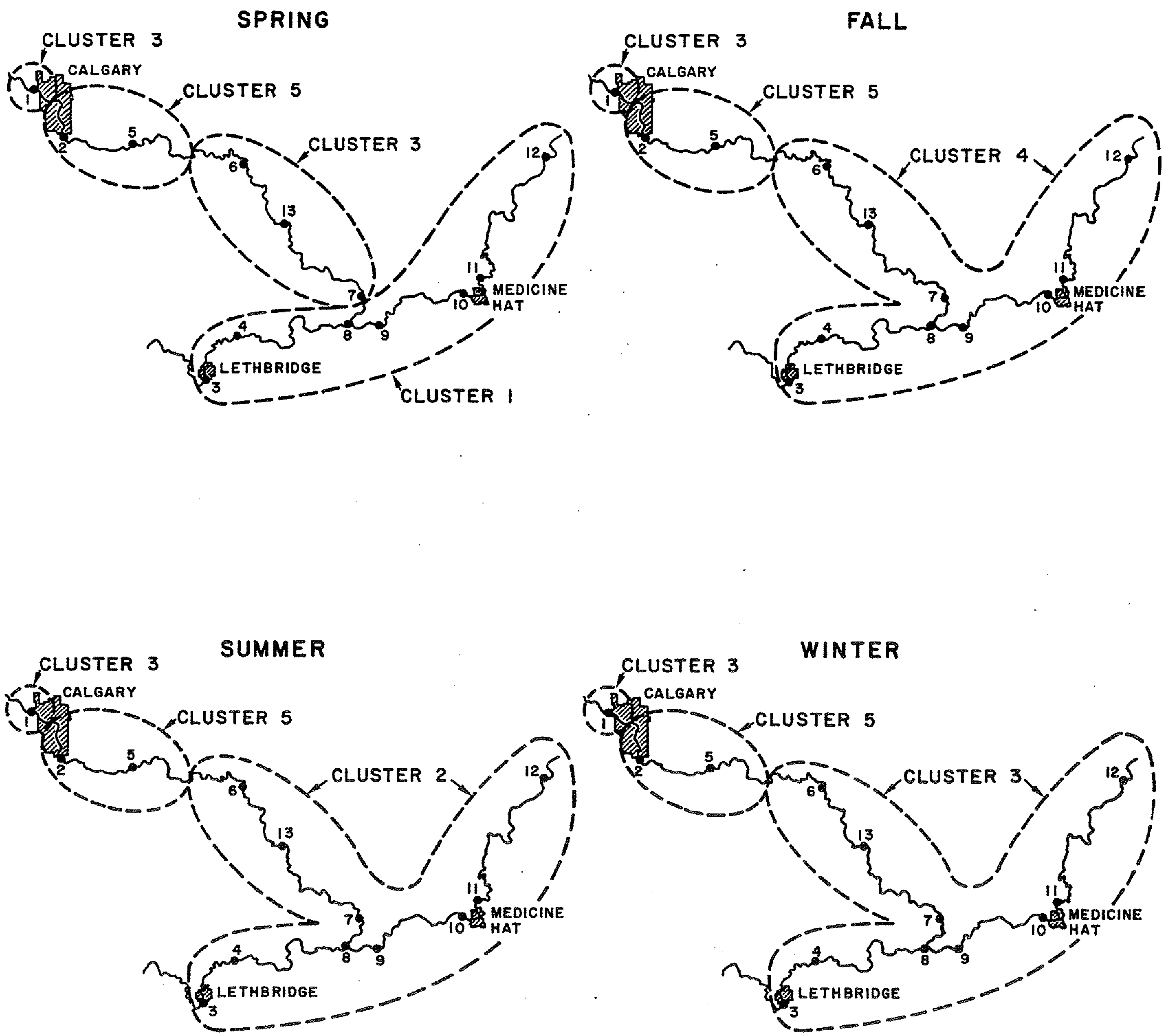


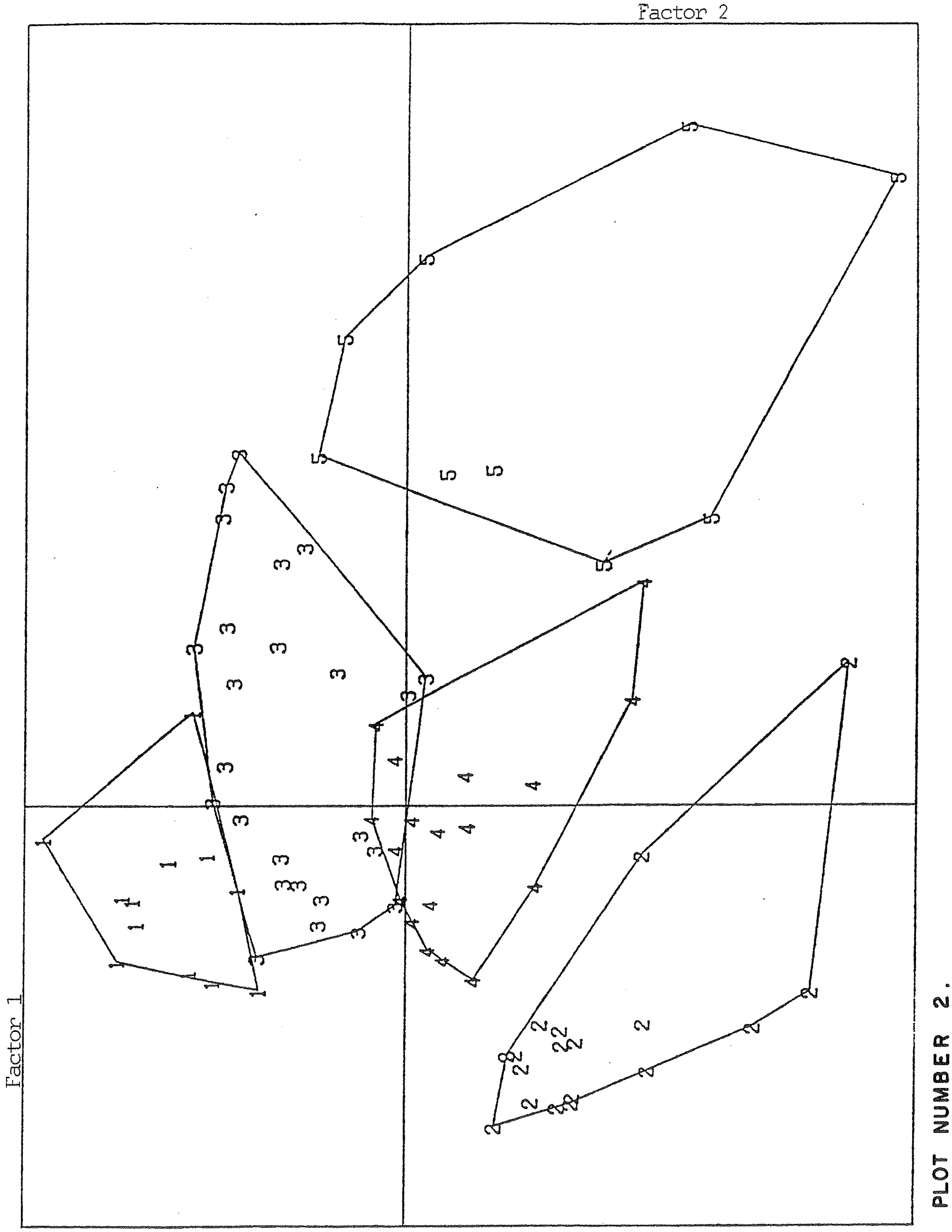
Figure 31 The distribution of clusters in relation to their geographic location and seasonal similarity for the South Saskatchewan River Basin .

winter. During the spring season, sites 6, 7 and 13 on the lower Bow River clustered separately from sites on the Oldman and South Saskatchewan rivers. Sites 2 and 5 immediately downstream of Calgary, and Site 1 upstream of Calgary (separately), consistently clustered for all seasons.

