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Pacific Rim Marsh Foraminiferal Distributions: Implications for Sea-Level Studies[1]

D.B. Scott†, E.S. Collins†, J. Duggan†, A. Asioli‡, T. Saito*, and S. Hasegawa**

†Centre for Marine Geology
Dalhousie University
Halifax, NS B3H 3J5, Canada

‡Istituto per la Geologia
Marina del C.N.R.
via Piero Gobetti 101
40129 Bologna, Italy

*Institute of Geology and Paleontology
Faculty of Science
Tohoku University
Sendai 980, Japan

**Graduate School of Environmental Earth Science
Hokkaido University
Sapporo 060, Japan

ABSTRACT

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New data on marsh foraminiferal distributions are presented for Hokkaido (Japan), Washington State and northern/central California (USA). These data, when compared to recently published information from British Columbia, Oregon, Chile and New Zealand, and older data from southern California, allow a comprehensive comparison of biogeographic zonations around the Pacific Rim. Most significant is that high marsh faunas change from brackish to more saline at the California border but all high marsh faunas have the same 2–4 species present. In the southern hemisphere, the species *Trochamminita salsa* becomes an important high marsh indicator. Their narrow range makes high marsh faunas excellent markers for relocating former sea levels. These data can be used to detect rapid, high amplitude sea-level events associated with earthquakes on the Pacific Rim.

ADDITIONAL INDEX WORDS: *Pacific rim, salt marshes, marsh foraminifera, high marsh.*

INTRODUCTION

Up until a few years ago, investigations of marsh foraminiferal distributions had been carried out largely on the Atlantic margins, not the Pacific (see SCOTT and MEDIOLI, 1980a, for summary). However, in the last few years, several authors (JENNINGS and NELSON, 1992; PATTERSON, 1990; JENNINGS *et al.,* 1995; HAYWARD and HOLLIS, 1994) have shown detailed marsh foraminiferal zonations from British Columbia, Canada, Oregon, USA, Valdivia, Chile and New Zealand. These studies were conducted to define precise sea levels and to delineate rapid land movements that take place in major earthquakes (ATWATER, 1987). This paper will enlarge on the data of the previous authors to include marshes on the eastern tip of Hokkaido, Japan (43°N, 145°E, Figure 1), Washington State (47°N, 123°W), northern California (41°N, 124°W) and central California (37°N, 122°W). Combining these data together with recently collected data of others should provide a comprehensive picture of what can be done in terms of accurate measurement of sea level using marsh foraminiferal zonations around the Pacific Rim.

PREVIOUS WORK

The earliest work conducted in marshes on the Pacific coast of North America is by PHLEGER and EWING (1962) who examined marsh faunas from Scammons Lagoon in Baja California. Subsequently, PHLEGER (1967) provided a rough biogeographical sketch of marsh foraminiferal faunas from the west coast of North America, extending from Alaska to Baja California (six areas in total). Except for Mission Bay, California, PHLEGER had no more than 10 samples from his study areas so could not provide any quantitative elevation data on whether or not these foraminifera were zoned according to elevation. PHLEGER and BRADSHAW (1966) provided an excellent 24-hour record of marsh physical parameters from an intertidal marsh in Mission Bay, California, including the rapid changes in pH, O_2, temperature, EH, sunlight and tidal ranges. This paper is funda-

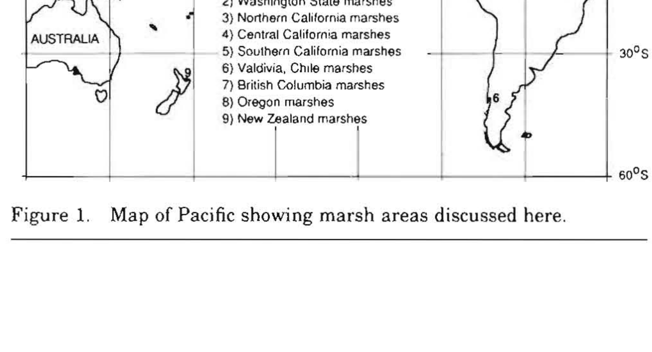

Figure 1. Map of Pacific showing marsh areas discussed here.

