Vegetation patterns in James Bay coastal marshes. II. Effects of hydrology on salinity and vegetation

Jonathan S. Price[1]
Department of Geography, McMaster University, Hamilton, Ont., Canada L8S 4K1

Kern Ewing[2]
Department of Biology, McMaster University, Hamilton, Ont., Canada L8S 4L8

Ming-ko Woo
Department of Geography, McMaster University, Hamilton, Ont., Canada L8S 4K1

AND

Kenneth A. Kershaw
Department of Biology, McMaster University, Hamilton, Ont., Canada L8S 4L8

Received September 23, 1987

Price, J. S., Ewing, K., Woo, M-K., and Kershaw, K. A. 1988. Vegetation patterns in James Bay coastal marshes. II. Effects of hydrology on salinity and vegetation. Can. J. Bot. **66**: 2586–2594.

The vegetation of a coastal marsh in southern James Bay was examined in reference to the salinity and hydrological processes. Regional hydrologic influences related to the freshwater budget of James Bay reduce the local salinity so that the vegetation typifies that of a fresh to brackish marsh system, in contrast to the Hudson Bay salt marshes reported in the literature. Thus species that thrive in areas of higher salinity have only limited occurrence at the study site. Infrequent tidal inundation of low salinity bay water diminishes surface salinity, which is primarily controlled by the interaction of marsh hydrology with fossil salt diffusing upward from postglacial deposits. The soil water salinity increases with depth and distance inland. However, local hydrologic gradients near raised beach ridges and incised stream channels affect surface runoff and groundwater recharge and discharge, producing further distinct spatial variations in salinity. These processes thus control the distribution of saline water in the rooting zone and hence the patterns of vegetation.

Price, J. S., Ewing, K., Woo, M-K., et Kershaw, K. A. 1988. Vegetation patterns in James Bay coastal marshes. II. Effects of hydrology on salinity and vegetation. Can. J. Bot. **66** : 2586–2594.

La végétation d'un marais côtier dans le sud de la baie James a été examinée par rapport à la salinité et les processus hydrologiques. Les influences hydrologiques régionales en rapport avec le bilan hydrique de la baie James causent une réduction de la salinité locale, donnant ainsi lieu à une végétation de type carctéristique des systèmes marécageux frais à saumâtre, par contraste aux marais salants de la baie d'Hudson mentionnés dans la littérature. Ainsi les espèces qui poussent bien dans des secteurs de forte salinité sont rarement présentes dans le site étudié. Des inondations occasionnelles d'eau à faible salinité de la baie, dues aux marées, diminuent la salinité à la surface, cette salinité étant principalement déterminée par l'interaction entre l'hydrologie des marais et le sel fossile qui diffuse vers le haut à partir des dépôts post-glaciaires. La salinité de l'eau du sol augmente avec la profondeur et avec la distance dans les terres. Cependant, les gradients hydrologiques locaux près des récifs côtiers et des chenaux creusés par le courant affectent l'écoulement superficiel et le recharge et la décharge de l'eau du sol, produisant davantage de variations spatiales distinctes de la salinité. Ainsi, ces processus contrôlent le distribution de l'eau saline dans la zone d'enracinement et, par conséquent, les patrons de la végétation.

[Traduit par la revue]

Introduction

Salinity strongly affects the distribution of vegetation in salt and brackish marshes (Clark and Hannon 1970; Tyler 1971; De la Cruz 1974; Mahall and Park 1976; Zedler 1977; Jaworski and Tedrow 1985), as well as the performance of perennial species along environmental gradients (Rozema and Blom 1977; Deschenes and Serodes 1985). The productivity of most salt marsh species is depressed as salinity increases (Rozema 1977; Smart and Barko 1980; Pearcy and Ustin 1984), so that salinity can be used to predict the distribution of species in coastal marshes (Hutchinson 1982; Ewing 1983). Similarly, correlations between the distribution of dominant species and salinity levels have been established in the Arctic (Jefferies 1977), Hudson Bay (Jefferies et al. 1979), and James Bay lowlands (Ringius 1980; Glooschenko and Harper 1982).

More recently, Ewing and Kershaw (1986) have shown that the vegetation composition of coastal marshes to the south of James Bay contrasts markedly with that in the more northerly regions of Hudson Bay, which has a higher occurrence of salt tolerant species. This may be due to differences in the climate, hydrology, and offshore salinity of southern James Bay. Price and Woo (1988a) found that marshes throughout the Hudson Bay Lowland receive fossil salt from underlying marine sediments deposited during the postglacial Tyrrell Sea episode. Upward molecular diffusion, locally enhanced by groundwater movement, has transported this salt to the marsh surface (Price and Woo 1988c). The objective of the present study is to examine the roles of tidal inundation and hydrologic processes in modifying the marsh salinity and hence the vegetational composition in several coastal morphological zones of the southern James Bay marshes.