Figures 32 and 33 depict the specific distribution of clusters. Clusters 2, 4 and 5 were divided along the first vector. Twenty-eight percent of the variation that occurred in the first vector was accounted for by dissolved nutrients, specifically dissolved nitrogen and dissolved phosphorus. Clusters 1, 3 and 4 contained seasonal data that had intermediate nutrient concentrations but were divided along vector two. Non-filterable residue, particulate organic carbon and discharge accounted for twenty percent of the variation along this vector.

Cluster 1 (Figures 32, 33) contained spring data from sites on the Oldman and South Saskatchewan rivers. These sites had the highest values for non-filterable residue, particulate organic carbon and discharge and lowest values for benthic standing crop and numbers of Bacillariophyta. Scour and discharge related variables appeared to reduce algal standing crop, particularly diatoms, in the Oldman and South Saskatchewan rivers.

Cluster 2 contained summer data from all South Saskatchewan River Basin sites except those upstream of Calgary (Site 1) and immediately downstream of Calgary (Sites 2 and 5). Cluster 2 represented the lowest values for dissolved phosphorus, dissolved nitrogen, particulate organic carbon, H^+ ions (high pH) and the highest values for ^{14}C uptake (benthic productivity), temperature and numbers of Cyanophyta. Productive, predominantly blue-green algae, appeared to



SSRBECS CLUSTER AND PRINCIPAL COMPONENTS ANALYSIS - COMBINED PARAMETERS.

Figure 32. Graphic distribution of South Saskatchewan River seasonal data clusters.