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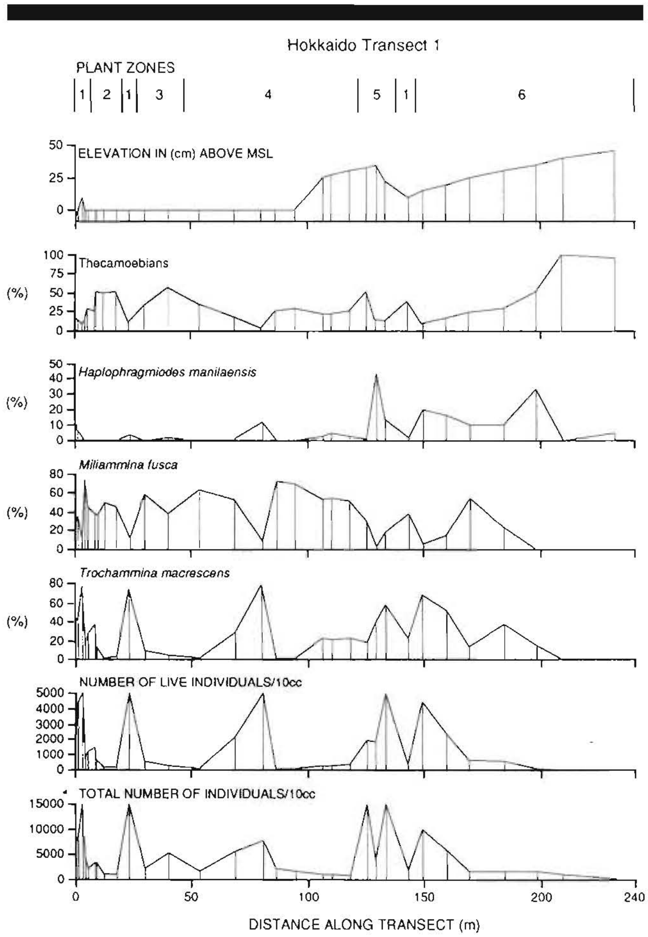

Figure 2. Foraminiferal and vegetation distributions along Hokkaido Transect 1. Elevations shown are approximate—they were not measured accurately. Foraminiferal data are detailed in Table 1. Vegetation zones by number: (1) *Eleocharis* spp./*Scirpus* spp., (2) *Carex* spp. + others, (3) *Scirpus* spp., *Juncus* spp., (4) *S. takemaemontani* + others (first tree at Stn. 19), (5) *Eleocharis* spp. + upland plants, dry soil, (6) *Eleocharis* spp. + others + upland (forest starts at Stn. 31).