The study area

The study area (51°10'N, 79°47'W), located at the southern tip of James Bay just west of the Harricanaw River (Fig. 1), has a conti-
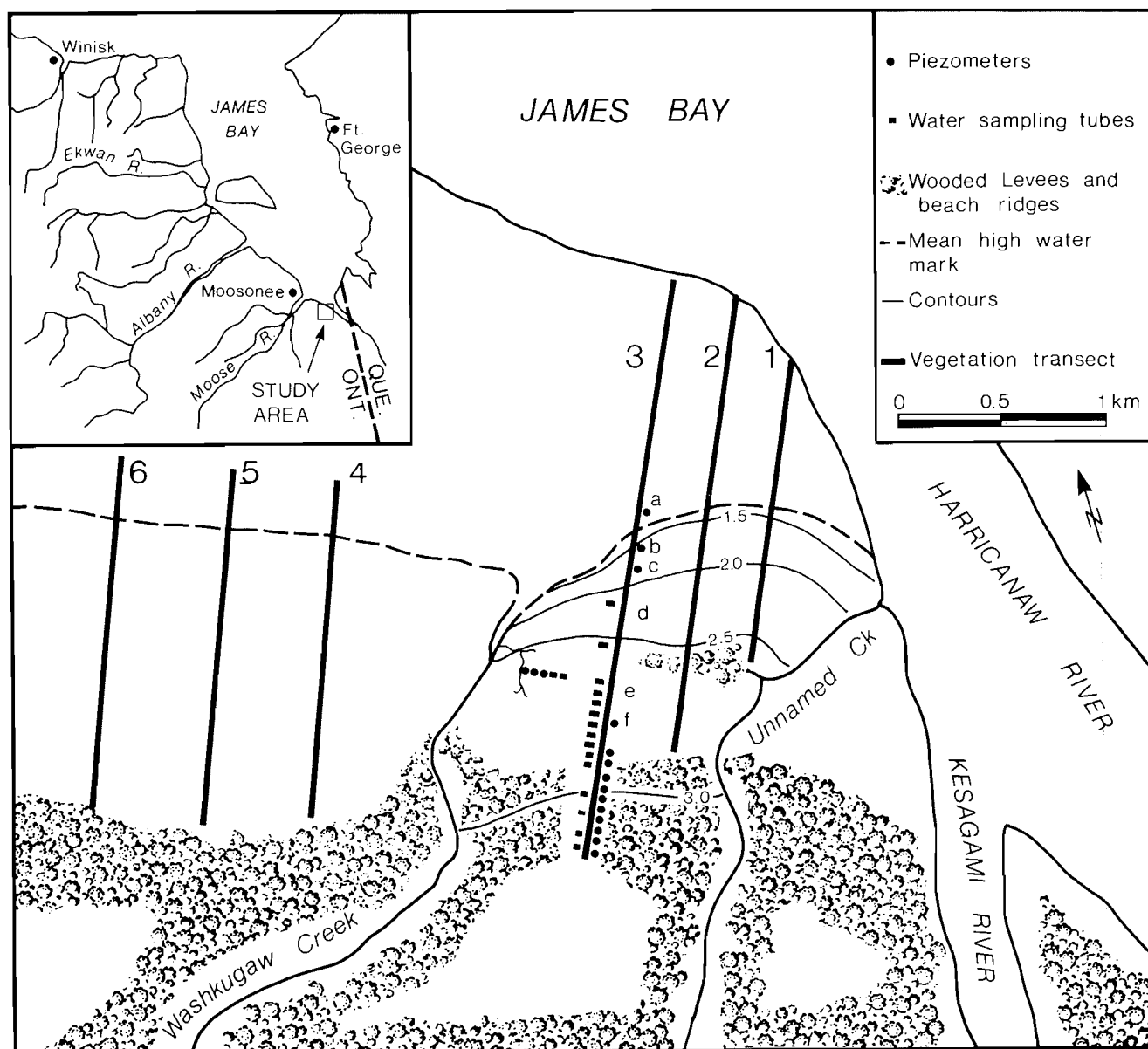
FIG. 1. Study location and details of the vegetation transects and the piezometric and salinity monitoring installations. Elevation contours are given in metres.

nental subarctic climate with mean January and July temperatures of −20.0 and 15.5°C, respectively. Mean annual precipitation is 727 mm, 30% of which falls as snow (Environment Canada 1982).

The area is underlain by paleozoic sedimentary rock (Hutton and Black 1975). The penetration of Atlantic waters into the area during the Holocene formed the postglacial Tyrrell Sea about 8000 years ago, depositing sparsely fossiliferous blue silty clay (Martini 1981). These clays are found at depths of 1.7−2.2 m and are overlain by more recent silty marine sediments. The hydraulic conductivity of the marine clay is in the order of 10^{-10} m/s and the overlying silts $10^{-6} - 10^{-8}$ m/s (Price and Woo 1988b). After deglaciation the coast has been uplifting isostatically. As the land rises continuously, peat is accumulated. The peat thickness increases from zero at 500 m shoreward from mean high water (MHW) to 0.30 m on the second major raised beach ridge that is the landward limit of the study area. The hydraulic conductivity of the peat layer ranges from 10^{-4} to 10^{-6} m/s (Price and Woo 1988b).

The topography is characterized by raised beaches formed parallel to the coast, spaced approximately 500 m apart. These ridges are formed from reworked sands and silts deposited by tidal flooding.

Considering the average rates of isostatic rebound of 0.7−1.25 m per century (Webber et al. 1970) and the average coastal gradient (0.001), progradation is approximately 1 km each century. The present coast is washed by semidiurnal tides with an amplitude ranging from 0.7 to 3.0 m (Martini 1981).

Methods

The vegetation composition and its associated hydrologic regime were studied in detail between April 1984 and November 1985 along a typical transect (transect 3) parallel to other replicate transects (Ewing and Kershaw 1986). Water samples were collected from 22 nests of 20 mm pipes slotted and screened at the lower 0.15 m. These were installed at depths ranging from 0.25 to 2.5 m, with two to six tubes per nest, and were bailed 24 h prior to sampling to remove the stagnant water. Salinity was measured within 48 h with an optical refraction salinometer. Chloride concentration in soil samples was determined by adding a known volume of deionized water to dried crushed soil samples of known mass and water content. After 24 h with frequent stirring the chloride content of the supernatant was
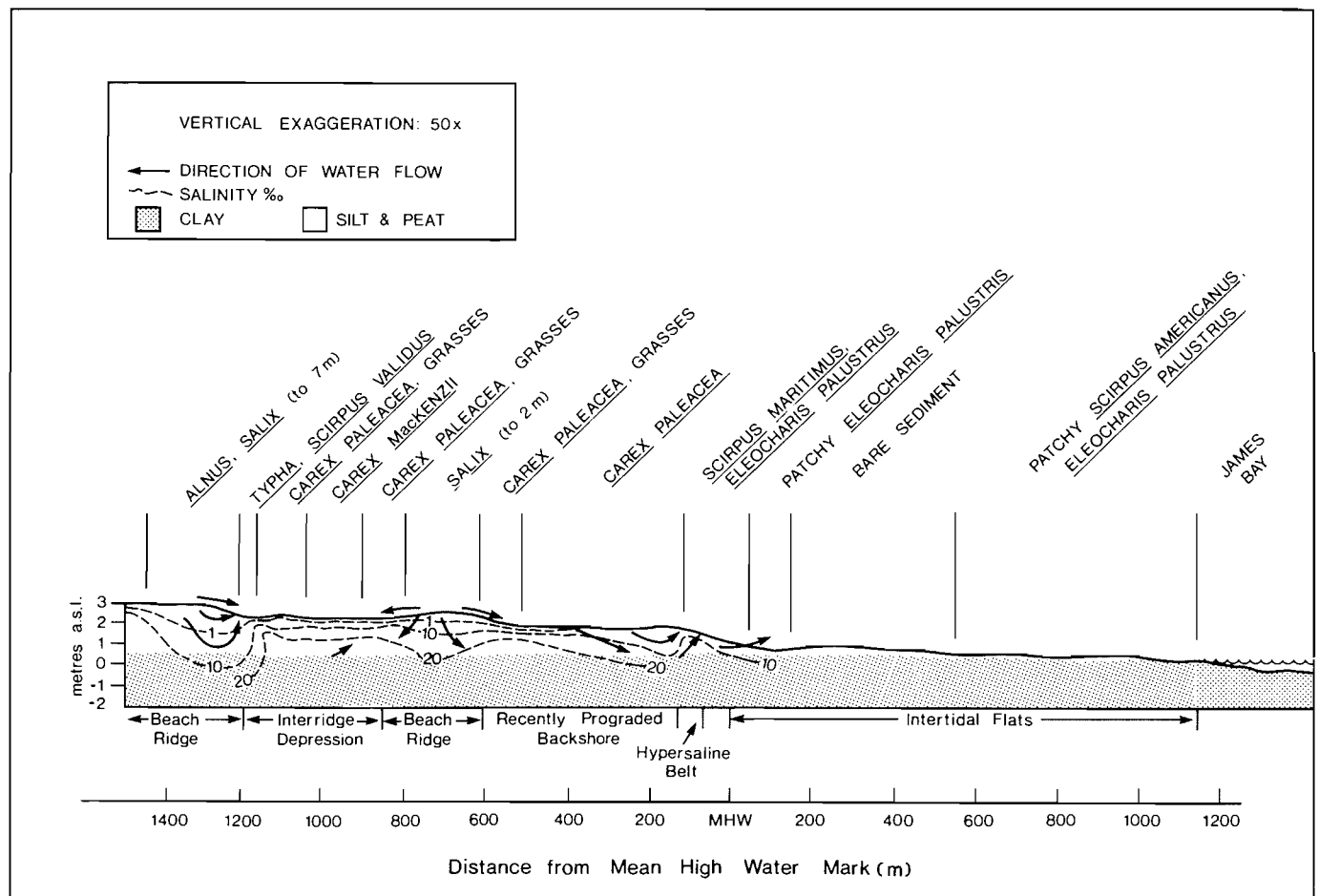
FIG. 2. Profile of transect 3, indicating geomorphic zonation, generalized lithologic strata, salt distribution, direction of groundwater and surface flow, and general vegetation distribution.