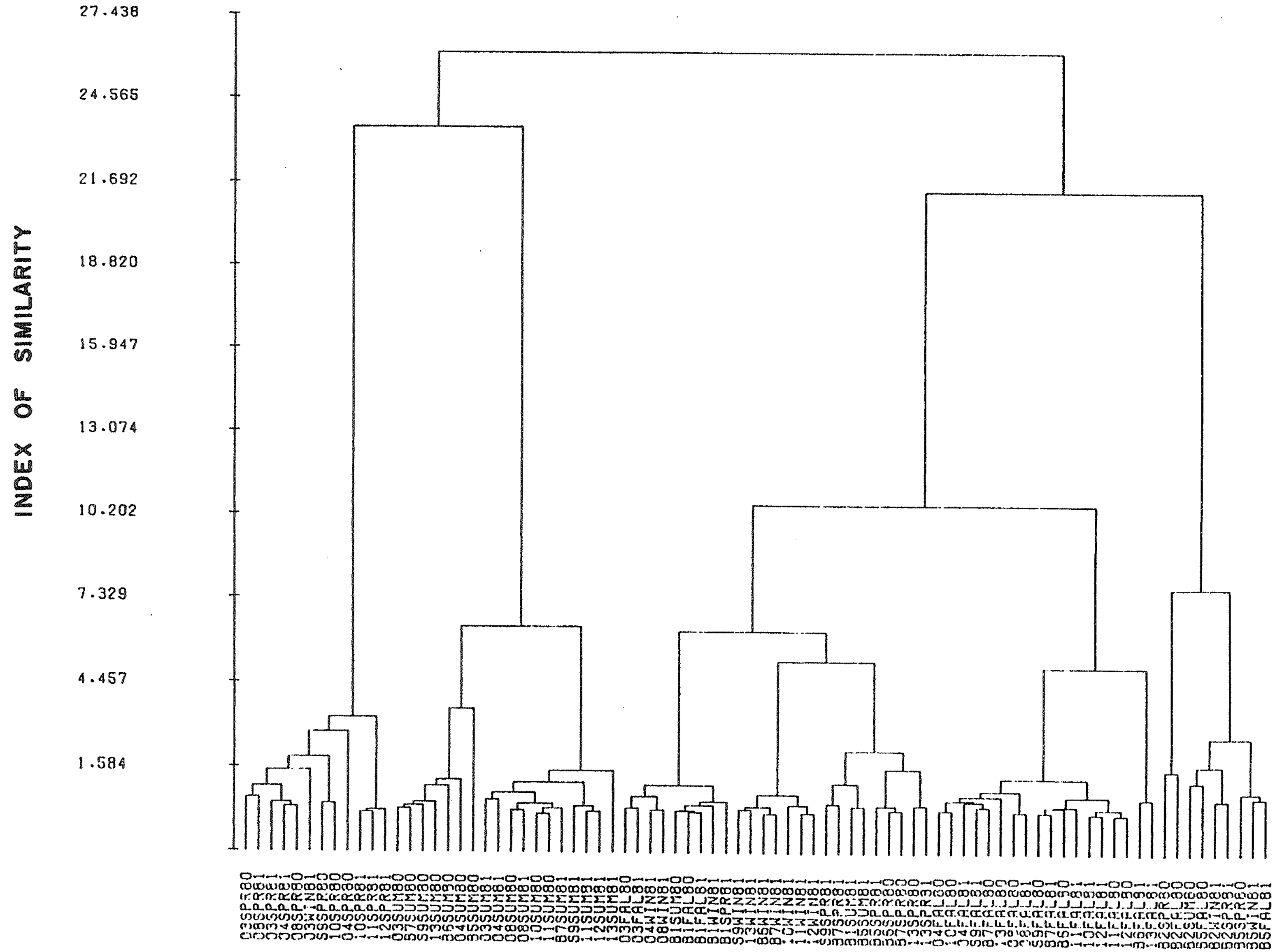


Figure 33. Dendrogramatic illustration of the South Saskatchewan River clusters and their principal components.

flourish in these reaches, even when dissolved phosphorus and dissolved nitrogen concentrations were low, during the warm water period.

Cluster 3 contained data for Site 1 in all seasons, most sites in winter and Sites 6, 13 and 7 in spring. This cluster was characterized by the lowest benthic productivity, temperature, numbers of Cyanophyta and Chlorophyta. The cold water period was particularly unproductive in the South Saskatchewan River basin at the time when Cyanophycean and Chlorophycean algae were least abundant numerically.

Cluster 4 contained mostly fall values and had the lowest concentration of silica, discharge and insolation. The dominant algae were diatoms and silica is a major component of diatom cell walls. Uptake of silica by diatoms reduced silica concentrations in the river water during the fall season.

Cluster 5 contained data from Sites 2 and 5 immediately downstream of Calgary. This cluster was characterized by the lowest non-filterable residue values and highest benthic standing crop, dissolved phosphorus, dissolved nitrogen, H^+ ions (low pH), silica, numbers of Chlorophyta and Bacillariophyta. This cluster represented the enriched zone of the Bow River where maximum macrophyte and benthic standing crops developed because of lack of scour and an abundance of nutrients. Benthic algal accumulations over the river substrate may have been self-limiting, and actually less productive than river areas where senescent algae were rapidly scoured away.

Following the cluster analysis, the periodic data and the original data (not seasonal means) were grouped according to their clusters and analyzed using regression techniques.

When all the periodic data were treated as a group, multiple regression analysis showed that benthic chlorophyll a was most highly correlated with dissolved phosphorus, temperature and discharge respectively. Simple regression analysis also showed the correlation with dissolved phosphorus, dissolved nitrogen and nitrate/nitrite. Productivity was found to have lower correlation coefficients that were particularly influenced by temperature, dissolved phosphorus and discharge.

Table 17 presents the results of the regression analyses including both the periodic and unaveraged data. Five clusters were defined and the relationships between epilithic primary producer chlorophyll a and ^{14}C uptake was compared between physical and chemical variables.