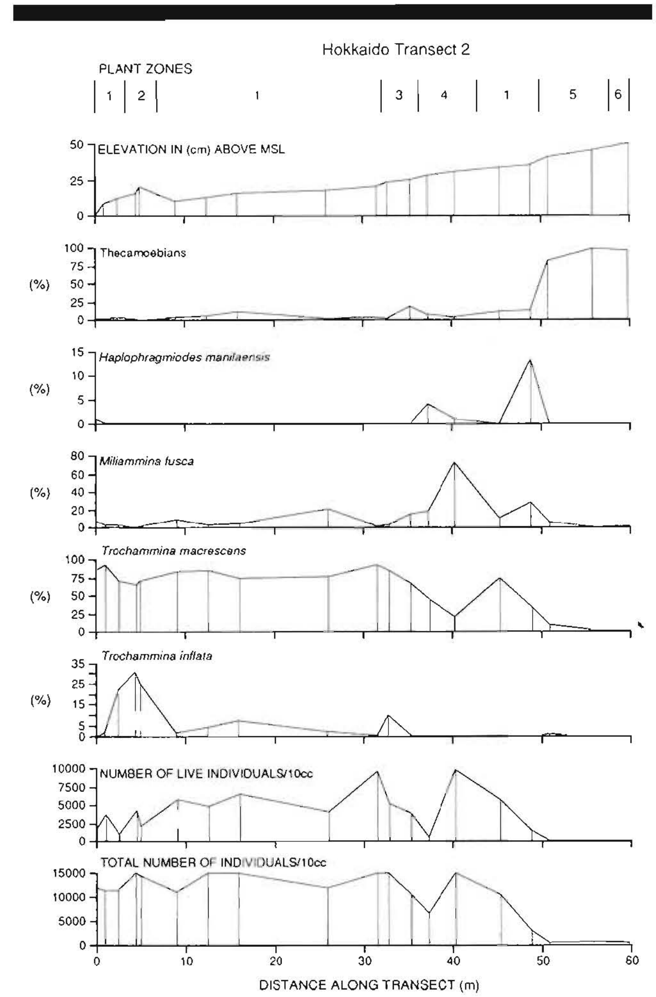

Figure 3. Foraminiferal and vegetation distributions along Hokkaido transect 2. Elevations shown are approximate. Foraminiferal data are detailed in Table 2. Vegetation zones are as follows: (1) *Carex* spp./*Eleocharis* spp., (2) *Calamagrantis* spp./*Carex* spp., (3) *Carex* spp./*Scirpus* spp., (4) *Scirpus* spp., (5) *Eleocharis* spp./upland, (6) upland plants.

mental to the understanding of how foraminifera are preserved in marsh sediments.

SCOTT (1976a,b) performed the first quantitative studies of saltmarsh foraminifera in southern California that suggested a strong relationship between elevation above mean sea level (MSL) and marsh foraminiferal patterns. After this initial work, little was done in the Pacific region until PATTERSON (1990) re-visited the Fraser River Delta marshes that PHLEGER (1967) had studied earlier and provided data that showed a strong vertical zonation of marsh foraminifera. JENNINGS and NELSON (1992) conducted a similar study in Coos Bay, Oregon, another of PHLEGER's (1967) sites. Finally, JENNINGS *et al.* (1995) did a study in Rio Valdivia, Chile, that again confirmed a strong vertical zonation of marsh foraminifera. Marsh foraminiferal data from Japan are not available but shallow water foraminifera from that region are well studied (for complete bibliography of Japanese work, see TAKAYANAGI and HASEGAWA, 1987; and AKIMOTO, 1990).

PHYSIOGRAPHY OF FIELD AREAS

Introduction

All elevations on Figures 2–7 are estimated based on higher high water tidal ranges of 2 m (except in Japan where the extreme range is 0.8 m) and assuming lowest marsh is mean sea level and highest marsh (strandline) is higher high water. The elevations were not measured directly—only estimated visually, with 10–20 cm accuracy.

Hokkaido Marshes

The marshes we sampled are on the extreme eastern tip of Hokkaido Island, Japan, in the Nemuro Bay area within the Furen Lagoon. These are some of the last natural marshes

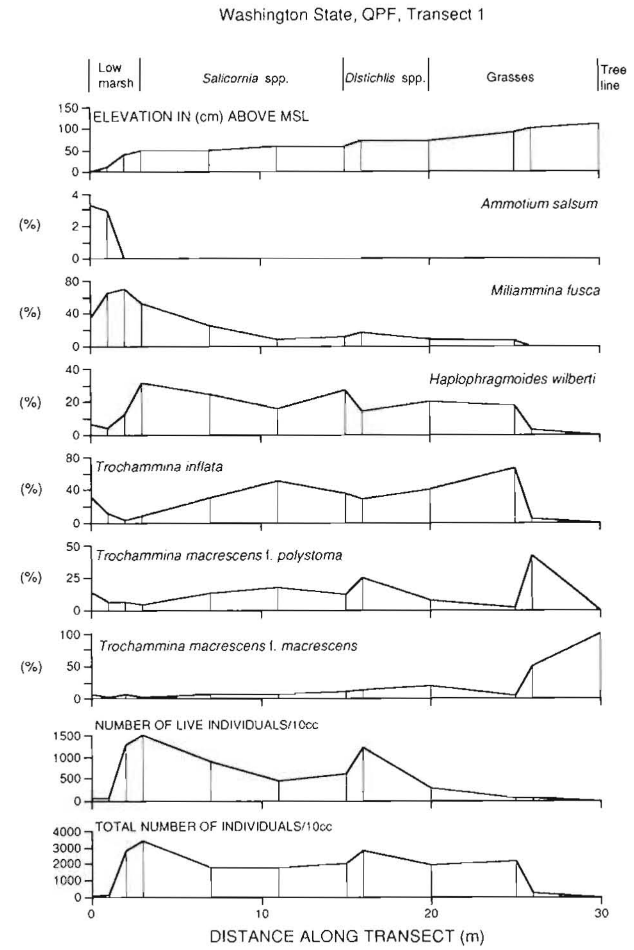

Figure 4. Washington Transect QPF 1. Qualitative plant zonations are also shown with estimated vertical ranges. Foraminiferal data are detailed in Table 3.

