Marsh foraminifera of Prince Edward Island: Their recent distribution and application for former sea level studies

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A detailed survey of all marsh areas of Prince Edward Island, Canada, was undertaken and the information derived was used to determine four optimal areas (i.e., thickest marsh deposits) for sea level studies. Although extensive studies of marsh foraminifera have been conducted in Nova Scotia, the mixed tidal system in Prince Edward Island necessitated further investigations which suggested different relationships in some foraminiferal distributions, possibly linked to the tidal regime of the Gulf of St. Lawrence. Plant species distributions were markedly different, indicating that plant remains, even if preserved, would not be suitable sea level indicators.

Using marsh foraminiferal zonations in subsurface sediments, four sea level curves were determined. These curves encompass the last 3000 years of submergence on Prince Edward Island. Average rates of relative sea level rise in the east (14-19 cm/century) were almost twice that observed in the west (8 cm/century). This contrasts with previous work that suggested the island had been subsiding at a uniform rate for the last 3000 years. The data obtained here helps to calibrate recently derived geophysical models of the earth's response following deglaciation.

Taxonomically, a new genus of marsh foraminifera (*Pseudothurammina* n. gen. Scott, Medioli and Williamson) has been proposed with the type species being *Thurammina (?) limnetis*, Scott and Medioli described from marsh sediments in Nova Scotia.

Un examen en détail de toutes les surfaces marécageuses de l'Ile-du-Prince-Edouard, Canada, a été entrepris, et l'information recueillie a servi à identifier quatre régions optimales (c.-à.-d., dépôts de marais les plus épais) dans le cadre d'études du niveau de la mer. Bien qu'en Nouvelle-Ecosse les foraminifères de marais aient été le sujet d'études poussées, le système de marées mixtes de l'Ile-du-Prince-Edouard a nécessité une étude plus approfondie. Cette étude révèle qu'il existe peut-être des différences de rapport entre certaines répartitions de foraminifères, liées au régime des marées du Golfe du Saint-Laurent. Les répartitions des espèces végétales étaient très différentes, indiquant que les débris de plantes, même si préservés, ne conviendraient pas comme indicateurs de niveau marin.

Quatre courbes de niveau marin ont été déterminées en employant la distribution par zones des foraminifères dans les sédiments sous-jacents. Ces courbes embrassent les 3,000 dernières années de submersion sur l'Ile-du-Prince-Edouard. Les taux moyens d'élévation du niveau de la mer à l'est (14 à 19 cm/siècle) étaient presque le double de ceux observés à l'ouest (8 cm/siècle). Ceci contraste avec des travaux antérieurs qui suggéraient un affaissement uniforme de l'ile depuis 3,000 ans. Ces données aident à étalonner de récents modèles géophysiques qui simulent la réaction de la terre suite à la déglactiation.

Quant à la taxonomie, on a proposé un nouveau genre de foraminifère de marais (*Pseudothurammina* n. gen. Scott, Medioli et Williamson) dont l'espèce type est *Thurammina (?) limnetis*, décrite par Scott et Medioli à partir de sédiments de marais de la Nouvelle-Ecosse.

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INTRODUCTION

The general effects of Holocene relative sea level rise on Prince Edward Island (hereafter referred to as P.E.I.) are fairly well known. It has been realized for some time that P.E.I. is in a critical position for the study of the response of land masses following deglaciation since one end (the east end) appears to have experienced more relative sea level rise than the other (Kranck 1972). Additionally, raised marine features occur in the west but not the east end of P.E.I. (Prest 1973). The object of our investigation is to provide a detailed framework of information which will aid in the calibration of theoretical models of the earth's response following deglaciation (Peltier and Andrews 1976, Quinlan and Beaumont 1981).

Until recently it was difficult to obtain detailed information on sea level changes because movements of relative sea level in the late Holocene are only in the order of 1 - 2 m. Most methods of relocating former sea levels intro-

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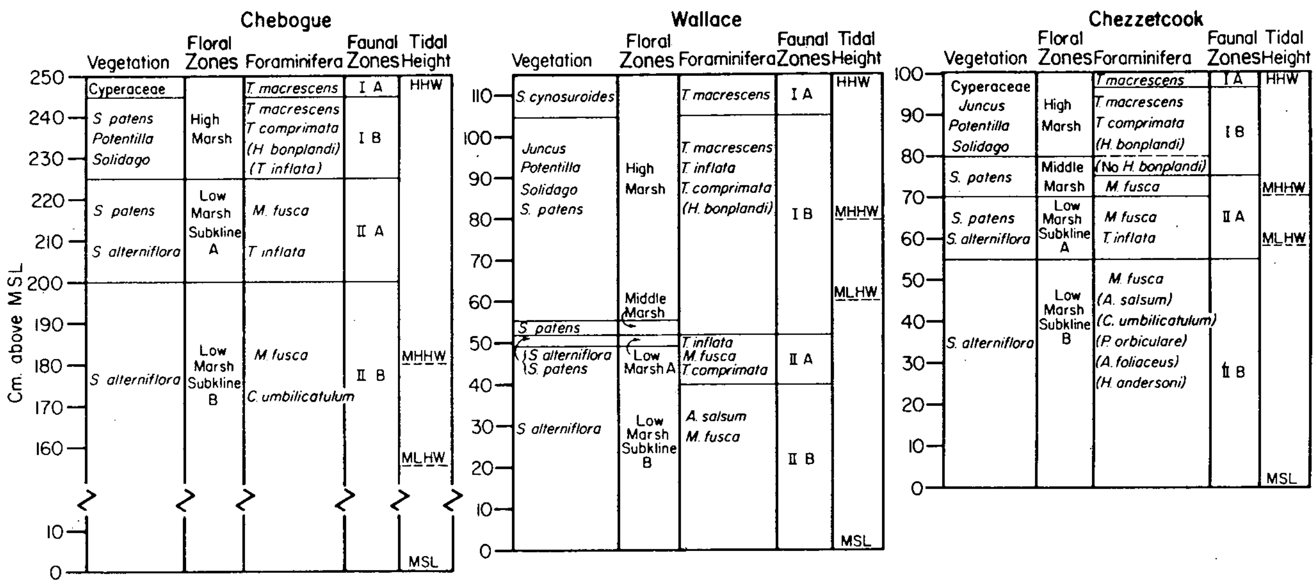

Fig. 1 - Comparative diagram of marsh floral and foraminiferal zones from Nova Scotian marshes (taken from Scott and Medioli, 1980a).

duce errors larger than this (Scott and Medioli 1978a). However, a method has been developed using marsh foraminiferal zonations (Fig. 1) that has a potential accuracy of ±5 cm (Scott 1977; Scott and Medioli, 1978a, 1980a). Factors that limit accuracy are difficulties in measuring during coring or drilling, compaction of sediments, or the absence of Zone IA (the zone which marks the area near HHW, Fig. 1). However, if the method is used properly, it is possible to accurately measure the small movements of sea level that have occurred in the last 2000-3000 years.

A large data base is available on marsh foraminifera from nearby Nova Scotia (Scott and Medioli 1980a), however, the tidal regime in the Gulf of St. Lawrence is significantly different (mixed vs semi-diurnal) than that of Nova Scotia which could alter relationships observed in P.E.I. Since no foraminiferal distribution data existed from P.E.I., detailed transects such as those from Nova Scotia were obtained at three locations and less detailed information from another. These data can be used for comparison with areas of more normal tidal regimes, increasing the reliability of the sea level work on P.E.I.

Subsequent to obtaining data on surface distribution of foraminifera it was then necessary to locate suitable marsh deposits (i.e. thick enough) for the study of sea level changes. Prest (1973) observed marsh thicknesses up to 5 m but no precise locations were shown. Hence a detailed exploration of all P.E.I. marshes was undertaken to optimize our detailed drilling effort. Using information obtained in the exploratory phase, four areas were selected for further study: Percival River, Tryon, Pisquid and Orwell (Fig. 2). Using data from these areas it was possible to detect small scale differences in relative sea level rise rates from west to east on P.E.I.

PREVIOUS WORK

Submergence on P.E.I. was first suggested by Gesner (1846, 1961), Dawson and Harrington (1871) and Johnson (1913a, b); however, these early workers had no temporal frame of reference since C^{14} dating had not been developed. Frankel and Crowl (1961) were first to place a date on submerged features on P.E.I., indicating 1.5 to 2.4 m of submergence in the last 900 years. These data came from Nicholas Point (near Orwell, Fig. 2). Kranck (1972) carried out a study of the surficial sediments in the Northumberland Strait and inferred a large tilting of the strait (and hence, P.E.I.) relative to present sea level. Deeply submerged features were recognized in the east, and there was progressively less submergence westward. Additionally, emerged marine deposits have been reported in the western end but not in the eastern end of P.E.I. (Owen 1949; Prest 1962, 1973; Dyck and Fyles 1963, 1964). More recently tidal gauge data (Grant 1970 a, b) for Charlottetown indicates submergence during the last 100 years to be 25 - 30 cm.

Palmer (1974) investigated a mixed marine and freshwater sequence at Basin Head Harbour (near Little Harbour, Site 42, Fig. 2). He suggested sea level rise rates of 3.6 to 10.4 cm/century during the last 1060 years.

Although no marsh areas have been previously examined for foraminifera in P.E.I., many estuarine areas have been studied. Most work was carried out by G.A. Bartlett or his students at Queen's University, Kingston, Ontario. Studies indicated essentially the same assemblage in all estuaries (dominantly calcareous species) and a complete listing of these reports can be found in Scott and others (1980).

METHODS

All samples were collected in June 1978. Detailed surface transects with elevations determined from benchmarks were obtained from Wolfe Inlet (Fig. 3), Mt. Stewart (Fig. 4) and Tryon (Fig. 5). Additional semi-detailed transects were obtained from Percival River (Fig. 6). Drilling was carried out in Pisquid (Fig. 4), Tryon, Percival River, and Orwell (Fig. 7).

Collection and preparation of surface foraminiferal samples was similar to that by Scott and Medioli (1980a). Drill hole sample preparation was similar except that no Rose Bengal or formalin was added, only denatured ethanol. All samples were examined in a water-alcohol mixture.

Exploratory sampling of the subsurface marsh deposits was carried out using a Davis peat corer. This tool can be pushed to the desired depth, triggered, and a small test core retrieved.

Following exploratory testing, detailed drilling was done in those areas with thickest peat sequences. This drilling was carried out with a post-hole auger, a method described by Medioli and Scott (1976). Carbon - 14 dates were determined on material obtained only at the base of the drill holes, just above non-compactible substrate to avoid peat compaction problems (Kaye and Barghoorn 1964). Foraminiferal content of the sediment was determined at the dated intervals to establish the exact relative sea level position. This procedure required that several locations be drilled in a transect to obtain an adequate sea level curve. Initially small wood fragments found in the deposits were used for carbon-14 dating; later, however, a whole peat sample was used for dating at Orwell because of the scarcity of wood fragments.

RESULTS

Vegetation and physio-chemical

Vegetation: Vegetation and salinity values for Percival River are summarized in Table 1 while

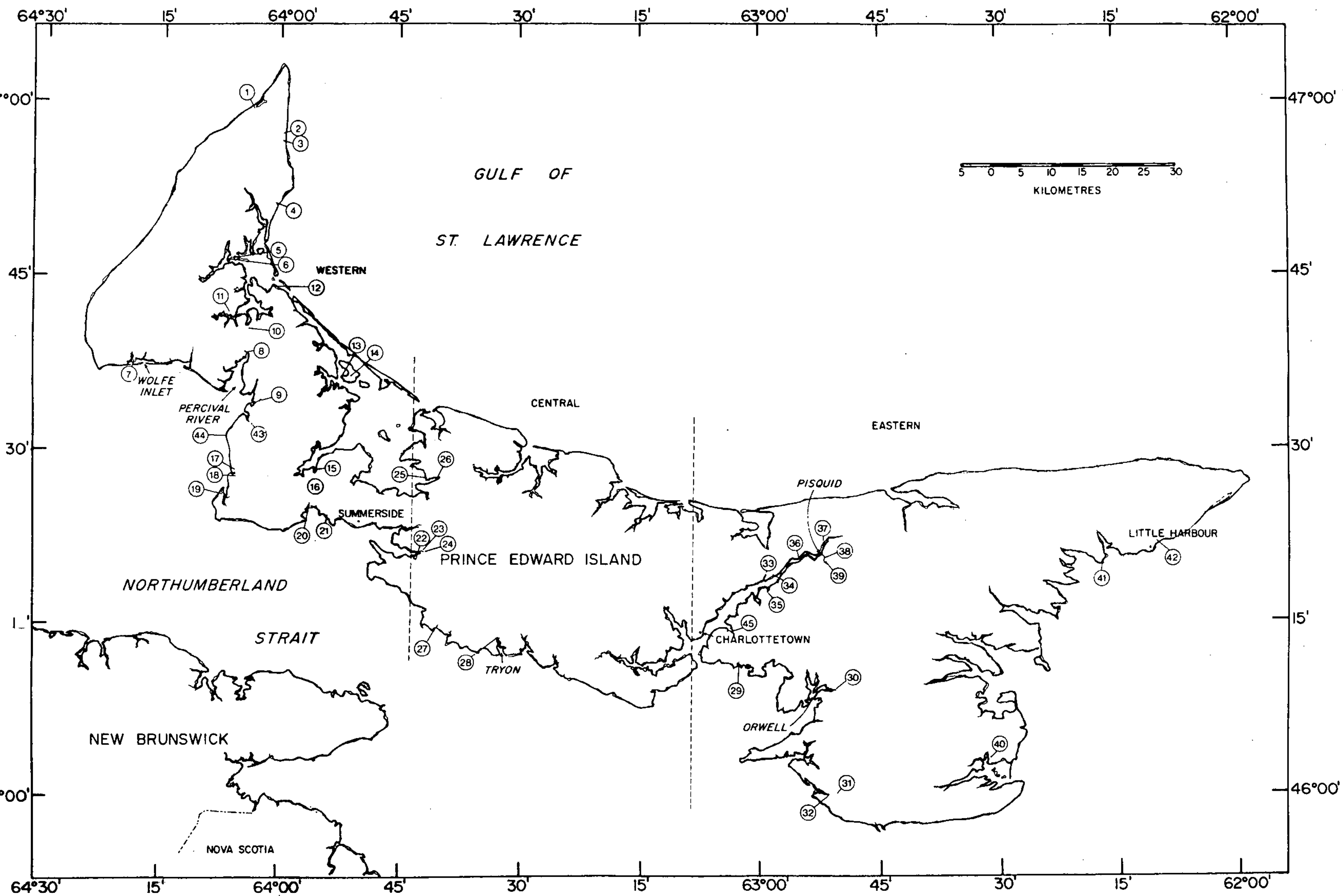
GULF OF
ST. LAWRENCE
NORTHUMBERLAND
STRAIT
NEW BRUNSWICK
NOVA SCOTIA
PRINCE EDWARD ISLAND
WESTERN
CENTRAL
EASTERN
SUMMERSIDE
CHARLOTTETOWN
WOLFE INLET
PERCIVAL RIVER
TRYON
PISQUID
ORWELL
LITTLE HARBOUR
KILOMETRES
5 0 5 10 15 20 25 30
64°30'
15'
64°00'
45'
30'
63°00'
62°00'
47°00'
46°00'
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45