Analysis of Cluster 1 data (spring in Oldman and South Saskatchewan rivers) showed no strong relationships with biomass but productivity was correlated with phosphorus forms using periodic data, and particulate variables using unaveraged data.

Cluster 2 data (summer) showed a strong correlation between biomass and dissolved phosphorus, using multiple regression. Other phosphorus and nitrogen forms were also highly correlated using simple regression. Productivity was correlated with phosphorus forms and inversely correlated with temperature using periodic data. Productivity showed an additional inverse relationship with turbidity and silica using unaveraged data.

Multiple regression analysis of fall periodic data (Cluster 4) showed biomass most closely correlated to non-filterable residue, followed by discharge. Total phosphorus and particulate organic

TABLE 17 Results of regression analysis using periodic and unaveraged data for biomass and productivity vs. chemical and physical variables.

DATA SET	MULTIPLE REGRESSION Variables	MULTIPLE REGRESSION Coefficient	CORRELATION COEFFICIENT Variables	CORRELATION COEFFICIENT Coefficient	N
All data					
- Periodic	Chl vs DP	.60	Chl vs DP	.61	88
	Temp	.70	OP	.60	88
	Disc	.72	DN	.56	88
	Pro vs Temp	.38			
	DP	.46			
	Disc	.52			
	OP	.57			
Cluster 1					
- Periodic	Pro vs OP	.81	Pro vs OP	.81	12
	TP	.92	DP	.73	12
			PN	.69	12
			TP	.66	12
- Unaveraged			Pro vs Turb	.75	23
			TP	.75	23
			POC	.63	23
			PN	.62	23
Cluster 2					
- Periodic	Chl vs DP	.86	Chl vs DP	.83	21
			DN	.82	21
			Nit	.79	17
			OP	.78	21
			TP	.73	21
			Temp	-.69	18
	Pro vs DP	.73	Pro vs DP	.67	18
	TP	.83	OP	.56	18
			Temp	-.69	18
- Unaveraged			Chl vs DP	.69	63
			OP	.67	63
			Pro vs Turb	-.57	27
			Si	-.51	27
Cluster 3					
- Periodic	Chl vs Light	.65	Chl vs Light	.65	26
Cluster 4					
- Periodic	Chl vs NFR	.83	Chl vs NFR	.83	18
	Disc	.94	POC	.83	18
			TP	.71	18
	Pro vs Si	.48			
Cluster 5					
- Unaveraged			Pro vs DOC	-.55	24

carbon were also correlated using simple regression. Productivity was weakly correlated to silica.

Cluster 3 showed biomass correlated to light using periodic data and no strong correlations with productivity. Cluster 5 (Bow River Sites 2 and 5) showed no relationships using periodic data, but unaveraged data showed a negative correlation between productivity and dissolved organic carbon.

4.1 Predictive Equations

This investigation has provided evidence of the significant role of nutrients and physical factors in relation to the primary producers. Both biotic and abiotic variables were shown to fluctuate seasonally with some degree of similarity. Therefore, the relationships defined statistically during this study for Clusters 1 and 2 were utilized to formulate equations for predicting future primary producer abundance and productivity.

The highest correlation coefficient ($r = 0.81$) for predicting benthic algal productivity was obtained using average seasonal data for orthophosphorus from Cluster 1 (spring in the Oldman and South Saskatchewan rivers). A second linear correlation was found for predicting productivity using unaveraged data and total phosphorus. Benthic algal productivity in summer at all sites except 1, 2 and 5 on the Bow River (Cluster 2) can be predicted from summer average seasonal data, however the correlation coefficient was much lower.

The highest correlation coefficient for predicting benthic chlorophyll a ($r = 0.83$) was obtained using average seasonal data for dissolved phosphorus from Cluster 2 (summer at all sites except 1, 2 and 5 on the Bow River). Unaveraged data can also be used with a second equation for this prediction.