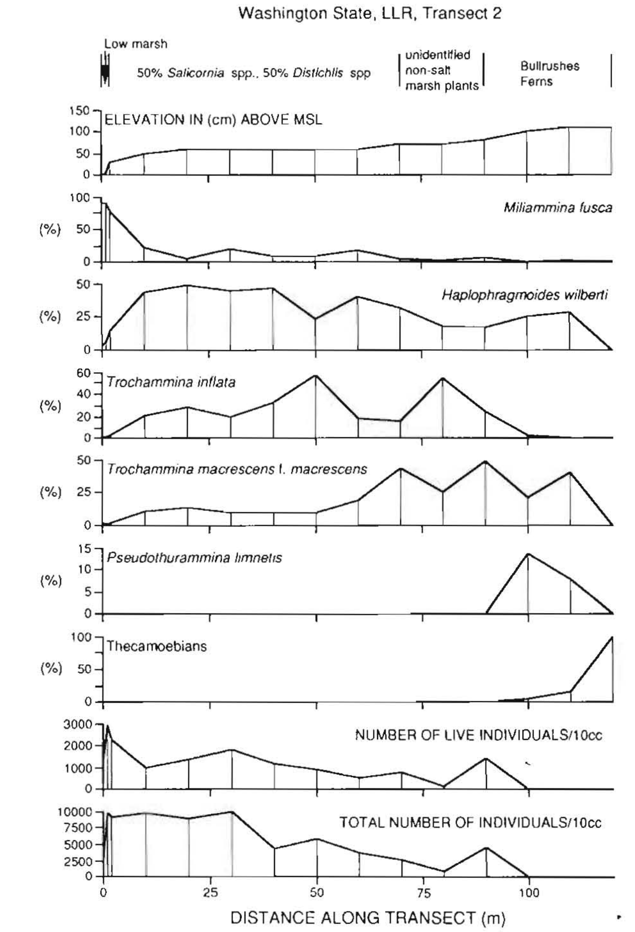

Figure 5. Washington Transect LLR 2. Same format as Figure 4. Foraminiferal data are detailed in Table 4.

left in Japan except for some mangroves in Okinawa. They had never been sampled for marsh foraminifera. However, studies were underway using diatoms for sea-level studies in these same marshes by M. UMITSU (Nagoya Univ.). These salt marshes were tidal but probably with very low salinities because the plant types were almost all freshwater. We had no means to measure the salinity. The only salt-marsh plants were *Trigloglin* sp. and *Glaux maritima*; others were *Phragmities australis, Carex lyngbyei, Eleocharis* sp., *Scirpus* spp. and various others, all of them typical of freshwater marshes but obviously capable of withstanding some tidal inundation. Vertical zonation, typical of brackish marsh plant in other places, was obscure (see SCOTT *et al.*, 1991). Both transects were far up tidal creeks very close to the river influence.

Washington State Marshes

Two transects sampled were from two small marsh areas within the Hoods Canal which is the part of Puget Sound that fronts the Olympic Mountain Range. Transect QPF is from the delta area of a small river called the Quilicene. The other transect (LLR) was from the end of a road called Linger Longer Road. Both transects had similar vegetation; the middle marsh was the broadest which had *Salicornia virginica* and *Distichlis* sp. as the only two species. The lower marsh in both areas was occupied by *Scirpus* spp. Various grasses, *Potentilla* sp., and bullrushes characterized the high marsh. In both cases, we sampled from the lowest low marsh into the totally freshwater areas (ferns, Trans. 2, or trees, Trans. 1). We measured salinities where possible but on the marsh surface salinities of no greater than 4‰ were measured. In the water, the salinities were up to 10‰. These marshes, unlike Japan, contained a distinct zonation of plants which we followed when sampling for foraminifera.

Northern California

This transect was obtained from an area in the Humboldt Bay marsh system near Eureka, California. Plants here were similar to those in the Washington marshes with *Salicornia virginica* and *Distichlis* species dominating the middle marsh

Table 1. *Foraminiferal and thecamoebian percentage occurrences in Hokkaido Transect 1. L = living, T = total, x = <1%. These data are plotted in Figure 2.*