measured with a combination chloride electrode. Supernatant chlorinity was then reduced to pore water chlorinity based on the original moisture content of the sample and converted to total salinity for comparison with pore water salinities.

To obtain information on groundwater movement along the transect, 6 mm i.d. piezometer tubes with 0.1 m slotted screened intakes were installed at depths of approximately 0.5, 0.9, 1.4, and 1.9 m at the locations shown in Fig. 1. Rainfall was measured with a tipping bucket rain gauge and infiltration was measured with a 165 mm diameter ring infiltrometer.

Dilution of ponded water by surface inflow was measured with an open cylinder (0.3 m diam.) inserted into the soil to isolate a study plot from surface and near-surface flow, while still allowing evaporation, rainfall, and vertical groundwater and salt exchange. Two flexible bladders half filled with water were connected below the water level (one inside the cylinder, one outside) so that the pressure heads inside and outside the cylinder equilibrated without artificially inducing vertical flow in the cylinder. Tide data were collected in July and August 1984–1985 using a pressure transducer linked to a water level recorder at the mouth of the Harricanaw River and related to manual staff gauges surveyed into the groundwater network. For the periods April to June when the tide gauge was not operational, the major tide peaks were estimated from a water level recorder on Washkugaw Creek.

To measure vegetation, three transects were established to the east of Washkugaw Creek and three to the west (Fig. 1). All were approximately perpendicular to the shoreline and extended from the outer edge of emergent vegetation in the intertidal flats to the second beach ridge where woody vegetation occurs. Transect 3 (Fig. 2) was chosen as typical of the area and was used for the detailed hydrologic study.

A multivariate analysis procedure (TWINSPAN) used to develop vegetation groupings was reported by Ewing and Kershaw (1986).

Results and discussion

The water flow patterns and generalized vegetation groupings associated with the characteristic geomorphic features of transect 3 are shown in Fig. 2. Water flows along the regional gradient toward the coast, but is interrupted by beach ridges that cause ponding and groundwater discharge in the interridge depressions and groundwater recharge beneath the ridges (Price and Woo 1988b). There is a downward increase in salinity, from 0–1 ppt (parts per thousand) near the surface, to 10–20 ppt at a depth of 2.5 m. The high salinity at depth is related to the presence of connate groundwater that has higher salinity than the present James Bay at this location. The bay water in this vicinity was 0–2 ppt during the summer (Table 1). Tide data for the 1984–1985 (Fig. 3) indicate that only 4% of the tides exceeded 1.5 m in height (see Fig. 1) and thus rarely inundate the backshore of the study area. Most of these tides had a total salinity of 1 ppt or less. The highest tide (2.9 m) occurred in early October 1985, with a salinity of approximately 4 ppt. The elevation of this tide was estimated from the strand line, the salinity from samples of ponded water collected November 12, 1985, and the date from a local trapper. The only complete annual record of tide data available for James Bay is for Fort George, Quebec, in 1977–1978 (Canada Centre for Inland Waters, unpublished data). The
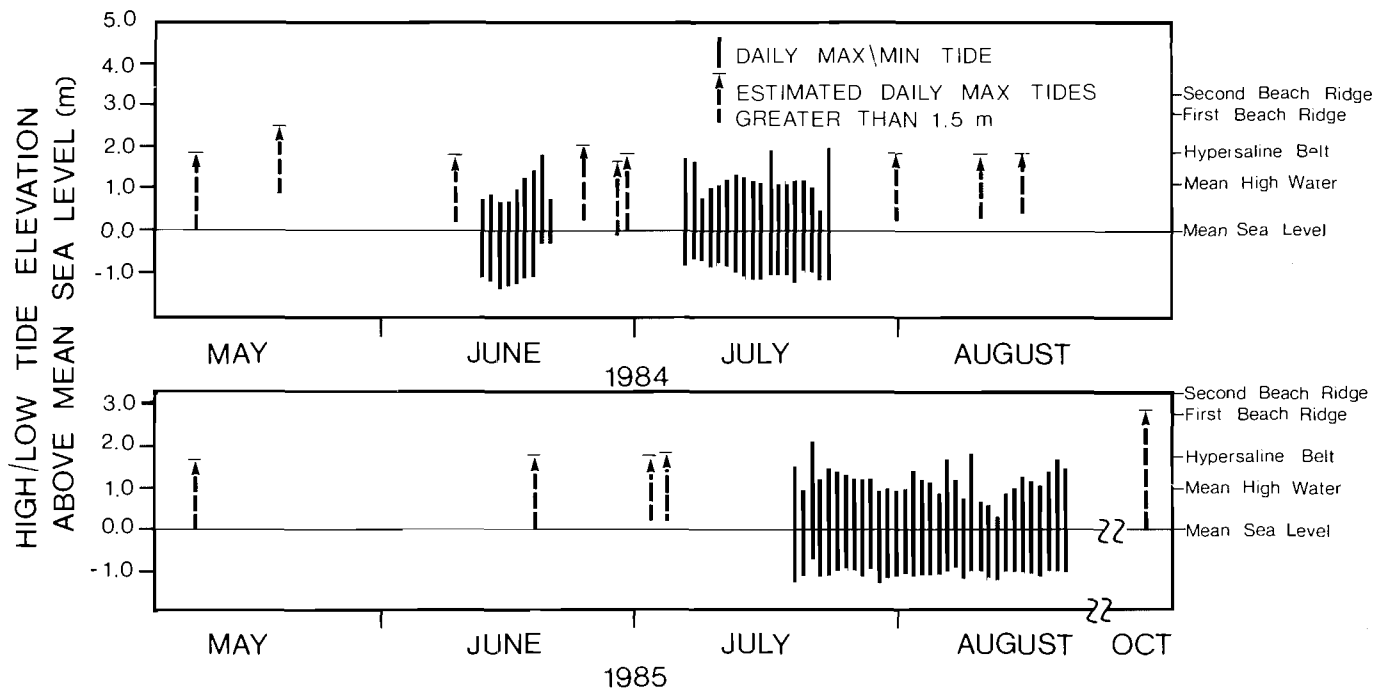
FIG. 3. Highest and lowest of the daily semidiurnal tides. The landward extent of tides of a given elevation can be determined from elevation contours in Fig. 1. Broken lines represent tides exceeding 1.5 m that were estimated from tidal spikes on Washkugaw Creek before the tide gauge was operating. Approximate elevation of geomorphic zones are given on the right-hand side.