It would appear from the above comparisons that benthic algal productivity predictions may best be obtained using the following formula:

1) For spring average seasonal data in the Oldman and South Saskatchewan Rivers;

$$\text{Productivity} = 2.81 \bullet \text{orthophosphorus} - 5.66$$

where productivity is in mg carbon$\bullet m^{-2} \bullet h^{-1}$ and orthophosphorus is in $\mu g \bullet L^{-1}$ (10^{-3} $mg \bullet L^{-1}$)

2) For summer average seasonal data in the lower Bow, Oldman and South Saskatchewan Rivers;

$$\text{Biomass} = 3.05 \bullet \text{dissolved phosphorus} + 21.85$$

where biomass is in mg chlorophyll $\underline{a} \bullet m^{-2}$ and dissolved phosphorus is in $\mu g \bullet L^{-1}$ (10^{-3} $mg \bullet L^{-1}$).

5.0 DISCUSSION

All rivers change along their length with respect to such properties as temperature, depth, current velocity, substratum and chemistry. Moreover, it has been shown that rivers exhibit characteristic zonation with respect to a variety of physical, chemical and biotic variables (Hynes 1976; Guillory 1982; Vanlandingham 1976). Charlton and Hickman (1981) showed that northeastern Alberta rivers originating in muskeg wetlands are frequently more productive in their middle reaches. Although the Bow and Oldman Rivers originate in a mountainous region, they are similarly more productive within their middle reaches.

The merging of these two rivers results in the upper reach of the South Saskatchewan River supporting higher algal standing crops. Unlike northeastern Alberta rivers which are undisturbed, southern Alberta rivers are influenced by industrial, agricultural and domestic inputs, particularly phosphorus. This investigation has provided evidence of the role of phosphorus that resulted specifically in an amplification of primary producer abundance downstream of major nutrient inputs (i.e. downstream of Calgary and downstream of Lethbridge). A description of the temporal characteristics of the algae and macrophytes was also provided.

Lotic algal populations throughout the South Saskatchewan River Basin exhibited temporal patterns similar to those reported for Alberta rivers (Hickman et al. 1979; 1982) and other temperate regions of the world (Whitton 1975). With the exception of river regions supporting extensive macrophyte beds, the benthic algae flourished during the open water period. Spring and fall populations were predominantly diatoms which reduce silicate concentrations in the overlying waters. Diatoms occurred throughout the year in greater abundance in the zones of enrichment downstream of urban centres. Schelske et al. (1983), hypothesized that nutrient additions increased diatom production and the demand for silica, a major component of their frustules. The phenomenon results in the possible SiO_2 depletion and a shift to primary producers having no silica requirement. Macrophytes have a minimal silica requirement and have been shown to also flourish in the enriched lotic zones that received significant loadings of treated sewage effluent (Wong et al. 1976).

Green algae were the least abundant, numerically, of all the algae throughout the South Saskatchewan River Basin and their distribution was very patchy. Algae from this group were more abundant during the summer season. Blue-green algae (Cyanophyta) were the dominant, numerically, of all the algae throughout most of the South Saskatchewan River Basin and during every season. Benthic Cyanophycean algae are predominantly small, closely-adhering forms well adapted to a lotic existence. Macroscopic blue-greens, such as Nostoc spp., were particularly abundant in the upper and lower reaches of the Oldman River (Sites 3 and 8) and the upper reach of the Bow River (Site 1). Nostoc spp. are well-known nitrogen fixers and their occurrence was indicative of the potential for nitrogen limitation. Moreover, nitrate-nitrite seasonally averaged 0.04 $mg{\bullet}L^{-1}$ upstream of Calgary, 0.08 $mg{\bullet}L^{-1}$ upstream of Lethbridge (Site 3), and 0.13 $mg{\bullet}L^{-1}$ at Site 8 in the lower Oldman River. Findley et al. (1973) and Horne and Fogg (1970), noted that although there was no inverse correlation between the rate of nitrogen fixation and the actual concentrations of nitrate and total nitrogen, there was appreciable nitrogen fixation when nitrogen concentrations were less than 0.3 $mg \cdot L^{-1}$. Nitrogen fixation in the South Saskatchewan River Basin, therefore, was probably of some importance as nitrogen fixed and liberated by blue-green algae resulted in additional nutrients being added and ultimately being made available for the growth of other algae and aquatic plants.