Fig. 2 - Index map indicating all points that were initially investigated (opposite page):

Site 1
Nail Pond marsh — 15 cm of peat over sand

Site 2
Tignish Harbour marsh — marsh on sand flat (15 cm of peat)

Site 3
Little Tignish marsh — 15-180 cm of peat on sand

Site 4
Foxley peat bog — freshwater peat sample approximately 100 cm below present mean sea level

Sites 5 & 6
Mill River marshes — 90 cm of peat on sand

Site 7
Wolfe Inlet marsh — 90-120 cm of peat on sand

Site 8
Percival River marsh — 180-270 cm of peat on sand

Site 9
Robbs Creek marsh — 60 cm of peat on sand

Site 10
Portage Bog — 420 cm of peat — base with freshwater going into sandstone — no marine material

Site 11
Roxbury marsh — 90 cm of peat on sand

Site 12
Black Banks peat bog — freshwater peat 120 cm below mean sea level

Site 13
Lennox Island, Salt Grass Point — 90 cm of peat on sand

Site 14
Lennox Island peat bog — 50 cm of peat on sand

Site 15
Ellis River marsh — 90-120 cm of peat on sand

Site 16
Miscouche peat bog — 210-270 cm of freshwater peat going into sand — no marine material

Sites 17 & 18
Jacques River marshes — 90-150 cm of peat on sand

Site 19
Halidimand River marsh — 30 cm of peat on sand

Sites 20 & 21
Sunbury Cove marshes — 0-30 cm of peat on sand

Site 22
Bedeque marshes — 240-300 cm of peat on sand

Site 23
Central Bedeque marshes (west of causeway) — 600 cm of gray mud

Site 24
Central Bedeque marshes (east of causeway) — 450 cm of peat into sand

Sites 25 & 26
Indian River marshes — 30-120 cm of peat into sand

Site 27
Amherst's Cove marsh — 180 cm of peat into sand

Site 28
Tryon marsh — 500 cm of peat on sand

Site 29
Squaw Bay marsh — 90 cm of peat on sand

Site 30
Orwell marsh — 450 cm in gray mud, 360 cm in marsh mud into sand

Sites 31 & 32
Flat River marshes — 180-300 cm of mud, some peat into sand

Sites 33 & 34
Tenmile House marshes — 90-270 cm of peat on sand

Site 35
Glenfinnan marsh — 90 cm of peat on clay or sand

Site 36
Scotchfort marshes — 270 cm of peat on sand

Site 37
Mt. Stewart (west side of river) marshes — 270-300 cm of peat on sand

Sites 38 & 39
Pisquid marshes — 360-420 cm of peat on sand

Site 40
Murray Harbour north marsh — 30 cm of peat on sand

Site 41
Souris — Norris Pond marsh — 15 cm of peat on sand

Site 42
Little Harbour marsh — 15 cm of surface peat on sand

Site 43
Victoria West marsh — 90 cm of peat on sand

Site 44
Rock Point marsh — 30 cm of peat on sand

Site 45
Fullerton's marsh — 90 cm of peat on sand

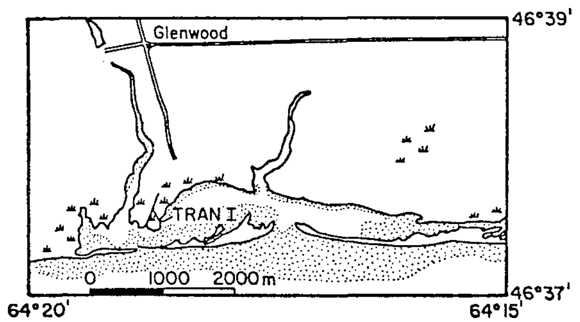

Fig. 3 - Map of Wolfe Inlet showing position of the transect.

data from other areas can be found in Scott and Medioli (1978b). Plant species are similar to those observed in Nova Scotian marshes (Scott and Medioli 1980a); however, vertical ranges appeared to differ significantly. At Wolfe Inlet, Percival River and Tryon, the middle marsh species *Spartina patens*, appeared to dominate at all but the lowest levels of the marsh, including supra-tidal areas. At Wolfe Inlet and Percival River *Spartina cynosuroides*, typically a supra-tidal species, extended into the high marsh zone. Typical

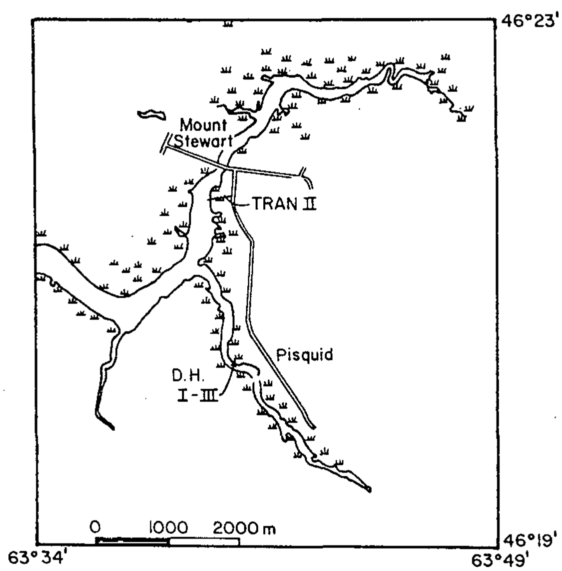

Fig. 4 - Map of the Pisquid - Mt. Stewart sampling area. Note causeway landward of the Mt. Stewart transect.

high marsh species (i.e. the Cyperaceae and *Juncus*) were only prominent at one study area, Mt. Stewart.

Salinity: Salinites followed the normal pattern for temperate marsh areas, increasing with decreasing elevation (Scott and Medioli 1978b). At Wolfe Inlet and Percival River salinites were abnormally low, probably because of precipitation that occurred just prior to collection.

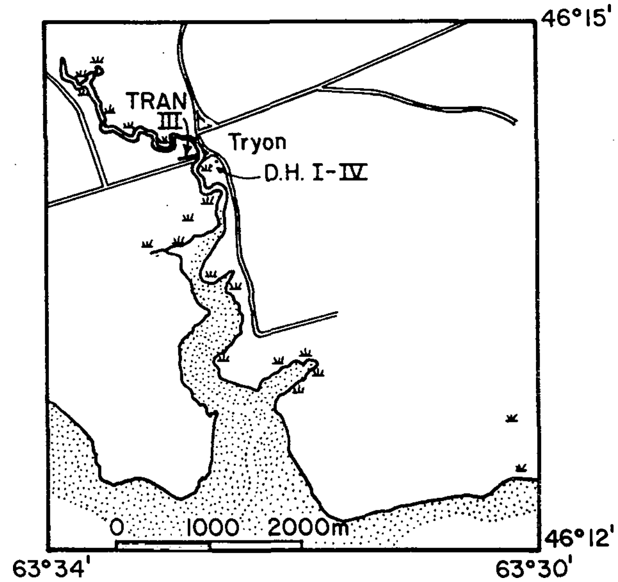

Fig. 5 - Map of Tryon sampling sites; note causeway just seaward of transect. Also, note the strong meander patterns of the Tryon marsh channels.

Tidal factors: Tidal gauge data were available for sites at or near all transect locations and displayed a significant range from east to west. At West Point (close to Wolfe Inlet and Percival River) total tidal range is given as 161 cm with higher high water (HHW) at +128, lower low water (LLW) at -33 cm and Z_0 at +67 cm (note position of Z_0 with respect to total tidal range). At Victoria (close to Tryon) total tidal range is 290 cm with HHW at +274 cm, LLW at -16 cm and Z_0 at +156 cm. At Charlottetown (same as that at Mt. Stewart, Pisquid, Orwell)

TABLE 1

SALINITY AND VEGETATION TYPES AT PERCIVAL RIVER STATIONS

SUB STATION	STATION	1	2	3	4
A	Plants	T, *J*, M, *SC*	*SC*	*J*, *S*, *PA*, M	*SC*, *SP*
	°/oo	0	0	0	0
B	Plants	*J*, *SC*	*J*, *SC*	*SP*, *S*, *PA*, M	*S*, *SP*, *J*, *PA*
	°/oo	0	0	0	0
C	Plants	*J*, *SP*, *PA*	*SP*, *J*, *S*, *SC*	*SP*, *S*	*SP*, *PA*
	°/oo	0	0	4	0
D	Plants	*SP*, *PA*, *J*, *S*, M	*SP*, *S*, *PA*	*SP*	*SP*, *P*, *PA*
	°/oo	0	0	7	4
E	Plants	*SP*, *PA*, *SA*	*SP*	*SA*, *SP*	*S*, *SS*, *PA*, *J*
	°/oo	2	3	6	2
F	Plants	*SP*	*SP*	*SA*	*S*
	°/oo	8	9	6	1
G	Plants	*SP*, *Sa*, *L*	*SP*, *SA*		
	°/oo	10	10		
H	Plants	*SP*, *SA*, *L*	*SA*		
	°/oo	10	10		
I	Plants	*SA*			
	°/oo	14			
J	Plants	*SA*			
	°/oo	14			

T - terrestials
J - *Juncus gerardi*
M - moss
SC - *Spartina cynosuroides*
SP - *Spartina patens*
PA - *Potentilla anserina*
S - *Scirpus*
SA - *Spartina alterniflora*
Sa - *Salicornia*
L - *Limonium*
P - *Plantago*
SS - *Solidago semiviperens*

total tidal range is given as 280 cm with HHW at +280 cm, LLW at 0 cm, and Z_0 at +172 cm.

Tidal regimes in the Gulf of St. Lawrence are mixed (i.e. both diurnal and semi-diurnal components have significant influences). Consequently tidal constants (particularly mean sea level) as determined from tide gauges, are slightly different than for systems with a dominantly semi-diurnal components. Most tidal gauge stations from P.E.I. indicate Z_0 (mean sea level or MSL) as occurring in the upper $^2/_5$ of the tidal range rather than in the middle. It appears from our transect studies, however, that benchmark datum (given as MSL) is the midpoint of the tides rather than Z_0 from the tidal gauges (i.e. the midpoint is not the average level).

Foraminiferal Results - Surface Distributions

The surface sample data (Tables 2-9) include percentages of living and total foraminifera. Although numbers of living foraminifera were generally high, they were irregular; hence total populations were used to determine assemblages. Also, it has been demonstrated that total populations best represent prevailing marine conditions, particularly in a marsh (Scott and Medioli 1980b).

In general, 22 species of foraminifera and thecamoebians were recorded from the surface samples, 17 of which had living representatives at the time of collection. Marsh foraminiferal zones and subzones discussed here are those de-

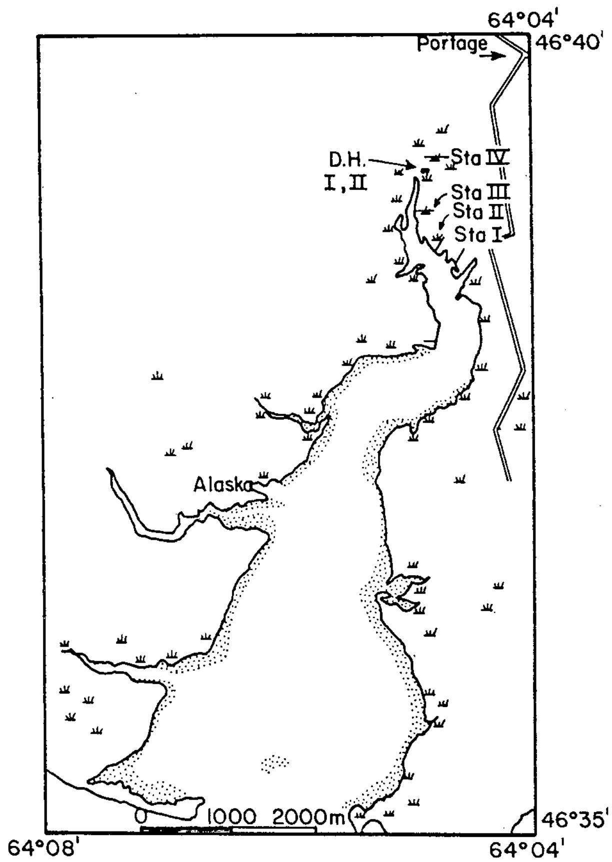

Fig. 6 - Map of Percival River sampling localities.

fined in Scott and Medioli (1978a, 1980a) and have previously been briefly illustrated (Fig. 1).