TABLE 1. Tide salinity data (ppt) for samples near transect 3

Date	Salinity	Tide
1984		
April 15	0*	High
April 17	0	Low
May 6	0	Low
May 19	0	Surge (2.3 m)†
June 20	<1	High
July 5	1−2‡	Low
Aug. 4	0‡	Low
Aug. 20	2§	
1985		
July 11	0	Low
July 14	0.5	High
July 22	0.5	Surge (2.1 m)†
Aug. 18	1	High
Oct. 20	4‖	Surge (2.9 m)†

*Zero readings are below detection limit (<0.5 ppt).
†Maximum elevation of surge.
‡Samples east of Washkugaw (transects 4−6) on this date measured 2−4 ppt.
§5 km offshore at 3 m depth.
‖Samples of ponded water collected Nov. 12, height estimated from strand line.

exceedance probability for given tide heights at this location is approximately lognormally distributed (Fig. 4) and shows the low frequency of major inundation for this 1 year of record. Tidal surges with such low frequency and low salinity as observed in the study area indicate their limited direct effect beyond the MHW zone.

The 13 plant communities derived using TWINSPAN (Ewing and Kershaw 1986) and their geomorphic and hydrologic characteristics are summarized in Table 2. There is a general succession, progressing from the intertidal flats to the raised beaches (Fig. 2). This has developed in response to (i) the isostatic uplift of this region following the Wisconsin glacial period, (ii) the unique source of salt, and (iii) local hydrological processes associated with each geomorphic zone. These zones are described below.

Intertidal flats

The lower portion of the intertidal flats, defined here as the area more than 150 m seaward of MHW (Fig. 2), is characterized by a low topographic gradient (<0.001) and a thin layer (0.2−0.4 m) of sandy sediments overlying marine clay. In the upper intertidal flats nearer MHW, the topographic gradient increases to 0.004, apparently due to active sedimentation that has increased the thickness of the sediment layer to 1.1 m at the MHW mark. The upper 0.9 m of this layer is mostly silt and fine sand, with medium to coarse sand in the lower 0.1−0.2 m.

Most of the lower flats remain saturated because of inadequate drainage caused by the low gradient and relatively short periods of exposure at low tide. The low salinity (0−4 ppt) in the thin layer of sediments overlying the marine clay (Fig. 5) reflects the average salt content of the tidal water.

Nearer to MHW, the steeper gradient and longer period of exposure improve lateral drainage and enhance drying through evaporation. The diurnal increase in concentration due to evaporative drying is masked by the regular infiltration of low salinity tidal water during inundation (Fig. 5). The frequent changes in direction and magnitude of the hydraulic gradient caused by cyclical wetting and drying causes salt dispersion, thus minimizing the vertical variation of salinity within the depth range of 0.2−0.8 m (i.e., above the clay). The salinity along transect 3 contrasts with that of the marshes west of Washkugaw Creek where the salinities in the rooting zone of the upper intertidal flats can exceed 10 ppt. This suggests that the near surface salinity of the tidal flats along transect 3 is diluted by the freshwater discharge from Washkugaw Creek,

TABLE 2. Plant communities generated by TWINSPAN classification

TWINSPAN class and geomorphic zone	Characteristic location	Dominant plant species*	n
Intertidal flats			
1	Mostly in outer intertidal flats	*Eleocharis palustris* *Scirpus americanus*	42
2	Areas in intertidal flats with ponded water, near MHW	*Potamogeton filiformis*	87
Mean high water			
3	Just above and below MHW on transects 1, 2, and 3. Upward g.w.	*Eleocharis palustris*	55
4	Recently prograded backshore just above MHW on transects 4, 5, and 6. Upward g.w.	*Scirpus maritimus*	26
Hypersaline belt			
5	Around bare soil areas at MHW. Strong upward g.w.	*Puccinellia phryganodes* *Triglochin palustris* *Triglochin maritimum*	11
Recently prograded backshore			
6	Recently prograded backshore near and above MHW. Weak variable direction g.w.	*Carex paleacea* *Triglochin palustris* *Triglochin maritimum*	172
Beach ridges			
7	Gradually rising front slopes of beach ridges. Moderate downward g.w.	*Potentilla egedii* *Carex paleacea* *Triglochin maritimum* *Calamagrostis neglecta* *Hierochloe odorata* *Leptodictyum riparium* *Circuta maculata*	180
9	Less mature beach ridges, mostly on transects 2 and 3. Strong downward g.w.	*Juncus balticus* *Potentilla egedii* *Carex paleacea* *Triglochin maritimum* *Lathyrus palustris* *Leptodictyum riparium* *Festuca rubra* *Aster junciformis*	49
10	Mature beach ridges and edge of woody vegetation at back of marsh; mostly on transects 4, 5, and 6. Moderate to strong downward g.w.	*Carex paleacea* *Campanula uliginosa* *Calamagrostis neglecta* *Triglochin maritimum* *Lathyrus palustris* *Aster junciformis*	51
Inter-ridge depressions			
8	Found in interridge depressions in shallow standing water. Weak upward g.w.	*Carex paleacea* *Calamagrostis neglecta* *Sium suave* *Triglochin maritimum* *Galium trifidum* *Potentilla egedii*	84
11	At edges of open standing water. Weak upward g.w.	*Eleocharis palustris* *Carex mackenzii* *Ranunculus gmelinii*	73
12	In shallow standing water over organic material. Weak upward g.w.	*Carex paleacea* *Calamagrostis neglecta* *Eleocharis palustris*	48
Riparian borders			
13	Along the bank of an incised creek. Strong downward g.w.	*Aster juncifolium* *Trifolium hybridum* *Vicia cracca* *Potentilla egedii* *Cicuta maculata*	8