Although the Bow and Oldman rivers both supported higher aquatic plant standing crops downstream of major nutrient inputs, the problem was particularly acute downstream of Calgary where growth occurred at very high levels. Results from this investigation have shown that discharge and related variables (i.e., velocity, non-filterable residue, turbidity, scour) play a major role with respect to biomass accumulation. The Bow River unlike the Oldman River, is a regulated river in which the effects of natural annual floods are dampened by weirs and dams. Thus perennial aquatic plants were well established in the Bow River and were rarely subjected to sufficient scouring for thorough removal. The Oldman River substrate, in contrast, is annually scoured to the extent that bed movement has been documented (Warner, 1973).

Attached algae, unlike macrophytes, are less firmly attached to the substrate and particularly sensitive to physical abrasion. Survival and success, therefore, command that this group of primary producers must grow and reproduce rapidly. Benthic algae have life spans ranging from a few days to weeks.

The rate of growth within the community was highly variable and directly related to the morphological characteristics of the individual community components, as well as to the overlying characteristics of the aquatic habitat. It was this complexity which contributed to the extremes of variation concerning algal standing crops and productivity in the South Saskatchewan River Basin.

During 1980, a "low flow" year, the benthic communities were more productive than during 1981, a "higher flow" year, despite the occurrence of similar standing crops. During 1981, only those species more firmly attached to the substrate overcame physical disruption. However, that type of community proved to be less actively absorbing ^{14} Carbon. During 1981, filamentous green algae such as Cladophora sp. were more abundant than during 1980, and they frequently formed long flowing masses. The development of this type of community resulted in shading and disruption of the less firmly attached matrix of macroalgae and bacteria. This reduced the apparent rate of ^{14}C uptake, and at the same time yielded high chlorophyll a estimates. Moreover, Cladophora sp. accumulated new actively-growing cells on the filament tips and retained fewer actively-growing cells for attachment. Again, this contributed to a high chlorophyll a estimate of algal standing crop (which is not particularly active photosynthetically). Therefore, caution is warranted with respect to the interpretation or classification of lotic systems using any particular assay.

Throughout the South Saskatchewan River Basin the benthic algae and macrophytes underwent distinct temporal maxima. The patterns, although similar throughout the Basin, are moderated by the availability of nutrients, the suitability of bottom substrates, competition and consumption by other organisms, temperature, turbidity and light. The factors that most affected benthic algae and macrophytes were nutrients (orthophosphorus, dissolved nitrogen) and discharge velocity. Physical factors have been shown to override the stimulating effects of nutrient additions upon the primary producers. Under the circumstances, dissolved phosphorus concentrations of 0.060-0.090 $mg \bullet L^{-1}$ failed to produce high macrophyte standing crops. Therefore, the use of critical or growth controlling concentrations of phosphorus at 0.060 $mg \bullet L^{-1}$ (Wong _et al_. 1976) as an indicator of the potential for primary producer growth requires careful interpretation and evaluation when applied to lotic systems.

6.0 SUMMARY

Lotic systems in southern Alberta are precariously balanced ecological systems existing in close proximity to man. During the past 100 years, they have been particularly vulnerable to man's uses and abuses. The rivers range from small crystal clear, (upper Bow River, upper Oldman River) streams that are remarkably uniform in flow and composition, to larger water courses subjected to violent fluctuations in biotic composition, chemical characteristics and discharge.