Wolfe Inlet - Transect I: Foraminifera' dis'ribu'ions here closely parallel those observed in Nova Scotia (Fig. 8, Tables 2,3). Supratidal areas are characterized by relatively low numbers of the thecamoebian species *Centropyxis aculeata* together with a few specimens of *Trochammina macrescens* (Stations 1, 2 Table 2). In the elevation range +88 to +93 cm (Fig. 8), foraminiferal zone IA is recognized except that instead of being monospecific with *T. macrescens* (Fig. 1), *C. aculeata* (a thecamoebian) is also present. Zone IB occurs at +42 to +75 cm, characterized by co-dominant species *T. macrescens* and *Tiphotroc'a compr'ma a; Trochammina inflata* increases near the base of this zone. Also, near the base of this zone, significant populations (100 - 200 ind./10 cm^3) of *Polysaccamina ipohalina* occur, the first such occurrence reported outside the type locality in southern California (Scott 1976a). In the narrow elevation range +29 to +39 cm an assemblage similar to zone IIA occurs, except that *Miliammina fusca* is not one of the dominant constituents. Below this elevation *M. fusca* dominates together with *T. inflata* and percentage frequencies are reduced for *T. macrescens*. *Ammotium salsum* has low but sustained percentage occurrences, demonstrating the affinity with zone IIB faunas in Nova Scotia (Fig. 1).

Mt. Stewart - Transect II: A complex distribution pattern was observed in this transect (Fig. 9, Tables 4, 5). The upper part of the transect (Stations 1-6, Table 4 is supra-tidal and characterized by low numbers of several thecamoebian species. At +144 cm (Station 7) a zone IA fauna occurs; however, total numbers of foraminifera are low. Directly below this, the IB zone is found;

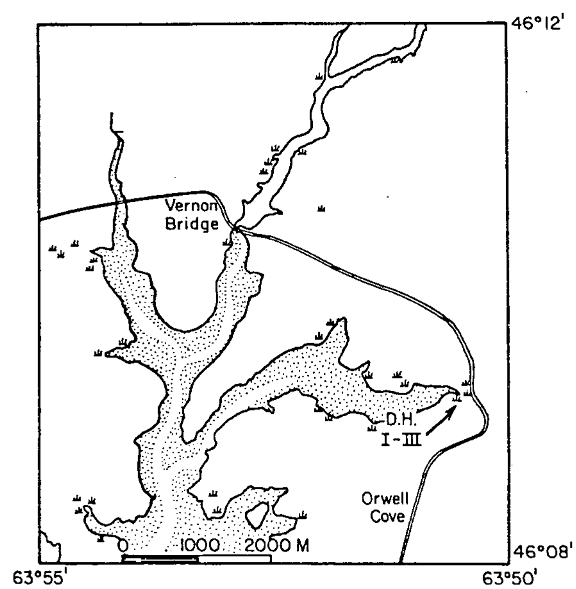

Fig. 7 - Map of Orwell drill holes.

TABLE 2

FORAMINIFERAL PERCENTAGE OCCURRENCES ALONG WOLFE INLET TRANSECT (STATIONS 1-12)

STATION NUMBER		1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B	11A	11B	12A	12B
Elevation above MSL (cm)		97	97	98	98	90	90	93	93	88	88	75	75	75	75	74	74	74	74	62	62	56	56	52	52
Total species	Living	2	1	2	3	2	1	2	2	2	2	2	2	2	2	3	2	2	3	6	2	6	6	4	4
	Total	3	2	4	4	4	2	2	5	4	3	5	4	6	4	3	6	3	4	6	5	9	8	6	6
Total individuals per 10 cm^3	Living	12	26	25	45	13	29	69	45	348	258	148	124	768	212	80	178	186	266	644	382	1208	386	1374	268
	Total	47	84	50	196	171	205	294	168	1218	690	1320	1158	4040	1138	520	914	940	964	2086	1020	2818	1306	2470	636
Ammonia beccarii	L																					1			
	T																					1	x	x	
Ammotium salsum	L																								
	T																								
Arenoparella mexicana	L																								
	T											x													
*Centropyxis aculeata**	L	17		4	51	8		10	16	1	5								2	x		2	2		
	T	51	1	14	81	14	3	26	34	2	14	1	x	x			x		3	x	x	3	2	x	
Difflugia globulosa	L																								
	T	6		2	4	x			x																
Haplophragmoides bonplandi	L																							1	
	T													x			x						x	1	1
Miliammina fusca	L				2											1				1		14	8	5	4
	T			2	x					x	x	1	2	1	2	2	3	x	x	1	2	15	9	7	3
Polysaccammina ipohalina	L																			x		x	x		
	T													x						1	x	1	x		
Reophax nana	L																								
	T																								
Textularia earlandi	L																								
	T																								
Pseudothurammina limnetis	L																						x		
	T														x		x					x	x		1
Tiphotrocha comprimata	L											23	39	42	26	10	11	5	2	39	19	19	22	9	25
	T					x			x	x		26	35	26	29	6	4	5	2	32	16	22	21	10	24
Trochammina inflata	L																			x					
	T								x											x		x			1
T. macrescens forma macrescens	L	83	100	96	47	92	100	90	84	99	96	77	61	58	74	88	89	95	97	58	81	64	68	84	71
	T	42	99	82	14	78	97	74	64	98	86	72	63	73	69	92	91	95	93	65	81	58	66	81	70
T. macrescens forma polystoma	L																								
	T																					x			

L = Live, T = Total, x = <1%

TABLE 3

FORAMINIFERAL PERCENTAGE OCCURRENCES STATIONS 13-25, WOLFE INLET

STATION NUMBER		13A	13B	14A	14B	15A	15B	16A	16B	17A	17B	18A	18B	19A	19B
Elevation above MSL (cm)		49	49	46	46	46	46	42	42	38	38	36	36	29	29
Total species	L	3	4	3	2	5	6	5	6	5	5	5	4	7	7
	T	6	7	7	7	8	7	7	8	6	8	7	7	7	9
Total individuals per 10 cm³	L	125	356	236	28	206	224	432	296	260	60	548	88	148	190
	T	497	1136	1026	592	562	966	2216	3034	1042	622	2530	1712	1320	1258
Ammonia beccarii	L														
	T														
Ammotium salsum	L														
	T														x
Arenoparella mexicana	L														
	T														
*Centropyxis aculeata**	L		1				1								1
	T		1		x	x	2	1	x		x				x
Difflugia globulosa	L														
	T														
Haplophragmoides bonplandi	L						4		3						
	T		x	x	1	1	2		4		x	x	x		
Miliammina fusca	L	2	4	2		1	8	x				4		16	3
	T	7	10	3	2	2	7	5	5	3	1	7	16	21	18
Polysaccammina ipohalina	L							3	8	8	3	3	2	1	2
	T	x	x	x	1	1	1	8	9	16	16	4	1	x	8
Reophax nana	L														
	T												x		
Textularia earlandi	L														
	T														
Pseudothurammina limnetis	L								1	1	3			1	
	T	x				x		x	x	x	1	x		x	x
Tiphotrocha comprimata	L	51	43	32	43	16	21	44	43	8	3	16	7	32	15
	T	41	35	33	49	20	25	29	30	5	11	18	22	28	22
Trochammina inflata	L					3	3	2	11	1	3	23	2	34	26
	T	1	1	3	12	14	10	5	22	2	2	25	31	39	27
T. macrescens forma macrescens	L	42	52	66	57	80	63	50	34	82	87	54	89	14	50
	T	51	52	59	35	61	52	52	30	74	68	44	29	10	22
T. macrescens forma polystoma	L													1	2
	T													1	1

STATION NUMBER		20A	20B	21A	21B	22A	22B	23A	23B	24A	24B	25A	25B
Elevation above MSL (cm)		14	14	14	14	7	7	3	3	-7	-7	-23	-23
Total species	L	8	8	7	7	2	3	2	6	4	6	4	5
	T	9	9	8	10	8	8	8	8	9	7	6	8
Total individuals per 10 cm³	L	144	148	170	122	12	20	32	120	24	102	176	148
	T	2348	1226	1360	1890	1756	2064	832	942	421	1040	1272	1516
Ammonia beccarii	L												
	T												
Ammotium salsum	L	1	4		2						2		
	T	1	3	2	2	2	2	1	1	1	1	2	1
Arenoparella mexicana	L								2				
	T	x	x		x				x	x			x
*Centropyxis aculeata**	L												
	T												
Difflugia globulosa	L												
	T												
Haplophragmoides bonplandi	L												
	T												
Miliammina fusca	L	12	26	2	8	33	20		5	12	41	77	65
	T	53	63	63	68	69	75	64	56	49	34	48	47
Polysaccammina ipohalina	L	6	1	1	5				3				3
	T	x	1	1	2	1	1	1	4	x	1	1	6
Reophax nana	L												
	T												
Textularia earlandi	L												
	T				x								
Pseudothurammina limnetis	L	3	3	1							2		
	T	x	1	3	2	5	2	9	4	3	3		
Tiphotrocha comprimata	L	25	15	9	8		20	25	35	8	29	2	8
	T	12	8	6	6	2	3	7	11	8	15	6	8
Trochammina inflata	L	40	36	73	56	67	60	75	45	62	22	14	16
	T	25	18	18	15	17	14	14	19	32	35	37	28
T. macrescens forma macrescens	L	47	14	6	18				10	17	4	7	8
	T	5	5	4	4	4	3	4	4	7	11	8	9
T. macrescens forma polystoma	L	8	1	7	3								
	T	2	1	3	1	x	x	x		x			x

L = Live, T = Total, x = <1%

TABLE 4

FORAMINIFERAL PERCENTAGE OCCURRENCES ALONG MT. STEWART TRANSECT (STATIONS 1-13)

STATION NUMBER		1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B	11A	11B	12A	12B	13A	13B
Elevation above MSL (cm)		213	213	184	184	170	170	154	154	158	158	156	156	144	144	135	135	130	130	130	130	130	130	119	119	112	112
Total species	L	0	0	1	1	1	1	1	1	2	3	1	2	1	1	2	5	4	4	4	4	4	4	6	6	4	4
	T	1	0	1	3	5	1	4	1	3	3	3	2	2	3	6	6	5	5	6	6	6	5	6	6	6	5
Total individuals per 10 cm³	L	0	0	1	1	5	12	5	7	11	17	9	17	39	33	28	123	40	116	73	238	63	86	596	868	536	130
	T	1	0	1	4	16	17	13	8	21	37	26	28	65	72	109	394	122	486	441	1078	262	346	2032	3310	2544	910
Ammobaculites dilatatus	L																										
	T																										
Ammonia beccarii	L																										
	T																										
Ammotium salsum	L																										
	T																										
Arenoparella mexicana	L																										
	T																										
*Centropyxis aculeata**	L										12																
	T					16		15			11				3	4											
Difflugia globulosa	L				100						6																
	T				50	6		15			11	12															
*D. oblonga**	L					100	100	100	100	91	82	100	59														
	T	100			25	75	100	62	100	90	78	73	64	2													
*D. urceolata**	L																	2									
	T															1		1									
Haplophragmoides bonplandi	L																1	20	2	22	6	22	13	15	12		5
	T															4	x	8	5	15	4	21	17	12	11		9
Miliammina fusca	L																2							2	2		
	T									5							2			1	x			2	5	19	11
Polysaccammina ipohalina	L																1							x	x		
	T															1	1		x	x	x	1	x	1	x	x	
*Pontigulasia compressa**	L																										
	T					6																					
Pseudothurammina limnetis	L															71	55	42	49	33	44	10	13	18	10	1	2
	T														1	62	58	48	40	20	50	29	19	42	25	8	10
Tiphotrocha comprimata	L			100															1	7	10	14	28	27	33	17	22
	T			100	50	6		8									1	2	1	12	9	7	19	15	19	6	21
Trochammina inflata	L																										
	T																										
Trochammina macrescens	L									9			41	100	100	28	41	35	48	38	39	54	46	38	42	82	71
	T									5		15	36	98	96	28	37	41	55	52	37	41	44	27	39	56	49