NOTE: n, the number of quadrats comprising each community class. The principle groundwater flow (g.w.) direction is given where applicable.

*Species with approximately 60% or greater frequency in quadrats, in decreasing order of importance.
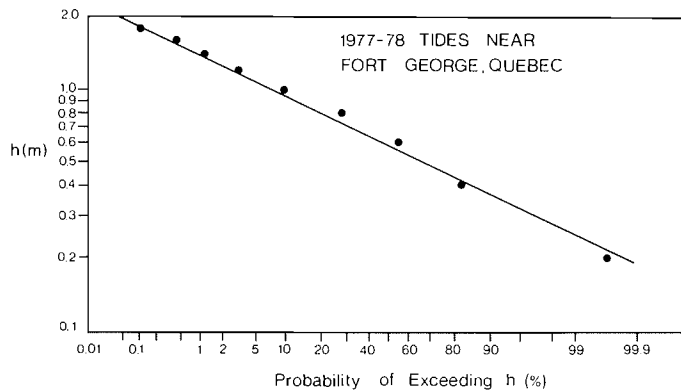
FIG. 4. Lognormal distribution of tides at Fort George, Quebec, 1977−1978, indicating low frequency of high magnitude tides for the one year of record.

which moves in an easterly direction due to the counterclockwise circulation of the Bay water (Prinsenberg 1978).

The lower intertidal area is characterized by scattered clones of *Scirpus americanus* and *Eleocharis palustris* (community 1), although shallow ponded areas host *Potamogeton filiformis* (community 2). *Eleocharis palustris* also occurs above.and below MHW, whereas *Scirpus maritimus* can be found just above MHW (communities 3 and 4, respectively).

Hypersaline band

Approximately 100−150 m landward of MHW hypersaline pore water exists in the rooting zone along a band of discrete salt pans that are up to 10 m in width. These patches are beyond the range of normal tides, but are within the reach of the infrequent storm surges. There is 1.1 m of silt overlaying 0.2 m of sand, and the topographic gradient averages 0.003. The surface is irregular, with 0.1−0.2 m ledges and mounds that may be relict ice push features uplifted to their present position.

Piezometers installed at this location measured a strong upward hydraulic gradient (Table 3) causing groundwater migration to the surface. The upward component is associated with the decreasing sediment thickness in the seaward direction, which necessitates groundwater discharge. Moderately saline waters from upslope and salt diffusing upward are transported towards the water table, which lies at an average depth of 0.45 m during summer. Evaporative drying concentrates the salt (Casey and Lasage 1987), yielding a high salt concentration near the surface (Fig. 5). Several centimeters below the surface the salt content decreases markedly, only to increase again as the marine clay soil is approached.

The hypersaline patches are generally unvegetated and the surface is covered by a thin, dry, hydrophobic algal mat. The infiltration rate is only 2.4 mm/h, so little leaching occurs. Since the hypersaline band is not inundated and is rarely flushed by low salinity tidal water, the plant communities developed in this zone are generally salt tolerant.

The dominant vegetation is *Puccinellia phryganodes* (Community 5), but halophytes such as *Salicornia europa* and *Plantago maritima* also occur.

Recently prograded backshore

This area extends from the hypersaline band up to 500 m landward of MHW. It has a relatively featureless topography with a low slope of 0.001 (Fig. 2). There are 1.7−1.8 m of
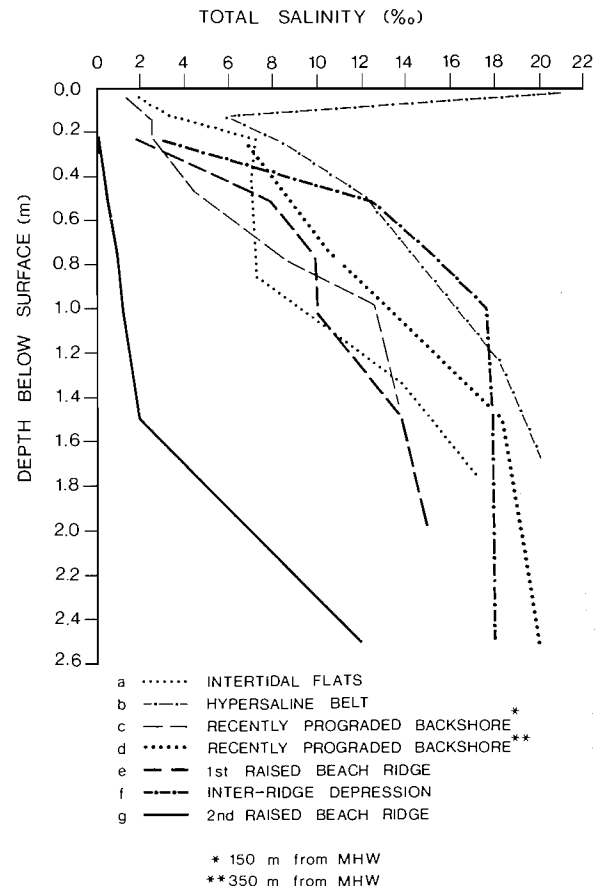

FIG. 5. Pore water salinity at points along transect 3. Values given for *a*, *b*, and *c* are determined for water extracted from soil samples collected 6 July 1985. Other values were measured directly from water withdrawn from sampling tubes on 7 July 1985.

silt and sand overlying marine clay and a peat layer has not yet developed.