The middle reaches are enriched by nutrient additions of domestic, industrial and agricultural origin, which stimulate the primary producers. The lower reaches of the Bow, Oldman and the entire South Saskatchewan River are chemically and biologically similar seasonally. Nitrogen is a particularly important, possibly-limiting nutrient in the lower Oldman River. Phosphorus, discharge and temperature are the variables (limiting factors) controlling the development of primary producers throughout the South Saskatchewan River Basin. Physical factors have also been shown to exert a major controlling influence on the primary producers.

6.1 Conclusions

1. The South Saskatchewan River Basin supports a productive, diverse plant association.

2. With the exception of Medicine Hat, plants are most abundant downstream of urban centres.

3. Macrophytes are most abundant downstream of Calgary while algae (epilithic) dominate throughout the remainder of the basin.

4. Primary producer standing crops were highly correlated with phosphorus and nitrogen concentrations.

5. Physical and chemical factors primarily control aquatic plant standing crops in the South Saskatchewan River Basin.

6. The Bow and Oldman rivers exhibit higher standing crops throughout their middle reaches.

7. Primary producers exhibit temporal (annual and daily) fluctuations of primary productivity and standing crop. They are extremely opportunistic and extremely well adapted to the dynamic nature of lotic systems.

7.0 GLOSSARY OF ABBREVIATIONS

ABBREVIATION	DEFINITION
A:M	Algal, Macrophyte ratios
Baci	Bacillariophyta
C	Carbon or Celsius depending on usage
^{14}C	Carbon 14 isotope
Chl	Chlorophyll
Chl _a_, chl _a_	Chlorophyll _a_
Chlor	Chlorophyta
cm	centimeter
cm^2	square centimeter
cm^{-2}	per square centimeter
corr.	correlation
Cyano	Cyanophyta
D	degrees
Dev.	deviation
DIC	dissolved inorganic carbon
disc	discharge
diss	dissolved
DN	dissolved nitrogen
DOC	dissolved organic carbon
DP	dissolved phosphorus
d/s	downstream
dwt	dry weight
EP	epilithic
ft^2	foot squared
g	grams
GF/C	cellulose glass fiber filter
H	helicopter river course survey sites
H^+	Hydrogen ion/s
hr	hour
hr^{-1}	per hour
Hwy.	highway
JTU	Jackson turbidity units
L	left bank of the river
L	litre
L^{-1}	per litre
log	logarithm
M	minutes
m	meter
m^2	square meter
m^{-2}	per square meter
m^{-3}	per cubic meter
$meq \bullet L^{-1}$	milliequivalents per litre
mg	milligram
$\mu mhos \bullet cm^{-1}$	micro mhos per centimeter; for measuring electrical conductance

µg	micrograms
MJ	mega joules; units for measuring light
mL	millilitres
mm	millimeter
MST	Mountain Standard Time
N	nitrogen
n	number of samples or specimens
NFR	non-filterable residue
NFFR	fixed non-filterable residue
No.	number
OMR	Oldman River
OP	ortho phosphorus
P	phosphorus
p	probability of the event not occuring
P.A.R.	photosynthetically available radiation; 460 - 720 nm wavelength
PCA	principle component analysis
pH	concentration of hydrogen ions in pH units
phy	phyto-planktonic
POC	particulate organic carbon
PRO	productivity
R	right bank of the river
r	Pearsons product moment coefficient; measure of linear association
r^2	coefficient of determination; strength of the linear association
S	standard error of the mean
s	second
s^{-1}	per second
S.D.	standard deviation
sec	second
Si	silica, silicates
sp.	species
spp.	species
SPSS	Statistical Package for the Social Sciences
SSR	South Saskatchewan River
std.	standard
STP	sewage treatment plant
T	time
TN	total nitrogen
TP	total phosphorus
u/s	upstream
vs	versus
wt	weight
x	mean of the sample
=	equal to
<=	less than or equal to

8.0 REFERENCES

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