L = Live, T = Total, x = <1%

TABLE 5

FORAMINIFERAL PERCENTAGE OCCURRENCES (STATIONS 14-28) MT. STEWART TRANSECT

STATION NUMBER		14A	14B	15A	15B	16A	16B	17A	17B	18A	18B	19A	19B	20A	20B	21A	21B	22A	22B	23A	23B	24A	24B	25A	25B	26A	26B	27A	27B	28A	28B
Elevation above MSL (cm)		111	111	97	97	97	97	91	91	90	90	86	86	91	91	79	79	75	75	37	37	35	35	20	20	-25	-25	-29	-29	-57	-57
Total species	L	5	4	2	4	4	5	6	4	4	3	3	3	4	3	6	4	7	8	7	7	5	6	6	6	6	5	7	5	1	5
	T	5	5	3	6	7	7	8	7	6	5	8	4	7	4	8	9	7	8	8	8	7	8	7	8	8	8	9	9	6	9
Total individuals per 10 cm^3	L	418	224	3	35	90	194	278	59	75	252	25	53	304	264	138	162	222	102	102	212	152	138	256	196	52	54	104	88	2	20
	T	1444	1154	26	169	798	490	1026	230	165	678	155	352	830	888	620	902	656	518	954	746	608	466	770	870	706	562	762	670	922	568
Ammobaculites dilatatus	L																												2		
	T																												x		
Ammonia beccarii	L							4	5	4		4		1		17	18			6	1				1			8			
	T							1	1	2		1		x		5	4			1	x				x			1			
Ammotium salsum	L					2	1												2							12	4	29	41		40
	T					4	2	x											1							2	1	6	8	x	1
Arenoparella mexicana	L																	5	6	2	9	17	4	5	7	4	7	8			
	T																x	3	2	1	5	7	5	5	8	1	1	2			x
*Centropyxis aculeata**	L															1															
	T											1				x	x														x
Difflugia globulosa	L																														
	T																														
*D. oblonga**	L																														
	T																														
*D. urceolata**	L																														
	T																														
Haplophragmoides bonplandi	L	10	16			2	11	1										3	2	4	5	8	3	1							
	T	10	11		x	6	8	2	3	2	1	1		1	1	1	1	4	2	7	3	4	2	1	2	2	1	3	1	4	6
Miliammina fusca	L	3							3							3		1	2	2	1		1			4	7	12	16		10
	T	6	5		2	5	3	1	1		3	2	x	1		10	13	1	2	2	2	4	2	4	2	6	11	12	11	63	45
Polysaccammina ipohalina	L				3			1															1								
	T				5			1	x	1				x									x								
*Pontigulasia compressa**	L																														
	T																														
Pseudothurammina limnetis	L	2	4		6		3	4		8	2		4	3	4	1	2	6	4		15	16	14	4	2	12		3		100	10
	T	4	6	4	2	x	4	2	1	9	2	1	1	4	6	5	10	10	1	x	8	8	10	2	x	5	4	3	4	3	4
Tiphotrocha comprimata	L	10	15	33	28	47	50	55	58	32	49	32	79	28	18	17	36	48	35	69	59	49	75	70	80	58	78	33	32		20
	T	12	18	27	30	39	40	45	50	39	48	37	68	31	23	23	33	53	50	43	59	66	70	70	63	52	57	39	40	14	15
Trochammina inflata	L																	3	2	2				5	3						
	T					1	1					1				x	x	2	2	2	2	2	1	3	6	5	4	3	4		1
Trochammina macrescens	L	76	64	67	63	49	34	36	34	56	48	64	17	69	78	59	43	34	47	16	9	10		16	7	12	4	8	9		20
	T	68	60	69	60	44	42	48	43	48	45	54	30	62	70	55	38	27	38	43	21	10	8	16	17	27	21	31	30	16	26

L = Live, T = Total, x = <1%

TABLE 6

FORAMINIFERAL PERCENTAGE OCCURRENCES ALONG TRYON TRANSECT (STATIONS 1-14)

STATION NUMBER		1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B	11A	11B	12A	12B	13A	13B	14A	14B
Elevation above MSL (cm)		115	115	108	108	100	100	90	90	85	85	82	82	66	66	47	47	36	36	30	30	28	28	22	22	27	27	20	20
Total species	L	0	0	0	0	0	0	0	0	1	1	2	2	3	3	3	3	5	3	5	5	3	5	6	7	5	6	7	6
	T	0	0	0	0	0	0	0	0	1	1	3	2	3	3	5	4	8	5	5	5	6	6	7	7	6	6	7	7
Total individuals per 10 cm³	L	0	0	0	0	0	0	0	0	2	147	56	360	298	160	254	42	34	30	89	50	56	93	190	170	494	565	38	47
	T	0	0	0	0	0	0	0	0	100	173	103	506	620	382	1230	463	453	397	338	188	570	393	1350	1406	988	1165	171	214
Ammobaculites dilatatus	L																												
	T																												
A. foliaceus	L																												
	T																												
Ammonia beccarii	L																	3							1			32	8
	T																	x							x			8	3
Ammotium salsum	L																												
	T																												
Arenoparella mexicana	L																												
	T																							x					
*Centropyxis aculeata**	L																												
	T																												
*C. constricta**	L																												
	T																												
*Difflugia oblonga**	L																												
	T																												
*D. urceolata**	L																												
	T																												
Eggerella advena	L																												
	T																												
Haplophragmoides bonplandi	L																			2	2	7	2	4	2	5	8	3	
	T															x		4	3	2	1	10	2	3	2	5	8	3	x
Miliammina fusca	L																			1	6			5	4		1	16	6
	T															1	2	2	2	1	6	10	1	16	19	2	7	15	12
Polysaccammina ipohalina	L																	3											
	T																	1											
Reophax nana	L																												
	T																												
Pseudothurammina limnetis	L											5	6	1	2	13	7	33	93	50	42	28	67	6	14	28	17	10	26
	T											4	7	1	1	6	3	22	27	61	48	36	76	32	26	46	29	23	50
Tiphotrocha comprimata	L													2	1	12	17	9	3	8	2		1	9	2	4	5	3	4
	T													2	x	16	30	4	4	6	3	4	2	4	3	3	5	6	3
Trochammina inflata	L																									25	20	5	13
	T																	x				x	1	16	9	14	10	4	5
T. macrescens forma macrescens	L									100	100	95	94	97	97	75	76	53	3	38	48	64	29	59	67	38	51	32	42
	T									100	100	96	93	97	99	76	66	68	64	30	41	40	19	40	46	30	41	40	28
T. macrescens forma polystoma	L																												
	T											1																	

L = Live, T = Total, x = <1%

TABLE 7

FORAMINIFERAL PERCENTAGE OCCURRENCES (STATIONS 15-28) TRYON TRANSECT

STATION NUMBER		15A	15B	16A	16B	17A	17B	18A	18B	19A	19B	20A	20B	21A	21B	22A	22B	23A	23B	24A	24B	25A	25B	26A	26B	27A	27B	28A	28B
Elevation above MSL (cm)		32	32	30	30	28	28	33	33	32	32	28	28	33	33	33	33	13	13	18	18	-17	-17	-22	-22	-69	-69	-106	-106
Total species	L	9	7	4	5	7	4	5	3	9	6	7	4	6	8	5	4	6	4	5	4	5	4	4	4	5	5	6	7
	T	9	7	6	9	9	10	6	5	9	7	9	11	6	9	8	6	7	7	7	8	8	9	9	6	9	8	12	10
Total individuals per 10 cm³	L	402	136	24	100	74	56	76	22	210	126	98	20	134	171	146	129	260	112	123	150	44	26	10	10	35	71	19	18
	T	1086	388	576	1170	808	1028	926	592	944	992	264	410	512	295	331	244	744	267	270	336	281	147	233	230	591	433	769	1206
Ammobaculites dilatatus	L																											5	6
	T											x	1															1	x
A. foliaceus	L																											5	6
	T												x															x	x
Ammonia beccarii	L	1	1	17	8	8	11			6	17																		
	T	x	x	1	2	1	1			1	3																		
Ammotium salsum	L											3														8	3		6
	T											2	x			x		x			x	1	1	1		2	1	x	x
Arenoparella mexicana	L	x								5	3																		
	T	x								2	x										x						x	x	
*Centropyxis aculeata**	L																												
	T				x	x	x								x														
*C. constricta**	L																												
	T																						1						
*Difflugia oblonga**	L														x														
	T														x					x		x		x		x		x	x
*D. urceolata**	L																												
	T																							x					
Eggerella advena	L																												
	T																									x			
Haplophragmoides bonplandi	L	5	5												x														
	T	3	2		x	x	x					x	x		x	x	1		x	1	x	1	1	2	1	3	5	4	4
Miliammina fusca	L	2	1		2	24	11	5		3	3	78		7	9	3	15	5	4	6		7	12	10	20	26	17	37	11
	T	2	3	50	48	52	55	21	11	9	14	62	37	20	16	15	22	15	13	7	7	11	8	11	14	9	18	10	6
Polysaccammina ipohalina	L					3				2																			
	T				x	x	x			1			x																
Reophax nana	L																												
	T																											x	
Pseudothurammina limnetis	L	35	53	34	32	49	68	68	18	13	43	8	80	15	8	5		2		6	2	2							
	T	54	69	39	21	33	28	58	73	50	51	22	39	21	9	3	x	11	1	5	4	2	1	x	1	1	2	2	1
Tiphotrocha comprimata	L	9	5	17	16	3	11	3	27	35	17	1	10	1	x	1	1	2	4	1	2	11	8	10	30	20	8	16	6
	T	8	8	1	12	2	2	2	3	14	9	2	2	2	4	2	4	4	5	2	6	10	9	7	10	22	9	10	11
Trochammina inflata	L	4	1			5		21	54	30	16	7	5	67	60	83	62	85	77	9	47	30	4	30	10	17	48	10	17
	T	4	1	1	x	6	7	15	10	17	21	5	3	48	41	66	40	61	41	14	39	17	7	21	14	7	19	13	17
T. macrescens forma macrescens	L	43	32	34	42	8		3		5		1	5	7	19	8	22	6	15	77	49	50	77	50	40	28	24	26	50
	T	28	16	8	16	5	6	2	2	4	2	5	15	6	27	12	31	9	39	70	43	58	71	57	60	55	45	59	59
T. macrescens forma polystoma	L	x								1		1		1	2			1											
	T	x					x	x		1		1	x	3	2	x		x	x				1						

L = Live, T = Total, x = <1%

TABLE 8

FORAMINIFERAL PERCENTAGE OCCURRENCES AT PERCIVAL RIVER

(STATIONS 1a-1j)

SAMPLE NO.		$1a_1$	$1a_2$	$1b_1$	$1b_2$	$1c_1$	$1c_2$	$1d_1$	$1d_2$	$1e_1$	$1e_2$	$1f_1$	$1f_2$	$1g_1$	$1g_2$	$1h_1$	$1h_2$	$1i_1$	$1i_2$	$1j_1$	$1j_2$
No. of species	L	0	0	0	0	1	1	1	1	4	4	4	4	3	3	3	4	5	3	3	3
	T	2	0	1	0	2	1	2	2	4	4	4	4	4	5	5	5	6	5	5	5
No. of individuals 10 cm^3	L	0	0	0	0	41	58	179	36	49	122	108	98	38	310	32	124	220	34	134	261
	T	4	0	2	0	125	293	424	132	270	725	281	266	782	1056	569	1108	1460	1104	1034	1233
Ammotium salsum	L																				
	T																				1
Arenoparella mexicana	L															19	16	5	65	7	7
	T															3	1	2	5	x	3
Haplophragmoides bonplandi	L																				
	T																				
Miliammina fusca	L									6	10	7	11	16	7	3	10	65	6	75	79
	T									9	12	7	7	20	21	45	55	84	48	85	77
Pseudothurammina limnetis	L														1			x			
	T													4	2			x			
Tiphotrocha comprimata	L									4	1	22	20		6	3	1	x			
	T	75				2		2	4	8	4	20	23	8	12	5	4	x	4	x	
Trochammina inflata	L									8	2	40	36	80	77	75	73	28	29	18	14
	T									12	3	30	23	58	57	38	37	13	41	13	18
T. macrescens	L					100	100	100	100	82	82	32	33	4	8						
	T	25		100		98	100	98	96	71	81	43	47	10	8	9	3	x	2	x	1
Thecamoebians	L																				
	T						x			x											

(STATIONS 2a-2e)

SAMPLE NO.		$2a_1$	$2a_2$	$2b_1$	$2b_2$	$2c_1$	$2c_2$	$2d_1$	$2d_2$	$2e_1$	$2e_2$
No. of species	L	1	0	1	0	1	1	2	1	1	3
	T	4	0	2	3	2	1	5	5	6	7
No. of individuals 10 cm^3	L	1	0	5	0	23	2	27	67	29	87
	T	13	0	21	6	131	21	161	392	463	351
Ammotium salsum	L										
	T										
Arenoparella mexicana	L										7
	T									x	2
Haplophragmoides bonplandi	L										
	T										1
Miliammina fusca	L										
	T	38		14	17			2	1	4	3
Pseudothurammina limnetis	L							7			
	T							9	4	x	1
Tiphotrocha comprimata	L										3
	T	8						4	5	12	12
Trochammina inflata	L	100									
	T	38			17	1		5	2	19	9
T. macrescens	L			100		100	100	93	100	100	90
	T	16		86	66	99	100	80	88	64	71
Thecamoebians	L										
	T				x		x				

L = Live, T = Total, x = <1%

however, this zone can be divided into an upper and lower part. The upper part (+119 to +135 cm) is characterized by high numbers of *Pseudothurammina limnetis* (new genus, formerly *Thurammina ? limnetis*), *Trochammina macrescens*, and slightly lower percentages of *Haplophragmoides bonplandi*. *Tiphotrocha comprimata* occurs in relatively low percentages. The lower part (+75 to +119 cm) is characterized by *T. macrescens* and *T. comprimata* in equal numbers, with reductions in the other species. In the elevation range that generally corresponds with zone IIA (+20 to +75 cm) *T. macrescens* is reduced in its percentage occurrence, *T. comprimata* becomes dominant and several species have sustained but low percentage occurrences (*Arenoparella mexicana*, *Miliammina fusca*, *Trochammina inflata*). The occurrence of *A. mexicana* here is the first report of this species as a significant part of an assemblage zone in Atlantic

TABLE 9

FORAMINIFERAL PERCENTAGE OCCURRENCES AT PERCIVAL RIVER

(STATIONS 2f-3f)