The water table is generally within 0.3 m of the surface throughout the summer. The water table rises rapidly to the surface during wet periods and ponding occurs in wet areas. The infiltration rate of 67 mm/h far exceeds the normal rainfall intensity so that leaching occurs as the rainwater percolates. This results in a lower salinity zone near the surface, but increasing salinity with depth due to the presence of connate salt. Lateral fluxes of salt and water are slow because of the low gradient and poor hydraulic conductivity of the silt.

The lowered salinity allows the survival of plants with moderate salt tolerance such as *Carex paleacea* (community 6), which has very high cover values in this zone.

Raised beach ridges

Raised beach ridges (Fig. 2) are common features in the James Bay lowlands, easily identifiable by the distinct change in vegetation type and increased species diversity. They have undergone active sedimentation, with the depth of recent marine deposits reaching 1.9 and 2.1 m for the first and second ridges, respectively. This has resulted in about a 0.3−0.5 m increase in the elevation of the sediment surface, sufficient to produce a marked effect on drainage. The topographic gradient of the ridges from peak to base exceeds 0.003.

The first beach ridge has a 0.05−0.08 m layer of peat, but

TABLE 3. Salinity, hydraulic, and vegetation characteristics of major geomorphic areas

Location	Salinity (ppt)*	Vertical flow direction	Hydraulic gradient	Plant communities†
Intertidal flat	2−8	Variable	−0.09 to +0.09	1, 2, 3
Salt pan	2−18	Up	0.57	5
Backshore‡	1−13	Down	0.02	4, 6
Backshore§	5−17	Down	—	6
1st ridge	0−14	Down	—	7, 9
Inter-ridge depression	0−18	Up	≪0.01	8, 11, 12
2nd ridge	0−8	Down	0.03	7, 10
Riparian borders	0−7	Down	0.16	13

*Pore water salinity range − marine clay interface.
†Generated by TWINSPAN (see Ewing and Kershaw 1986).
‡150 m from MHW.
§350 m from MHW.

this has little effect on subsurface drainage because of its limited thickness. During the wet periods, surface and subsurface flows move both seaward and landward, away from the high points of the ridge. In the dry period the water table rapidly recedes to 0.15−0.30 m below the surface.

The second beach ridge has developed a peat layer of 0.2−0.3 m. The hydraulic gradient across the ridge slopes primarily towards the bay, but the relatively strong downward gradient results in a downward groundwater flow. The mounded water table suggests that groundwater recharge also occurs on the first ridge. Both ridges exhibit a similar pattern of salt distribution (Figs. 2 and 5), with much lower salinities than at other locations. This is attributed to the recharge of fresh water (from snowmelt, rainfall, and surface runoff) into the ground to dilute the salt near the surface.

On the first beach ridge the good drainage and lower salinity promote species diversity so that forbes and grasses appear. *Juncus balticus* and *Potentilla egedii* are the dominant species of community 9 and the presence of woody species is notable. Mature beach ridges have a high cover of *Carex paleacea* (community 10) and support a considerable number of woody species including *Salix myricoides*, *S. candida*, and *S. serissima*.

Inter-ridge depressions

At the inter-ridge depression (Fig. 2) there is 1.4−1.5 m of silt intercolated with discontinuous sand lenses, overlain by 0.3−0.4 m of peat that is perpetually under water. Paludification is caused by the topographically higher adjacent ridges that interrupt the regional seaward drainage. The water table gradient is 0.0001, an order of magnitude less than in other locations. The depression is an area of weak groundwater discharge, although it is stronger at its southern margin near the second beach ridge.

The sediments in the depression are quite saline (Fig. 5) due to the low rate of groundwater movement that fails to remove the salts diffused upward from the saline clay. At or near the surface, however, the peat layer and the ponded water have salinities <1 ppt. This is related to a dilution and flushing of salts by surface inflow and rainfall. Between 22 July and 14 August 1985 there was an increase in the ratio of salinity of the isolated water of the dilution cylinder (see Methods section) to the water outside (Fig. 6), particularly following periods of heavy rainfall. The implication here is that the inflow of freshwater was responsible for diluting the surface water in the depression. Measurements by Price and Woo (1988b) suggest that this inflow is 16% or more of the seasonal precipitation. The lowered salinity maintains plant species
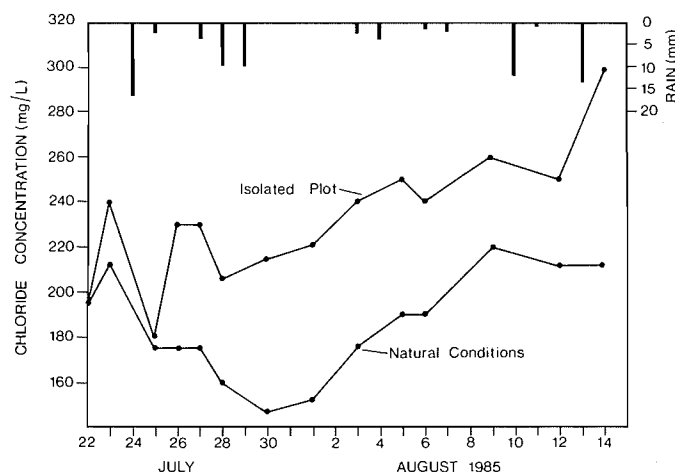

FIG. 6. Daily rainfall and salinity of water within and outside an enclosed plot in the inter-ridge depression. Water from inside the plot was isolated from surface inflow.

with lower salt tolerance than would otherwise be expected. *Carex paleacea* shares dominance with *Calamagrostis neglecta* in communities 8 and 12 in areas with deeper standing water. Slightly higher areas in inter-ridge depressions support *Eleocharis palustris* and *Carex mackenzii* (community 11).

Riparian borders

Along the borders of streams and creeks, there is normally an increase in vegetation species diversity or a change in species composition, resulting primarily from the better drainage near the channels (Gallagher and Kibby 1981). Such conditions apply to the small intermittent and tidal rivulets, as well as the larger rivers such as Washkugaw Creek and the Kesagami River.

A line of piezometers across a small unnamed creek that drains the inter-ridge depression provides insight into the water transfer process. Along this line, the marine clays are overlain by silt with an intermittent sand layer several centimeters in thickness. The salinity is much reduced around the stream due to the strong hydraulic gradients (Price and Woo 1988b) that cause the salts to be flushed out of the marsh into the stream (Fig. 7).

The vegetation is typical of the riparian plant community, with the most commonly occurring species being *Aster juncifolium* (community 13). Creekbanks support a number of species not widespread in the rest of the marsh, such as *Vicia*
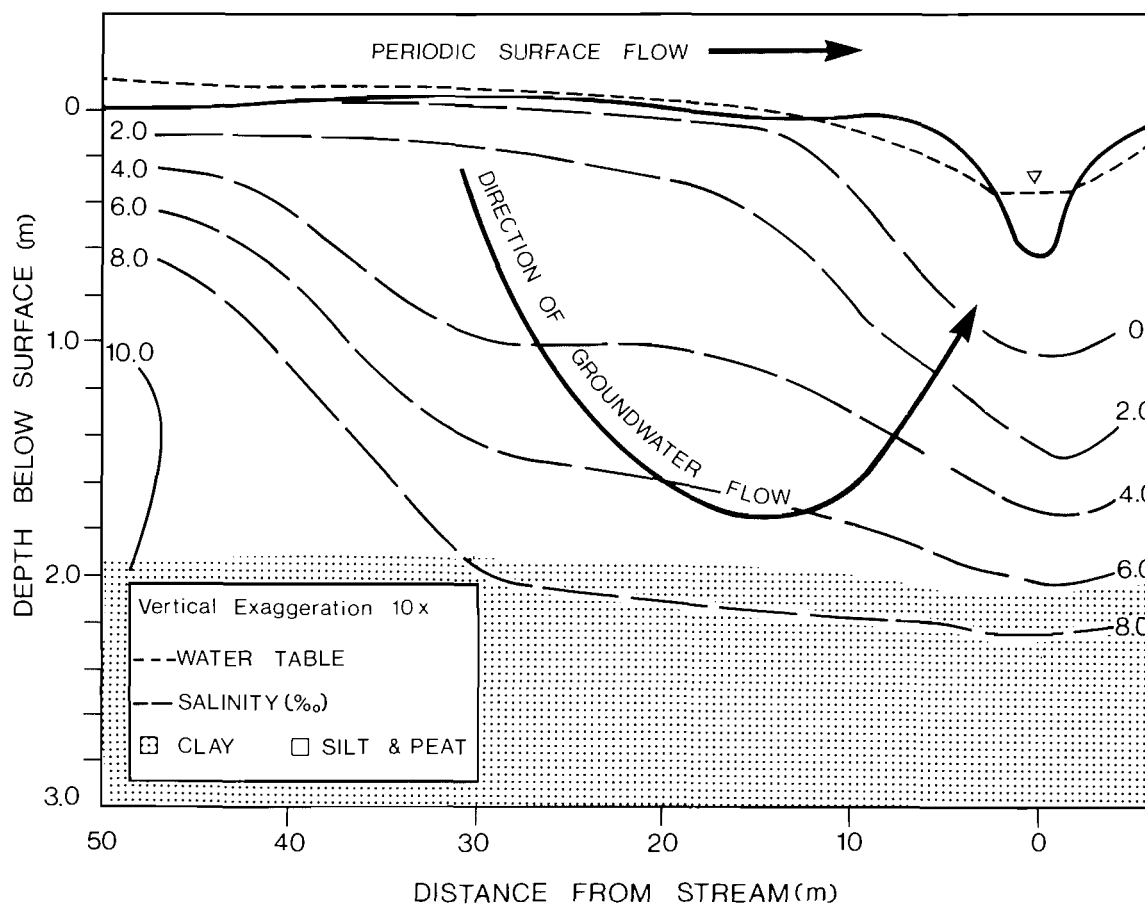
FIG. 7. Cross-sectional profile of stream transect indicating generalized lithologic strata, salt distribution, and direction of groundwater and surface flow. Surface flow direction was determined from hydraulic isopotential (Price and Woo 1988b).

cracca, *Trifolium hybridum*, *Achillea millefolium*, and *Elymus mollis*, as well as species found in a number of other community types. Within the creekbed, the vegetation is primarily composed of *Typha latifolia*.

Conclusions

Within the marsh ecosystem, the salinity decreases with distance from the coast, but increases with depth. The decreased surface salinity observed inland is due to coastal emergence; inland locations have had a longer period of interaction with meteoric water that removes the salt derived from deeper marsh sediments and carries them to the bay. Storm surges contain sufficiently low levels of salinity (an order of magnitude less) that they typically reduce surface salinity when inundation occurs. Surface hydrologic processes further reduce marsh surface salinity in most locations, which is evident from the predominance of freshwater or brackish marsh species (Table 2).

The salinity of the surface sediments of the intertidal flats is controlled by diurnal tide water salinity. This interaction is particularly evident in the lower intertidal flats where there is only a thin layer of recent sediments. Below MHW, semidiurnal tides moderate the surface salinity, whereas above MHW, salts may accumulate near the surface as in the hypersaline band. On the relatively featureless, recently emerged backshore, the high infiltration rate promotes leaching that reduces the surface salinity. As a result the normal zone of *Puccinellia phryganodes* typical of the lower levels of the Hudson Bay

marshes is replaced by brackish marsh species.

Where surface topography produces greater relief, such as on beach ridges and near streams, the relatively strong downward hydraulic gradient leaches salt away and allows the development of the richer beach-ridge and stream bank plant communities. In ponded areas between beach ridges the hydraulic gradients are very low and strong upward diffusion (Price and Woo 1988c) results in saline sediments. However, the overwhelming influence of surface inflow and precipitation maintains low surface water salinity, allowing the dominance of *Carex paleacea*, *Calamagrostis neglecta*, and *Carex mackenzii*. Thus, the topographic conditions peculiar to these geomorphic and hydrologic areas result in fairly predictable hydrologic and salinity regimes.