SAMPLE NO.		$2f_1$	$2f_2$	$2g_1$	$2g_2$	$2h_1$	$2h_2$	$3a_1$	$3a_2$	$3b_1$	$3b_2$	$3c_1$	$3c_2$	$3d_1$	$3d_2$	$3e_1$	$3e_2$	$3f_1$	$3f_2$
No. of species	L	1	2	4	5	3	4	1	1	1	2	3	2	3	3	4	2	2	2
	T	6	6	6	7	6	5	5	3	3	5	7	5	6	6	6	5	7	6
No. of individuals 10 cm³	L	4	17	36	34	8	52	24	125	3	14	25	5	8	4	42	9	62	4
	T	250	329	1108	760	458	872	97	156	111	297	335	295	326	207	329	227	332	131
Ammotium salsum	L																		
	T											3						1	
Arenoparella mexicana	L			33	29	25	8					12	20		25	x		92	25
	T	1	x	3	7	4	2	3				4	1	8	4	1		27	4
Haplophragmoides bonplandi	L																		
	T				x														
Miliammina fusca	L				18		69							25					
	T	15	22	20	33	16	26	5			2	2	4	10	10	8	19	28	62
Pseudothurammina limnetis	L														25	10			
	T	3	2	2	x	1		1	1	9	10	1	3	5	6	33	14	8	1
Tiphotrocha comprimata	L		12	6	29		8				14	16		37		34	22		
	T	12	16	28	13	8	6			26	26	39	38	28	37	29	42	18	16
Trochammina inflata	L			50	18	50	15							38					
	T	8	12	23	24	26	7	5	1		1	3	1	31	24	8	4	2	3
T. macrescens	L	100	88	11	6	25		100	100	100	86	72	80		50	56	78	8	75
	T	59	47	24	22	45	60	86	98	65	61	48	55	18	19	21	21	16	14
Thecamoebians	L																		
	T									x		x							

(STATIONS 4a-4f)

SAMPLE NO.		$4a_1$	$4a_2$	$4b_1$	$4b_2$	$4c_1$	$4c_2$	$4d_1$	$4d_2$	$4e_1$	$4e_2$	$4f_1$	$4f_2$
No. of species	L	0	1	1	1	1	1	2	2	2	5	2	2
	T	2	4	3	4	3	4	4	6	5	7	5	4
No. of individuals 10 cm	L	0	36	15	13	10	8	21	27	15	32	45	43
	T	7	90	160	255	175	168	224	285	110	352	75	103
Ammotium salsum	L												
	T												
Arenoparella mexicana	L												
	T												
Haplophragmoides bonplandi	L												
	T									3			
Miliammina fusca	L											11	2
	T	86	1		2	2	5	1	1	3	3	15	9
Pseudothurammina limnetis	L							5	7		9		
	T		10	8	13	17	10	5	10	2	5	1	1
Tiphotrocha comprimata	L										6		
	T		22	6	4	14	23	21	20	5	14	1	1
Trochammina inflata	L									67	31		
	T							x	x	39	16	1	
T. macrescens	L		100	100	100	100	100	95	93	33	37	89	98
	T	14	67	86	82	67	62	73	66	51	57	82	89
Thecamoebians	L												
	T	x			x						x	x	

L = Live, T = Total, x = <1%

Canada. Below this (-57 to 20 cm) *Ammotium salsum* appears in low percentages while *M. fusca* appears to increase, corresponding with zone IIB.

Tryon - transect III: Total numbers of foraminifera were generally lower in this transect (Fig. 10, Tables 6, 7) and mineral content of the sediments higher, perhaps indicating a higher sedimentation rate. The upper part of the transect contained no foraminifera or thecamoebians (sediment was generally very dry). At +85 cm a monospecific fauna of *Trochammina macrescens* (Zone IA) occurs. Below this (+28 to +82 cm) a zone IB fauna occurs, co-dominated by *Pseudothurammina limnetis* and *T. macrescens*, with small numbers of *Tiphotrocha comprimata*. Below this elevation, *Trochammina inflata* and *Miliammina fusca* become more prominent. At the seaward end of this transect (i.e.

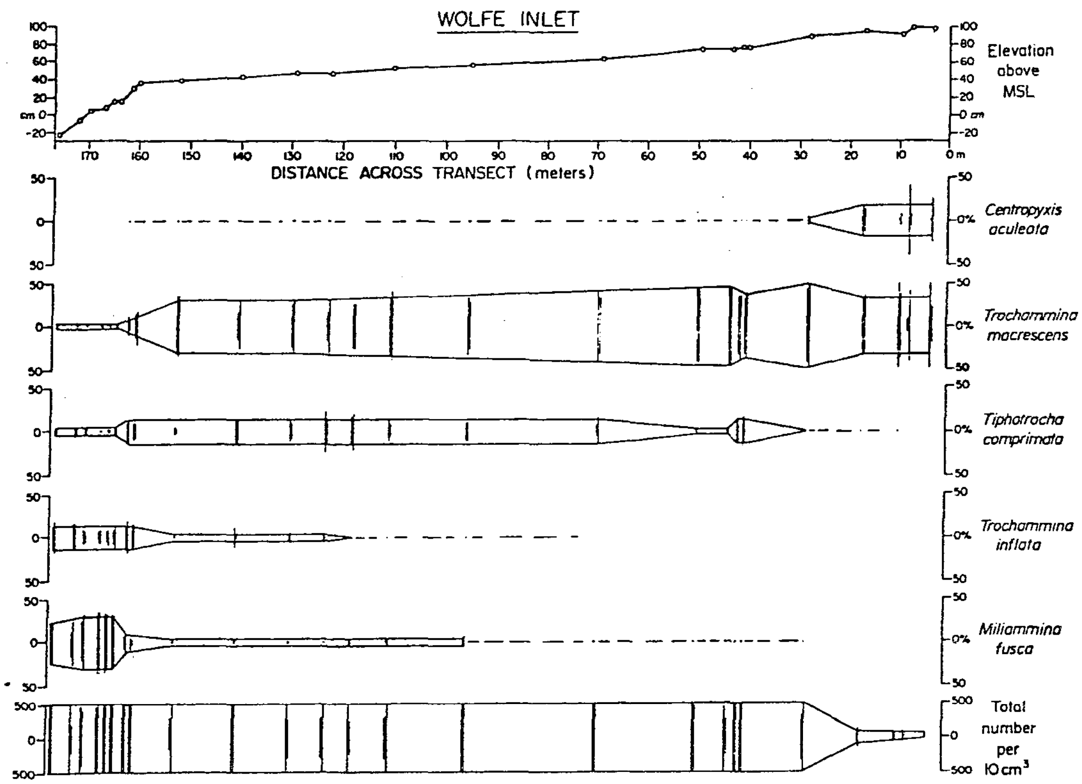

Fig. 8 - Foraminiferal distributions along Wolfe Inlet transect: Open circles are sampling localities; MSL - Benchmark MSL; double vertical bars represent the replicate samples at each locality; horizontal lines are subjective averaging (hence the vertical bars do not always fit perfectly); and, total numbers are only shown up to 1000/10 cm^3 since all significant variations occur below this value.

the low marsh end), where a zone IIB would normally occur, *T. macrescens* and *T. comprimata* (but notably not *P. limnetis*) again become dominant. Living populations in this area (Stations 23-28, Fig. 14, Table 7) become lower as percentages of *T. macrescens* increase. The slope of the channel and its sinuous nature (Figs. 5, 10) suggest that low marsh sediments are probably composed of a mixture of sediments from higher elevations, transported to lower elevations by bank undercutting and reworking.

Percival River transects: because this locality was isolated, a detailed transect with elevations was not possible. However, surface samples were collected in four semi-quantitative (without transects (Fig. 6) both to reveal differences between this area and the nearest detailed transect (Wolfe Inlet) and to detect possible spatial changes between transects (Tables 8, 9).

As in other locations the foraminiferal distributions divide into two faunal zones with attendant subzones. The low numbers of individuals recorded at stations 1A, B; 2A, B; 3A and 4A indicate supra-tidal conditions. There were no thecamoebians in these samples in contrast with similar areas of the Wolfe Inlet and Mt. Stewart transects. Just below these sites Zone IA is rep-

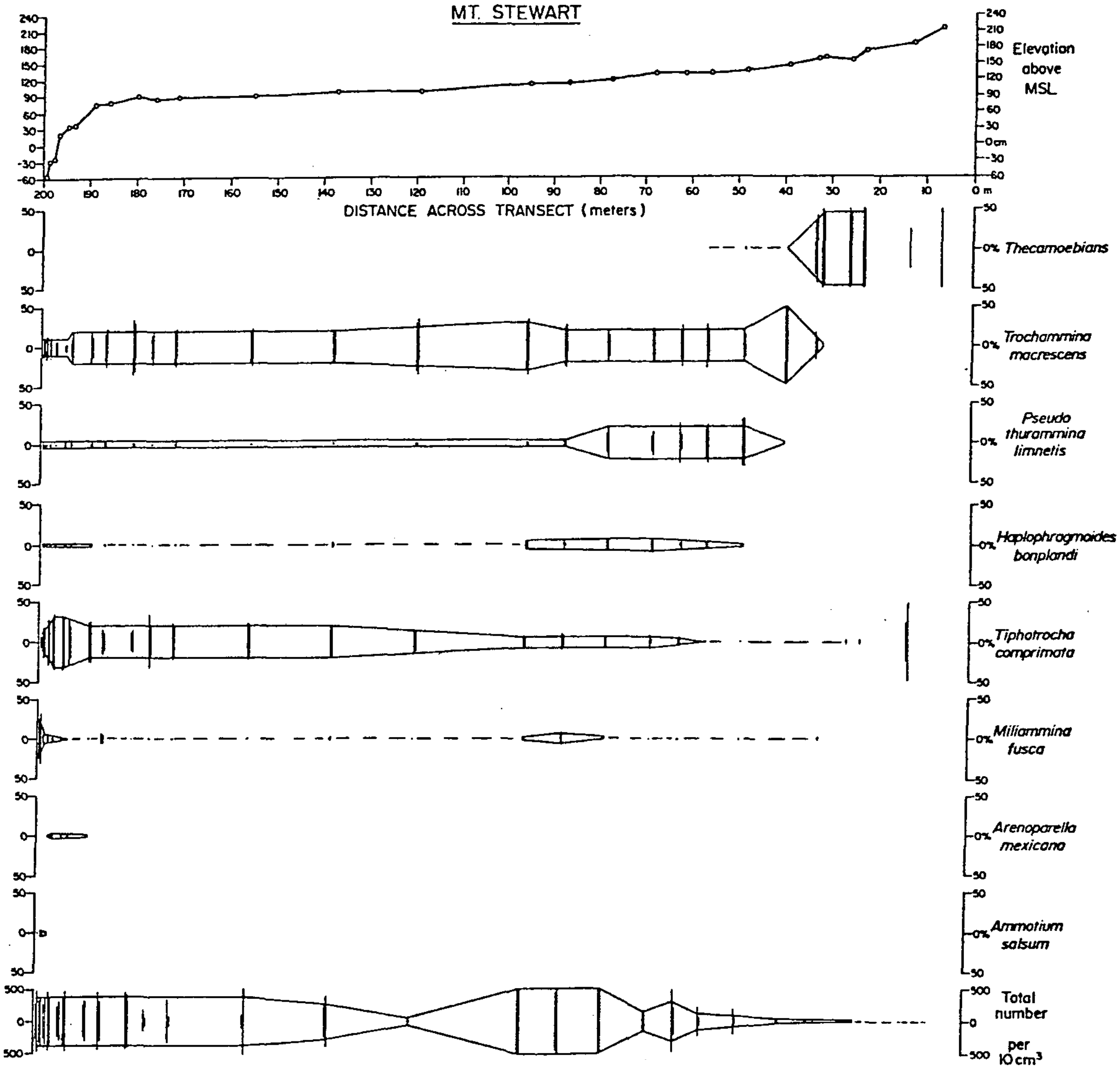

Fig. 9 - Foraminiferal distributions along Mt. Stewart transect; format same as Fig. 8.

resented at stations 1C, D; 2C, D; 3B, C; and 4B, C. Increasing percentages of *Tiphotrocha comprimata* and *Trochammina inflata* mark the occurrence of Zone IB. Zone IIA occurs in samples at lower elevations which are characterized by increased *T. inflata* and *Miliammina fusca*. Zone IIB occurs only in the lowest samples of transects 1-3 (none in transect 4), marked by increased *M. fusca*.

These faunas are virtually identical to those in Wolfe Inlet, particularly with regard to the reduced occurrences of *Pseudothurammina limnetis*. Occurrences of *M. fusca* vary spatially, decreasing significantly at transect 4. This is consistent with changing floral composition and lower salinites of the transects going from 1 to 4 (Table 1).

Transect results from the three main areas are summarized in Figure 11.

Foraminiferal Results in Drill Holes and Sea Level Results

Percival River: Two drill holes were located here (Fig. 6) and

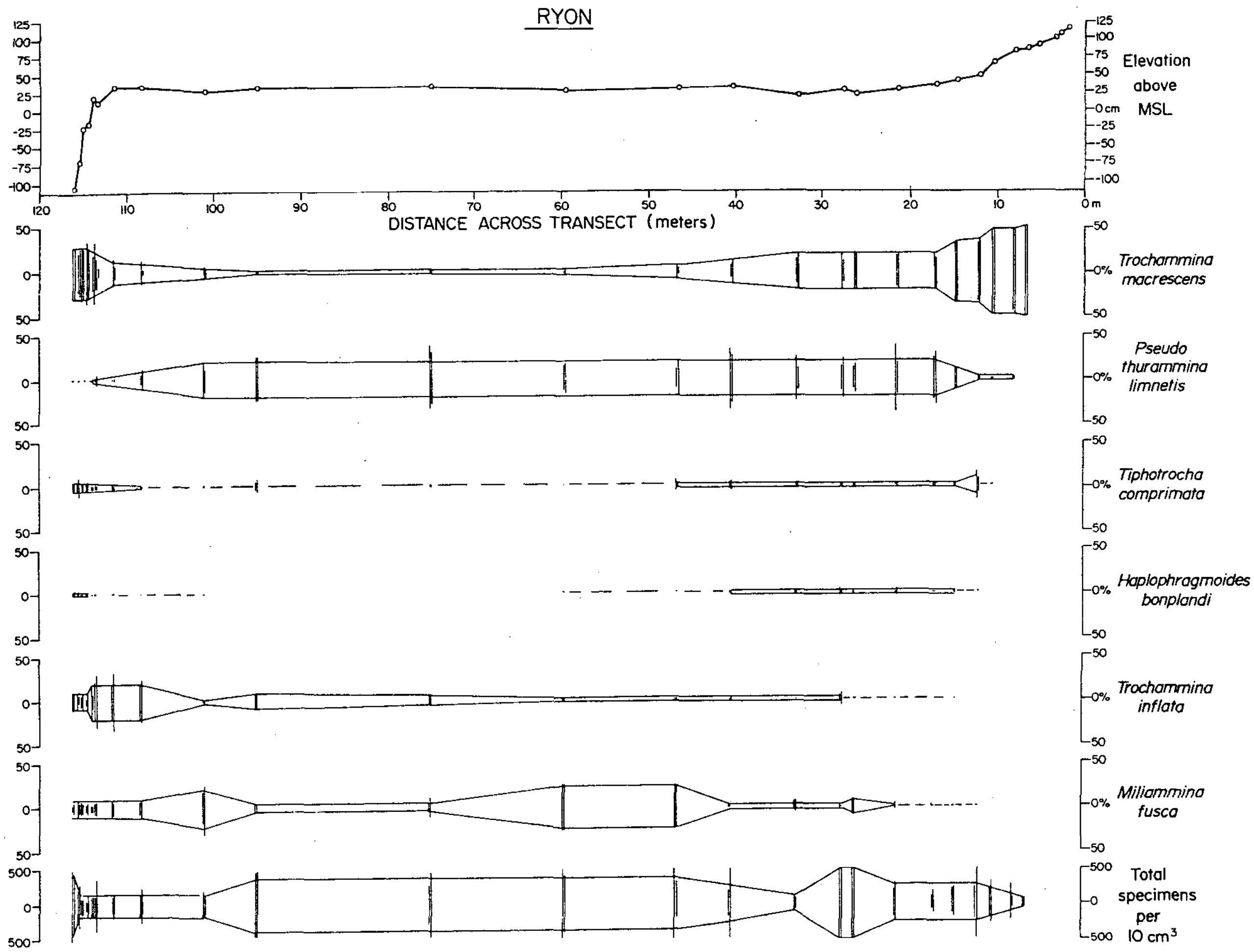

Fig. 10 - Foraminiferal distributions along Tryon transect; format same as Fig. 8.

exhibited sequences of continual marsh deposition (Fig. 12, Table 10). The faunal succession in both bore holes was similar but compressed in the shallower D.H. II. *Trochammina macrescens* has peak abundances near the base of both drill holes, indicating the elevation range of Zone 1A. The abundance of *T. macrescens* decreases towards the surface, accompanied by increase of *Tiphotrocha comprimata* and *Trochammina inflata*. An increase in *T. inflata* together with decreasing *T. macrescens* indicates the surface of the drill holes within Zone IIA.

Tryon: This was one of the thickest peat sequences observed on P.E.I. and four drill holes were located to cover adequately the entire range of sea level rise (Fig. 5). As in the surface transect, foraminiferal numbers were lower in these drill holes than might be expected. As a result foraminiferal distributions revealed the marsh zones less clearly (Fig. 13, Table 11). Towards the base of most boreholes, lower total numbers, together with dominance of *Trochammina macrescens* indicate a Zone I fauna. The presence of *Tiphotrocha comprimata* here probably places these basal samples within the upper part of Zone IB. The absence of *Pseudothurammina limnetis* in subsurface samples greatly limits interpretation here.

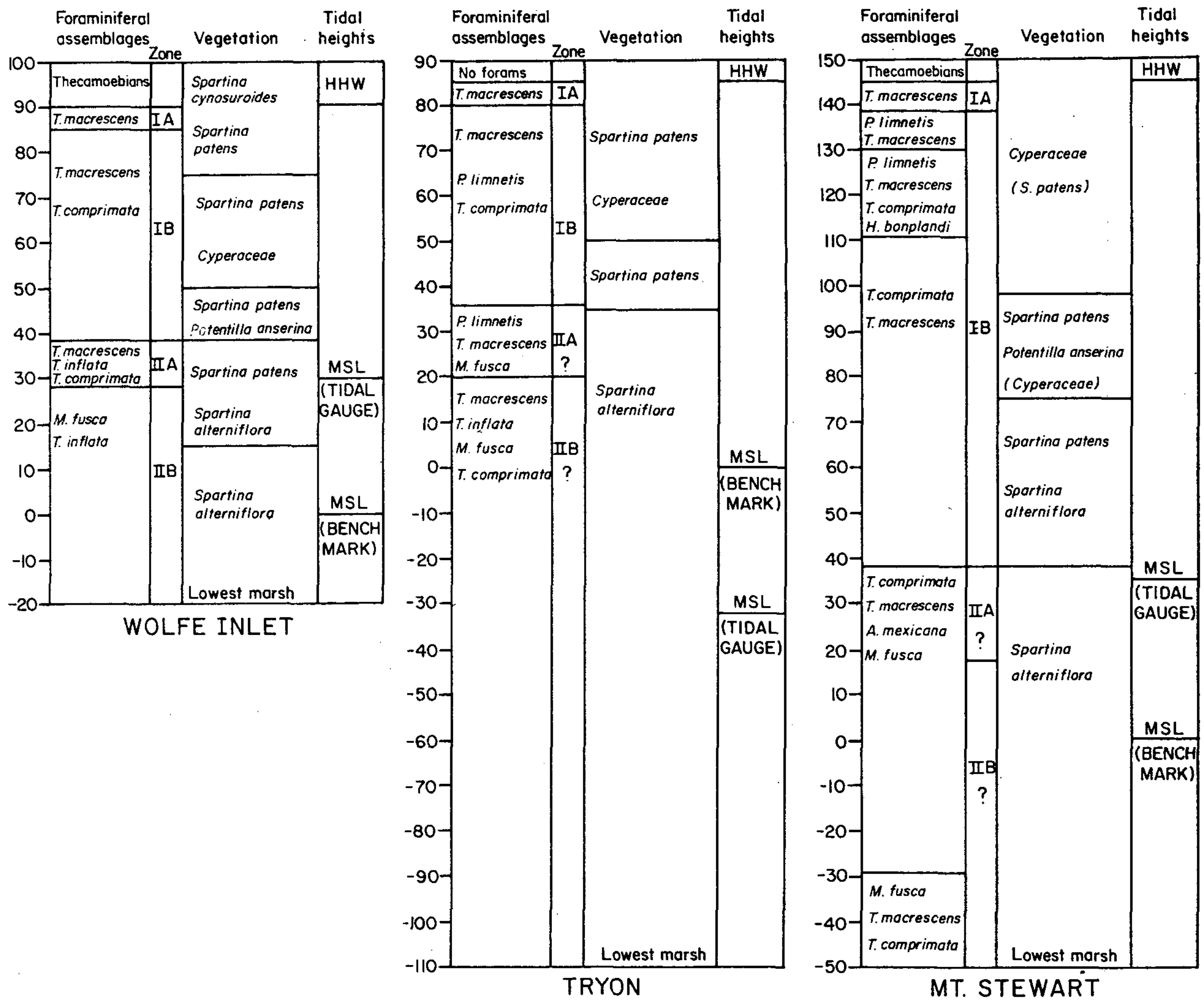

Fig. 11 - Summary diagram of the transect data. Note position of tidal MSL vs Benchmark MSL. Also note that most complicated patterns occur in the two transects located near causeways.

Pisquid: Three drill holes were located at Pisquid to cover just over 3 m of peat thickness (Figs. 4, 14). Foraminiferal distributions suggest a complete marsh sequence (Fig. 14, Table 12). Foraminiferal Zone IA occurs near the base of the three drill holes (monospecific in *Trochammina macrescens*). Abundances of *T. macrescens* decrease towards the surface together with increases in *Tiphotrocha comprimata* and indicate Zone IB faunas. Again *Pseudothurammina limnetis* is absent in subsurface sediments.

Orwell: Three drill holes were located here (Fig. 7) to encompass sea level changes recorded in just over 3 m of peat. Here again foraminiferal distributions revealed uninterrupted marsh sequences (Fig. 15, Table 13). In all three boreholes *Trochammina macrescens* dominates at the base but the presence of *Tiphotrocha comprimata* suggests these deposits formed near the top of Zone IB. Towards the surface *T. comprimata* increases with a corresponding decrease in *T. macrescens*. Just below the surface, *Miliammina fusca* and *Trochammina inflata* show peaks and may indicate Zone IIA. However,

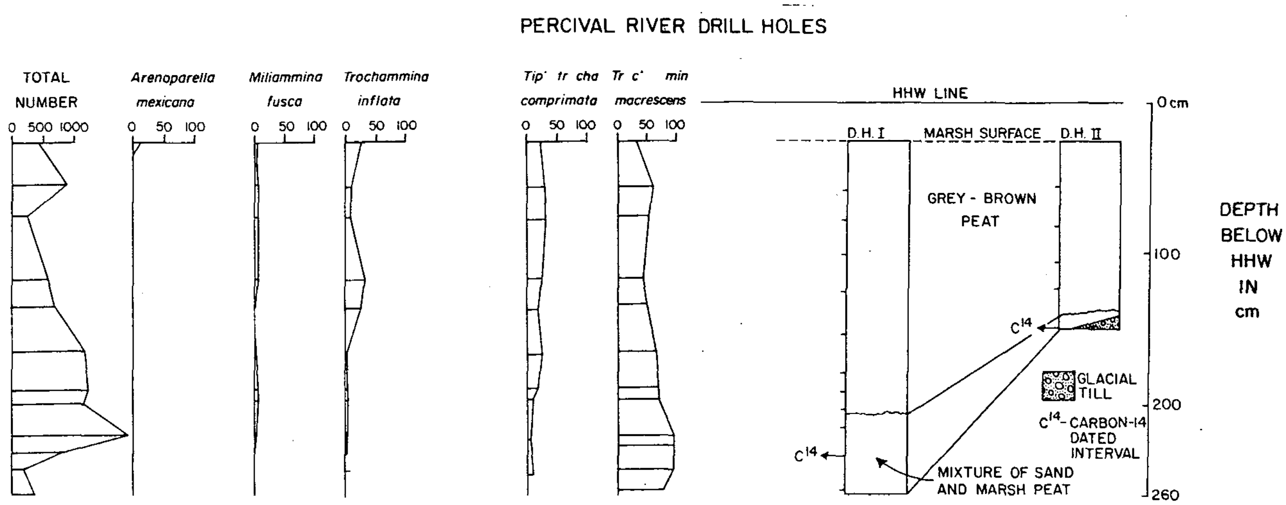

Fig. 12 - Litho- and biostratigraphy of Percival River drill holes. Only the deepest drill hole biostratigraphy is illustrated here and in subsequent figures.

high percentage occurrences of *Pseudothurammina limnetis* indicate Zone IB again at the surface.

As indicated earlier tidal ranges at the different study sites are not the same and this affects the position of HHW but not mean sea level (MSL). If tidal range did change through time, HHW could conceivably move more or less (depending on how tidal range changed) than MSL, and not truly represent sea level change. Since we are using HHW indicators, this is an important factor. However, tidal range deviations usually require substantial changes in basin configurations which could not be generated by the relatively modest changes in relative sea level recorded here (3 - 4 m). Hence, we make the assumption that tidal ranges have remained constant throughout the last 3000 years at our study sites, and that the movement of HHW truly represents relative sea level change over this period.

Relative sea level curves: Carbon-14 dates were obtained from indicated core depths (Figs. 12-15). At some sites, because of foraminiferal contents, dated levels were not located at the non-compactible substrate but were always within 20 cm of the base. Also, at some indicated levels, no Carbon-14 date was obtained because the sample submitted contained too little organic carbon to yield a reliable date.