The coastal marshes of the Hudson Bay Lowland are all similar in origin and geomorphic character, which implies that the hydrologic processes involved will be common to all. The ordination of the data for this study (Ewing and Kershaw 1986) correlate closely with this mosaic of hydrology and salinity. However, absolute salinities may differ from place to place along the coast and may modify the floristics of the marsh. For example, the vegetation of southern James Bay differs from Hudson Bay marshes (Kershaw 1976; Ewing and Kershaw 1986). In particular, the salt tolerant *Puccinellia* association (community 5) is restricted to the hypersaline zone 100–150 m above MHW, where it occurs as isolated patches rather than being widespread in its distribution (see also Glooschenko and Clarke 1982). This is related to the lower offshore salinity of the study area where the large freshwater

input and counterclockwise currents (Prinsenberg 1977, 1978) have reduced the salinity of the bay. In marked contrast, the salinity in the pore water of the coastal marsh sediments is up to 10 times that of the local tidal water. Thus the direct influence of tidal waters is largely restricted to the intertidal flats and represents, at most, a brackish water regime dominated by *Eleocharis palustris* and *Scirpus maritimus* at or near MHW. Nevertheless, the ambient salinity of local tidal water is perpetuated as the sediments and pore water are subsequently uplifted to locations well above the MHW. This explains the difference in marsh salinity at other locations that otherwise undergo similar geomorphic and hydrologic processes, such as at Ekwan Point (300 km further north) where offshore salinities result in typical extensive stands of *Puccinellia phryganodes* (K. A. Kershaw, unpublished data).

Acknowledgments

CASEY, W. H., and LASAGA, A. C. 1987. Modelling solute transport and sulphate reduction in marsh sediments. Geochim. Cosmochim. Acta, **51**: 1109–1120.

CLARKE, L. D., and HANNON, N. J. 1970. The mangrove swamp and salt marsh communities of the Sydney district. III. Plant growth in relation to salinity and waterlogging. J. Ecol. **58**: 351–369.

DE LA CRUZ, A. A. 1974. Primary productivity of coastal marshes in Mississippi. Gulf Res. Rep. **4**: 353–356.

DESCHÊNES, J., and SÉRODES, J.-B. 1985. The influence of salinity on *Scirpus americanus* tidal marshes in the St. Lawrence River estuary, Quebec. Can. J. Bot. **63**: 920–927.

ENVIRONMENT CANADA. 1982. Canadian climate normals, 1951–1980. Temperature and precipitation. Atmospheric Environment Service, Downsview, Ont.

EWING, K. 1983. Environmental controls in Pacific Northwest intertidal marsh plant communities. Can. J. Bot. **61**: 1105–1116.

EWING, K., and KERSHAW, K. A. 1986. Vegetational patterns in James Bay coastal marshes. I. Environmental factors on the south coast. Can. J. Bot. **64**: 217–226.

GALLAGHER, J. L., and KIBBY, H. V. 1981. The streamside effect in a *Carex lyngbyei* estuarine marsh: The possible role of recoverable underground reserves. Estuarine Coastal Shelf Sci. **12**: 451–460.

GLOOSCHENKO, W. A., and CLARKE, K. 1982. The salinity cycle of a subarctic salt marsh. Nat. Can. (Que.), **109**: 483–490.

GLOOSCHENKO, W. A., and HARPER, N. S. 1982. Net aerial primary production of a James Bay, Ontario, salt marsh. Can. J. Bot. **60**: 1060–1067.

HUTCHINSON, I. 1982. Vegetation–environment relations in a brackish marsh, Lulu Island, Richmond, B.C. Can. J. Bot. **60**: 452–462.

HUTTON, C. L. A., and BLACK, W. A. 1975. Ontario arctic watershed. Environment Canada, Ottawa.

JAWORSKI, A. Z., and TEDROW, J. C. F. 1985. Pedologic properties of New Jersey tidal marshes. Soil Sci. **139**: 21–29.

JEFFERIES, R. L. 1977. The vegetation of salt marshes at some coastal sites in arctic North America. J. Ecol. **65**: 651–672.

JEFFERIES, R. L., JENSEN, A., and ABRAHAM, K. F. 1979. Vegetational development and the effect of geese on vegetation at La Perouse Bay, Manitoba. Can. J. Bot. **57**: 1439–1450.

KERSHAW, K. A. 1976. The vegetational zonation of the East Pen Island salt marshes, Hudson Bay. Can. J. Bot. **54**: 5–13.

MAHALL, B. E., and PARK, R. B. 1976. The ecotone between *Spartina foliosa* Trin. and *Salicornia virginica* L. in salt marshes of northern San Francisco Bay. II. Soil water and salinity. J. Ecol. **64**: 793–809.

MARTINI, I. P. 1981. Morphology and sediments of the emergent Ontario coast of James Bay, Canada. Geogr. Ann. **63A**(1–2): 81–94.

PEARCY, R. W., and USTIN, S. L. 1984. Effects of salinity on growth and photosynthesis of three California tidal marsh species. Oecologia, **62**: 68–73.

PRICE, J. S., and WOO, M. K. 1988*a*. Origin of salt in coastal marshes of Hudson and James bays. Can. J. Earth Sci. **25**: 145–147.

——— 1988*b*. Studies of a subarctic coastal marsh. I. Hydrology. J. Hydrol. (Amsterdam). In press.

——— 1988*c*. Studies of a subarctic coastal marsh. II. Salinity, J. Hydrol. (Amsterdam). In press.

PRINSENBERG, S. J. 1977. Fresh water budget of Hudson Bay. Ocean and Aquatic Sciences, Central Region, Canada Centre for Inland Waters, Burlington, Ont., Manuscr. Rep. Ser. No. 5.

——— 1978. Analytical study of the circulation of Ocean and Aquatic Sciences, Central Region, Canada Centre for Inland Waters, Burlington, Ont., James Bay. Manuscr. Rep. Ser. No. 6.

RINGIUS, G. S. 1980. Vegetation survey of a James Bay coastal marsh. Can. Field-Nat. **94**(2): 110–120.

ROZEMA, J. 1977. Population dynamics and ecophysiological adaptations of some coastal members of the *Juncaceae* and *Gramineae*. *In* Ecological processes in coastal environments. *Edited by* R. L. Jefferies and A. J. Davy. Blackwell Scientific Publications, Oxford.

ROZEMA, J., and BLOM, B. 1977. The effects of salinity and inundation on the growth of *Agrostis stolonifera* and *Juncus gerardii*. J. Ecol. **65**: 213–222.

SMART, R. M., and BARKO, J. W. 1980. Nitrogen nutrition and salinity tolerance of *Distichlis spicata* and *Spartina alterniflora*. Ecology, **61**: 630–638.

TYLER, G. 1971. Hydrology and salinity of Baltic sea-shore meadows. Oikos, **22**: 1–20.

WEBBER, P. J., and RICHARDSON, P. W., and ANDREWS, J. T. 1970. Postglacial uplift and substrate age at Cape Henrietta Maria, southeastern Hudson Bay, Canada. Can. J. Earth Sci. **7**: 317–325.

ZEDLER, J. B. 1977. Salt marsh community structure in the Tijuana estuary, California. Estuarine Coastal Mar. Sci. **5**: 39–53.