These data indicate an increasing rate of relative sea level rise from west to east (Fig. 16). The Percival River data show an average of 8 cm/century relative sea level rise over the last 3000 years. Tryon (disregarding the dates from D.H.I. and II) indicates an average rate of 9 cm/century over the last 3300 years. In drill holes I and II at Tryon, dates appear anomalously young; this is probably the result of reworked materials at the base of drill holes I and II, much like the seaward end of the Tryon transect. In this case, the younger material could have come from higher elevations and been deposited in the channel bottom, giving the illusion of younger material below older material. Foraminiferal information from these drill holes also indicate this could be the problem. At

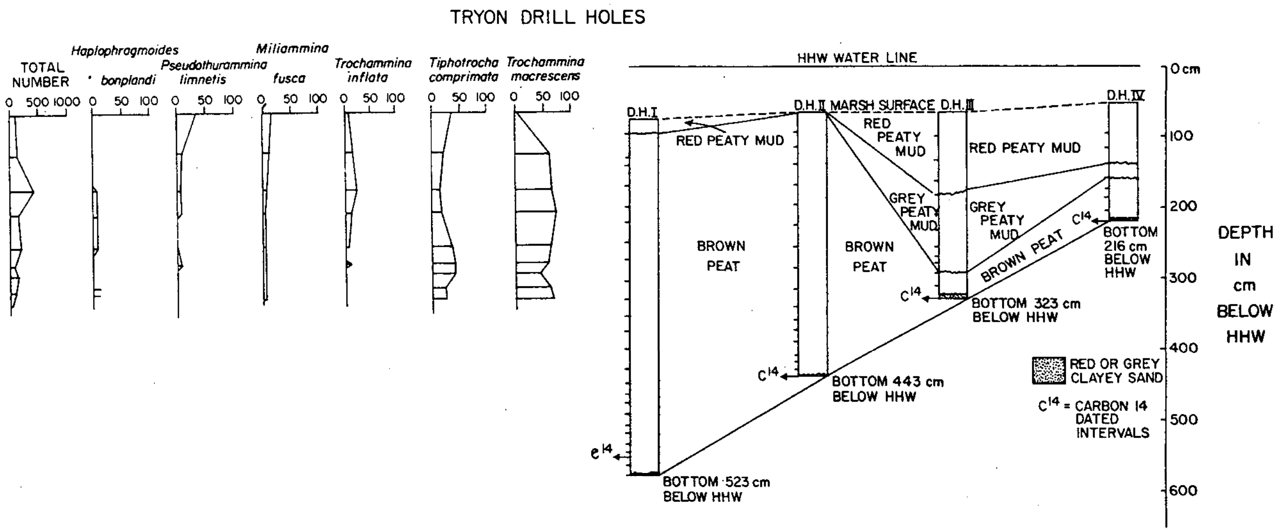

Fig. 13 - Litho- and biostratigraphy of Tryon drill holes (shallower drill hole stratigraphy illustrated since only shallow hole C^{14} dates were used to construct sea level curve).

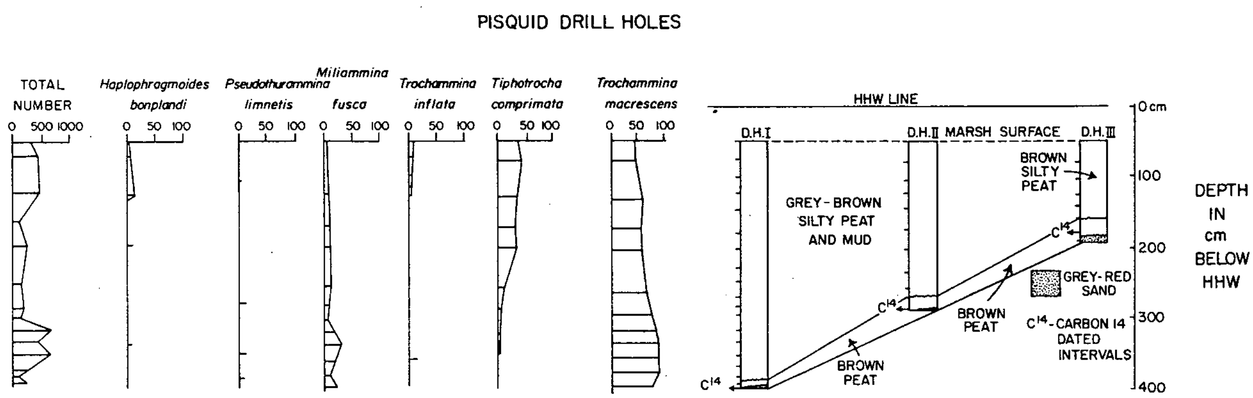

Fig. 14 - Litho- and biostratigraphy of Pisquid drill holes.

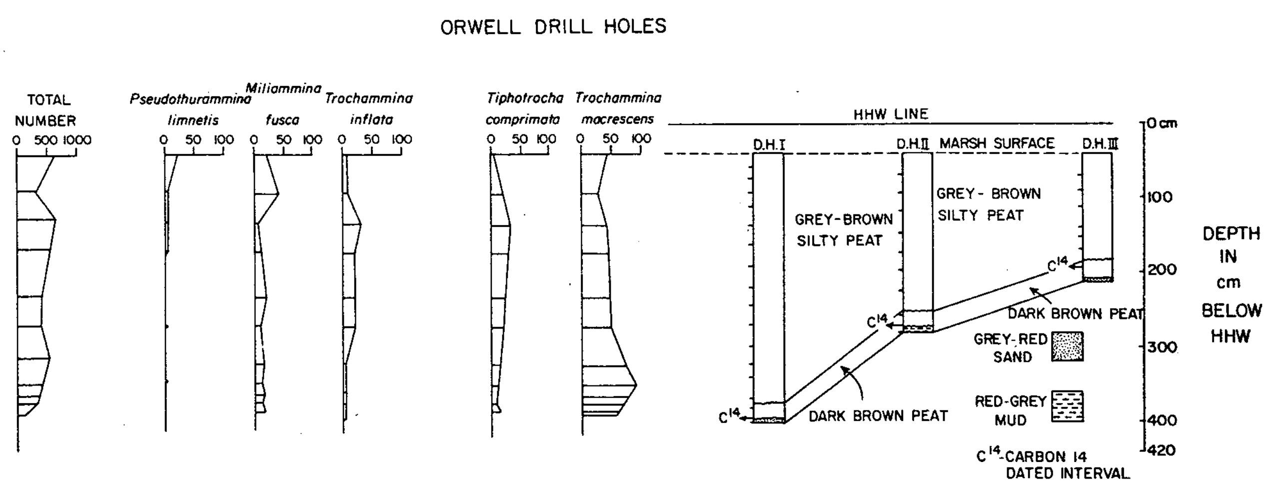

Fig. 15 - Litho- and biostratigraphy of Orwell drill holes.

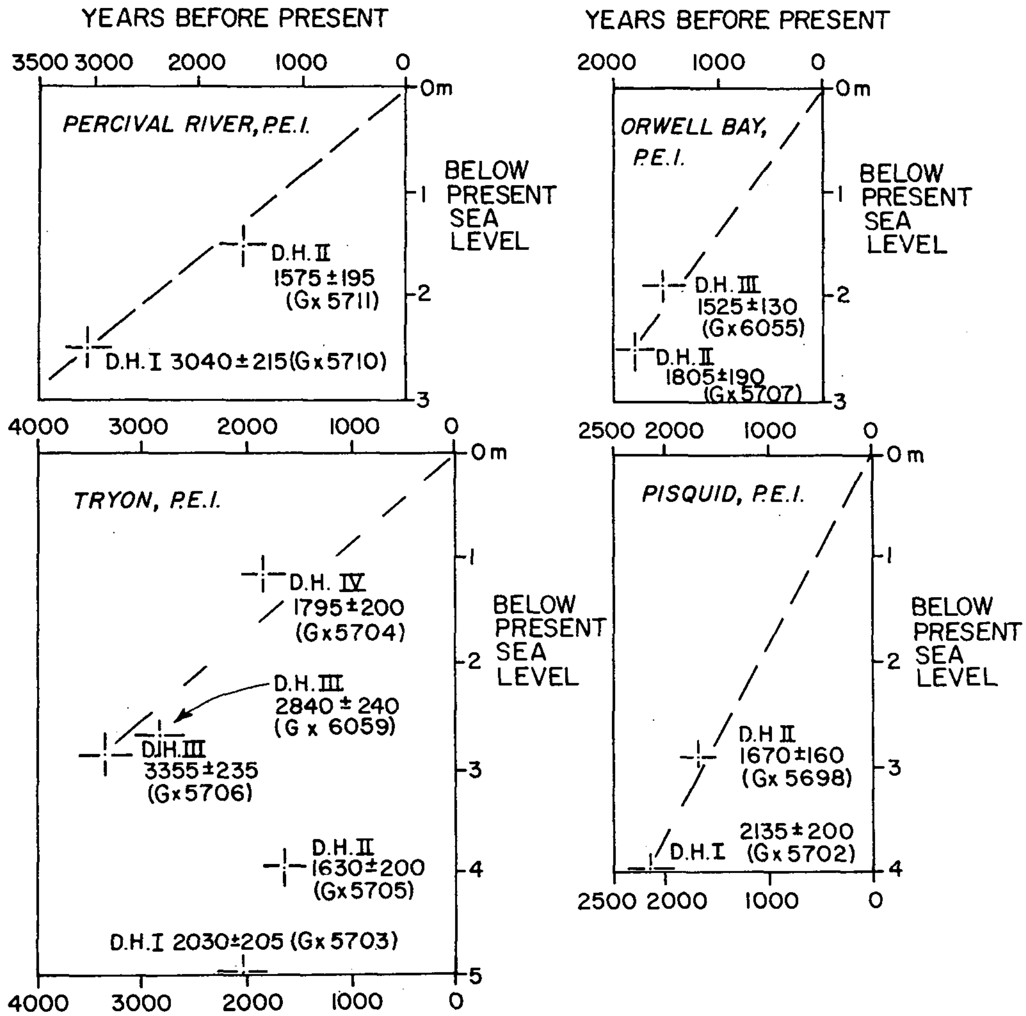

Fig. 16 - Sea level curves derived from drill holes in each of the four areas. C^{14} dates and lab numbers are included on the diagram. Vertical and horizontal bars indicate error limits of time and elevation.

Orwell, an average relative sea level rise of 14 cm/century is observed for the last 1800 years and at Pisquid, an average of 19 cm/century is recorded for the last 2100 years.

DISCUSSION

Surface plant relationships: Although plant distribution appears to be controlled in part by elevation above MSL, this distribution is inconsistent between areas in the same region. Several plant species have varying distributions depending, apparently, on several factors, only one of which is elevation above mean sea level. For example, *Spartina patens* is restricted to a narrow elevation range in Atlantic Coast marshes but dominates at all but the lowest levels (including some supra-tidal areas) in P.E.I. marshes. Oddly, in Wallace Basin, Nova Scotia (just across the strait from P.E.I.) *S. patens* again shows a restricted distribution (Scott and Medioli, 1980a). Differing elevational ranges for this species and others in adjacent areas significantly reduce vertical resolution of deposits using only plant remains. Hence, even if plant remains were easily recognizable in ancient marsh deposits, their reliability as sea level indicators would be low relative to those of foraminifera.

Surface foraminiferal distributions: There are some individual characteristics of the P.E.I. foraminiferal faunas that warrant special discussion. *Pseudothurammina limnetis*, a form described from Nova Scotia but never a dominant species there, appears to replace *Tiphotrocha comprimata* in Zone IB faunas of P.E.I. marshes where tidal range exceeds 2 m. However, *P. limnetis* does not appear in subsurface sediments or reworked sediments (low marsh area of Tryon); this suggests that tests of this species do not preserve once the organism dies. As noted in the type description of this species (Scott and Medioli 1980 a) the test is flexible and derives its strength from an organic inner lining rather than the cement of the agglutinated material covering the lining. Apparently the inner lining of this species, unlike inner pseudochitinous linings of other marsh species, is not resistant to decay and destruction in the highly bacteriologically active marsh sediments. Hence, although this species is common in some marshes, it is less useful than other species for paleoecological and sea level studies.

Two of the transect localities (Tryon, Mt. Stewart) were located near causeways. In Tryon the transect was just landward of the causeway (Fig. 5) and at Mt. Stewart the transect was just seaward (Fig. 4). It is difficult to assess the impact of the causeways on tidal ranges, circulation patterns, and the living marsh assemblages without having precise measurements of those elements, both before and after the causeways were constructed. However, comparing the Tryon and Mt. Stewart data with other marsh areas, most marked differences occur in the low marsh assemblages (i.e. between mid-tide and 3/4 tide). Additionally, distribution patterns observed at these two transects are among the most complex recorded from any marsh. Hence, we must conclude that those areas are affected in a complex manner and must be considered as abnormal systems, not comparable with unrestricted marsh systems, such as those studied in Nova Scotia or Wolfe Inlet and Percival River in this report. It is not the intent of this paper to discuss in detail what changes may have occurred as a result of causeway placements; however, it appears that a study of this kind could be initiated using as a starting point, data presented here and working back in time by means of drill holes or cores.

Characteristic of marshes examined in P.E.I. is the complete absence of calcareous species. This is unexpected since the shallow estuarine environments studied by Bartlett and associates are dominated by calcareous species. One calcareous species was recorded (mostly living specimens) but specimens lacked a carbonate test; only the organic inner lining was observed (*Ammonia beccarii*). Although salinites and temperatures in both Nova Scotia and P.E.I. marshes are similar, the areas physiographically are noticeably different. Areas investigated in Nova Scotia were large, open areas with high tidal turbulence while marshes examined in P.E.I. were in areas where channels were relatively small and turbulence reduced. The reduction of turbulence probably decreases the amount of dissolved oxygen in tidal waters. This in turn would depress pH levels at high tide when they are normally raised by high dissolved O_2 in flood tides (Phleger and Bradshaw 1966). Hence,

TABLE 10

FORAMINIFERAL PERCENTAGE OCCURRENCES IN PERCIVAL RIVER DRILL HOLES

D.H.I. 0-230

DEPTH (cms.)	0	35	53	88	113	140	163	175	188	200	220	230
No. of species	7	5	6	6	5	4	5	5	5	5	3	4
No. of individuals per 20 ml.	440	887	245	572	694	1245	1277	1201	2124	787	29	47
Arenoparella mexicana	10											
Haplophragmoides bonplandi	x											
Miliammina fusca	2	1	2	4	x	3	6	6	x	x	x	
Pseudothurammina limnetis												
Tiphotrocha comprimata	22	29	28	20	14	25	20	13	x	2	7	4
Trochammina inflata	29	9	9	31	29	2	1	6	1	1		9
T. macrescens	37	61	60	45	54	70	73	75	98	96	93	87
Thecamoebians												

D.H.II. 0-125

DEPTH (cms.)	0	32	84	101	125
No. of species	5	5	5	5	2
No. of individuals per 20 ml.	501	623	595	195	17
Arenoparella mexicana					
Haplophragmoides bonplandi	x	x	x	x	
Miliammina fusca	2	3	16	4	
Pseudothurammina limnetis					
Tiphotrocha comprimata	16	19	15	20	6
Trochammina inflata	29	10	1	1	
T. macrescens	53	67	68	74	94
Thecamoebians					

x = <1%

although salinities may be sufficiently high, pH may be the limiting factor for the calcareous species. An exact parallel was observed in California where Mission Bay marshes, flooded by turbulent waters of an open bay, were dominated by calcareous species in low marsh areas; only 30 km south (Tiajuana Slough) marshes with similar salinities but restricted flow, were dominated by

TABLE 11

FORAMINIFERAL PERCENTAGE OCCURRENCES IN TRYON DRILL HOLES

D.H.I.

DEPTH (cms.)	0	20	65	123	173	228	278	323	373	400	432	459	476	487	503
No. of species	6	5	4	4	5	5	6	6	5	5	5	5	5	4	3
No. of individuals per 20 ml.	274	460	170	154	372	177	572	700	612	664	396	284	222	156	178
Arenoparella mexicana															
Haplophragmoides bonplandi	2			4	x	0	2	1	x	1	1	x			
Miliammina fusca	15	20	7	3	9	7	8	6	7	5	7	5	23	13	4
Pseudothurammina limnetis	28	20				1	2	2	x	2	3	4	3	x	
Tiphotrocha comprimata	5	10	14	6	4	7	8	6	5	20	7	14	6	12	5
Trochammina inflata	7	39	1		x	1	1	1							
T. macrescens	43	11	78	87	86	84	79	84	87	72	82	76	66	74	91
Thecamoebians															

D.H.II.

DEPTH (cms.)	0	76	133	195	223	253	296	307	323	353	363	375
No. of species	5	6	4	6	5	5	5	4	6	5	7	2
No. of individuals per 20 ml.	62	127	82	141	122	146	121	139	168	166	195	44
Arenoparella mexicana												
Haplophragmoides bonplandi	19	5	23	1	2	2	1	1	x	1	2	5
Miliammina fusca		9		8	2	12	8	3	6	12	6	
Pseudothurammina limnetis	4	4		3		2			4	1	3	
Tiphotrocha comprimata	10	8	13	25	17	12	11	4	8	17	23	
Trochammina inflata	37	8	34	7	13		1		3		x	
T. macrescens	30	66	30	56	66	72	79	92	79	69	65	95
Thecamoebians											x	

D.H.III.

DEPTH (cms.)	0	53	103	132	186	210	223	242	263
No. of species									
No. of individual per 20 ml.									
Arenoparella mexicana		x							
Haplophragmoides bonplandi			1	1	x		1	7	
Miliammina fusca	15	10	-1	2	3	7	5	5	2
Pseudothurammina limnetis	34	1	x	3		1	4		
Tiphotrocha comprimata	39	23	13	17	33	30	40	23	25
Trochammina inflata	2	5	16	2	x		1		
T. macrescens	10	61	68	74	63	62	49	65	73
Thecamoebians				x					

D.H.IV.

DEPTH (cms.)	0	53	88	105	120	134	153	168
No. of species								
No. of individual per 20 ml.								
Arenoparella mexicana								
Haplophragmoides bonplandi	x	x	2	15	x	1	7	3
Miliammina fusca	49	8	12	5	4	3	7	2
Pseudothurammina limnetis	5	x	2	3				3
Tiphotrocha comprimata	21	54	24	12	7	18	8	4
Trochammina inflata	1	x	30	3	x		5	8
T. macrescens	23	37	30	61	88	78	73	79
Thecamoebians	x			1		x		1

X = <1%

TABLE 12

FORAMINIFERAL PERCENTAGE OCCURRENCES IN PISQUID DRILL HOLES

D.H.I. - 0-350

DEPTH (cms.)	27	76	123	171	213	244	266	283	303	315	328	340	350
No. of species	5	5	3	4	3	3	3	4	5	3	2	4	3
No. of individuals per 20 ml.	482	421	57	176	85	160	191	692	457	664	111	198	242
Arenoparella mexicana													
Haplophragmoides bonplandi	x	2		1				x					
Miliammina fusca	2	8	9	2	18	13	15	7	20	28	22	13	19
Pseudothurammina limnetis									x			x	2
Tiphotrocha comprimata	40	30	35	40	13	11	8	3	5	2	x		
Trochammina inflata	10	1							x				
T. macrescens	48	58	56	57	69	76	77	90	74	70	78	86	79
Thecamoebians													

	D.H.II. 0-240							D.H.III. 0-141					
DEPTH (cms.)	0	57	106	197	218	230	240	0	54	86	103	120	141
No. of species	5	6	4	3	4	3	2	5	5	5	4	5	6
No. of individuals per 20 ml.	172	292	200	295	450	65	78	212	248	266	340	205	86
Arenoparella mexicana													
Haplophragmoides bonplandi	3	2						2	1	6	4	7	13
Miliammina fusca	3	33	24	12	23	4	5	2	22	17	12	22	1
Pseudothurammina limnetis	10	1		x	x					x			1
Tiphotrocha comprimata	60	32	15	40	2			43	22	13	15	2	9
Trochammina inflata		6	1					1	3		x		1
T. macrescens	24	26	60	47	75	95	95	52	52	64	69	69	74
Thecamoebians													

X = <1%

arenaceous species (Scott 1976 b).

Vertical tidal relationships: There appears to be a discrepancy between tidal datum (MSL or Z_0) and the datum (given as MSL) used for benchmarks. Tidal MSL occurs consistently above the mid-tide level while it appears that mid-tide was used as MSL for the benchmarks. It is noteworthy, however, that marsh distributions, both vegetation and foraminifera, align as if MSL was at the mid-tide level. However, the middle and high plant zones and corresponding foraminiferal zones encompass a slightly broader elevational range than parallel zones in a non-mixed tidal system. Scott and Medioli (1980 a) suggested that these two zones are usually confined to the upper 30-40 cm of tidal range (sea level accuracy of ±15-20 cm), regardless of tidal amplitude. These same zones in P.E.I. marshes occupy up to 75 cm total range (Mt. Stewart) or the upper ¼ of the tidal range which gives them an accuracy of ±30-40 cm. This is also true in Wallace Basin marsh, Nova Scotia (a point overlooked by Scott and Medioli 1980 a). Hence, although Zone I species are still restricted to the upper ¼ of tidal range (Scott

TABLE 13

FORAMINIFERAL PERCENTAGE OCCURRENCES IN ORWELL DRILL HOLES

D.H.I. 0-353

DEPTH (cms.)	0	53	82	133	192	232	286	303	332	334	353
No. of species	5	5	5	5	4	5	5	4	4	5	4
No. of individuals per 20 ml.	564	382	694	541	430	366	545	489	378	300	198
Arenoparella mexicana											
Haplophragmoides bonplandi											
Miliammina fusca	25	41	4	6	16	6	8	7	15	15	17
Pseudothurammina limnetis	21	4	x	x		1		x		x	
Tiphotrocha comprimata	6	23	32	28	24	22	14	4	7	9	16
Trochammina inflata	3	5	25	17	21	21	2	x	3	x	2
T. macrescens	45	27	38	49	49	50	75	88	75	75	65
Thecamoebians											

	D.H.II. 0-182						D.H.III. 0-172						
DEPTH (cms.)	0	53	106	133	153	182	0	80	108	136	152	163	172
No. of species	4	5	7	5	5	5	5	5	5	4	5	5	4
No. of individuals per 20 ml.	518	858	896	328	280	660	393	318	667	1072	347	159	32
Arenoparella mexicana													
Haplophragmoides bonplandi			x	4	1				x	x	2	1	4
Miliammina fusca	12	28	31	13	10	16	31	15	22	23	11	12	6
Pseudothurammina limnetis	18	x	x			1	26						
Tiphotrocha comprimata	10	29	17	15	14	11	2	27	31	12	4	7	9
Trochammina inflata		2	x	3	2	1	1	7	3		1	3	
T. macrescens	60	40	51	65	73	71	40	51	44	64	82	77	81
Thecamoebians													

X = <1%

and Medioli 1978 b), their absolute vertical range apparently increases in response to the mixed tidal system. This however, does not appear to affect the absolute range of Zone IA (i.e. the *T. macrescens* zone), which even in P.E.I. still retains its absolute accuracy of ±5 cm.

Sea level changes: Orwell is the only area in this study close to sites where previous onshore sea level data are available. Frankel and Crowl (1961) report a range of 1.5 to 2.4 m of relative sea level rise in the last 900 years at Nicholas Point, about 20 km SE of Orwell; this is in contrast to 1.25 m over the same period recorded at Orwell (Fig. 16). The range of values indicated by Frankel and Crowl (1961) is probably the result of their use of less precise indicators of former sea level (tree stumps, undifferentiated peat), with their lower value (1.5 m/900 yrs) being closest to our relative sea level change.

The general trend of decreasing sea level rise westward was reported by Kranck (1972) from offshore studies but she suggested that, for the last 3000 years, all of P.E.I. has experienced uniform relative sea level rise. Our data suggest that the rate of rise has been almost twice as fast in the east than at the western end of P.E.I. Kranck (1972) acknowledged that her data were too limited to determine when differential movement terminated. Our data also indicate that magnitudes of sea level rise, particularly in the west, estimated by Kranck (1972) were excessively high. As with Frankel and Crowl (1961) the use of less precise indicators (in this case miscellaneous shells) probably caused the discrepancy in Kranck's (1972) sea-level figures.

Unfortunately, the lack of thicker marsh deposits limits the sea level record to only the last 3000 years. However, these data were still useful in calibrating the geophysical models of relative sea level movement presented by Quinlan and Beaumont (1981). We have also demonstrated that marsh foraminiferal zonations can be used to detect small scale differences of sea level change, which was not previously possible.

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SYSTEMATIC TAXONOMY

No synonymies or plates are included in this paper (except for the new genus). The reader is referred to Scott and Medioli (1980 a) for descriptions and plates of all foraminiferal species. Thecamoebian species are illustrated in Scott and others (1980) with the following name differences - *Difflugia oblonga* (here) = *D. capreolata* (Scott and others, 1980); *Centropyxis aculeata* (here) = *C. excentricus* (Scott and others, 1980); *Centropyxis constricta* (here) = *Urnulina compressa* (Scott and others, 1980).

Following is the description and systematic placing of the new genus, *Pseudothurammina* Scott, Medioli, Williamson.

Family - Saccaminidae Brady 1884
Sub-family - Saccammininae Brady 1884
Genus *Pseudothurammina* n. gen. Scott, Medioli and Williamson
Genotype: *Thurammina? limnetis* Scott and Medioli, 1980 a p. 43, 44, pl. 1, figs. 1-3

Generic diagnosis: Test free or attached, monothalamous, subglobular; variable number (0-5 in specimens we have observed) of irregular mammillae occur in the outer test; apertures at apex of the mammillae. Wall flexible with relatively thin layer of mineral grains cemented to an organic (not pseudochitinous) inner lining. Organic lining transparent, usually visible in area of attachment where there is no agglutinated material.

Ecology and occurrence: Occurrence is basically the same as reported for the type species, *P. limnetis* (Scott and Medioli 1980a). However, since that work, Dr. D. Haman (pers. comm.) has reported finding *P. limnetis* in levee deposits (presumably in or near a marsh) from the Northeast Pass, Mississippi Delta (lat. 29°7'59", long. 89°2'12"). Water depth at time of collection was 30 cm and he reported finding specimens to a depth of 30 cm in the sediment. Salinites were low (0-6°/₀₀) and temperatures high (21°C) at time of collection, not inconsistent with summer conditions in marshes of Maritime Canada. This report, together with probable occurrences in Brazil and Europe, lead us to believe the genus has a worldwide distribution.

Remarks: Specimens belonging to this genus have previously been placed with several genera, among them *Astrammina* Rhumbler, *Armorella* Heron-Allen and Earland and *Thurammina* Brady. It was suggested by Scott and Medioli (1980a) that a new genus was probably in order for the species *P. limnetis*, at that time doubtfully placed with *Thurammina*. Since that time we have had the opportunity to examine specimens of *Thurammina* species. Although these specimens had a slightly flexible test (as in *Pseudothurammina)* there was no inner lining and *Thurammina* appear to be deep water forms, as opposed to the marsh habitat of *Pseudothurammina*.

It was stated in the type description of *P. limnetis* that the organic inner lining was pseudochitinous (Scott and Medioli 1980 a). However, in addition to its transparent nature, the inner lining of *Pseudothurammina* does not preserve in subsurface or transported sediments, unlike the pseudochitinous linings of other marsh species. The term "pseudochitinous" is a loosely defined term, applied generally to all inner linings of foraminifera; however, here we chose to differentiate the lining in *Pseudothurammina* from that of other foraminiferal species because of its preservation characteristics.

Pseudothurammina was placed with the family Saccamminidae based on wall structure and general test form.

Generic derivation: The name *Pseudothurammina* was chosen because outwardly, specimens of this genus appear similar to those belonging to the genus *Thurammina*.

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