Station number	1		2		3		4		5		6		7		8	
Distance along transect (m)	0		0.5		1		1.5		5.5		8.5		9.5		12.5	
(live/total)	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T
No. of species	4	7	4	5	4	4	3	5	3	4	3	3	3	4	3	5
No. of individuals	1,314	6,588	4,464	8,688	10,896	16,872	752	4,512	1,176	2,296	1,520	3,448	680	3,216	152	1,224
Ammobaculites exiguus																
Haplophragmiodes manilaensis	6	17	4	6	1	2										
Miliammina fusca	33	24	33	34	8	12	55	73	41	45	32	39	31	36	74	49
Pseudothurammina limnetis				2						x						
Tiphotrocha comprimata		1														
Trochammina inflata		x														
T. macrescens f. *macrescens*	56	38	60	43	89	77	43	15	49	27	63	37	49	13	16	2
T. macrescens f. *polystoma*		0														
Planktonics								x								
Centropyxis aculeata	6	19	2	14	1	9	2	11	10	28	5	24	20	50	11	48
C. constricta																x
Difflugia oblonga								1						x		x
D. proteiformis																
Nebella collaris																
Tinnitinnopsis rioplatensis																

Station number	9		10		11		12		13		14		15		16	
Distance along transect (m)	17.5		23.5		30		40		53.5		68.5		80.5		86.5	
(live/total)	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T
No. of species	3	3	5	5	3	5	3	5	2	4	4	6	4	4	3	5
No. of individuals	200	1,060	10,752	17,280	584	2,256	272	5,280	104	1,688	2,160	5,568	5,808	7,728	88	2,176
Ammobaculites exiguus								1								x
Haplophragmiodes manilaensis			1	3				1				1	9	11		
Miliammina fusca	84	45	9	12	63	58	71	38	77	63	28	53	6	8	64	72
Pseudothurammina limnetis			x	1		x					1	x				
Tiphotrocha comprimata																
Trochammina inflata																
T. macrescens f. *macrescens*	12	3	87	74	32	10	24	5	23	2	65	28	85	79	9	2
T. macrescens f. *polystoma*																
Planktonics																
Centropyxis aculeata	4	51	2	10	6	32	6	56		34	6	18	x	2	27	25
C. constricta																
Difflugia oblonga										1						x
D. proteiformis												x				
Nebella collaris																
Tinnitinnopsis rioplatensis						x										

Station number	17		18		19		20		21		22		23		24	
Distance along transect (m)	94.5		106.5		110.5		118.5		125.5		129.5		133.5		143.5	
(live/total)	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T
No. of species	3	3	4	5	4	5	4	4	3	4	4	5	4	4	3	4
No. of individuals	104	1,680	276	1,048	316	1,012	336	844	1,908	15,840	1,896	3,996	10,908	19,872	416	1,872
Ammobaculites exiguus						x										
Haplophragmiodes manilaensis			1	2	4	4	1	2		1	35	43	11	13	4	2
Miliammina fusca	46	69	44	53	46	54	48	52	9	30		2	7	17	42	39
Pseudothurammina limnetis											1	1				
Tiphotrocha comprimata																
Trochammina inflata																
T. macrescens f. *macrescens*	31	2	52	23	44	21	30	22	64	18	63	40	82	58	54	22
T. macrescens f. *polystoma*																
Planktonics																
Centropyxis aculeata	23	30	3	21	6	21	21	24	26	52	1	14	1	12		38
C. constricta																
Difflugia oblonga				1												
D. proteiformis																
Nebella collaris																

Table 1. *Continued.*

Station number	25		26		27		28		29		30		31		
Distance along transect (m)	149.5		159.5		169.5		184.5		198.5		209.5		231.5		
(live/total)	L	T	L	T	L	T	L	T	L	T	L	T	L	T	
No. of species	4	4	4	5	4	5	4	5	3	4	2	5	0	2	
No. of individuals	4,480	10,000	2,416	5,968	688	1,584	520	1,704	136	1,656	32	1,240	0	384	
Ammobaculites exiguus															
Haplophragmiodes manilaensis	17	20	13	17	2	10	6	10	53	33				4	
Miliammina fusca	2	5	14	15	78	54	19	24				1			
Pseudothurammina limnetis				x						1					
Tiphotrocha comprimata															
Trochammina inflata															
T. macrescens f. *macrescens*	76	68	68	53	16	13	68	38	29	15					
T. macrescens f. *polystoma*															
Planktonics															
Centropyxis aculeata	4	8	5	16	4	22	8	29	18	51	25	96			96
C. constricta															
Difflugia oblonga						1		1				2			
D. proteiformis												1			
Nebella collaris											75	2			

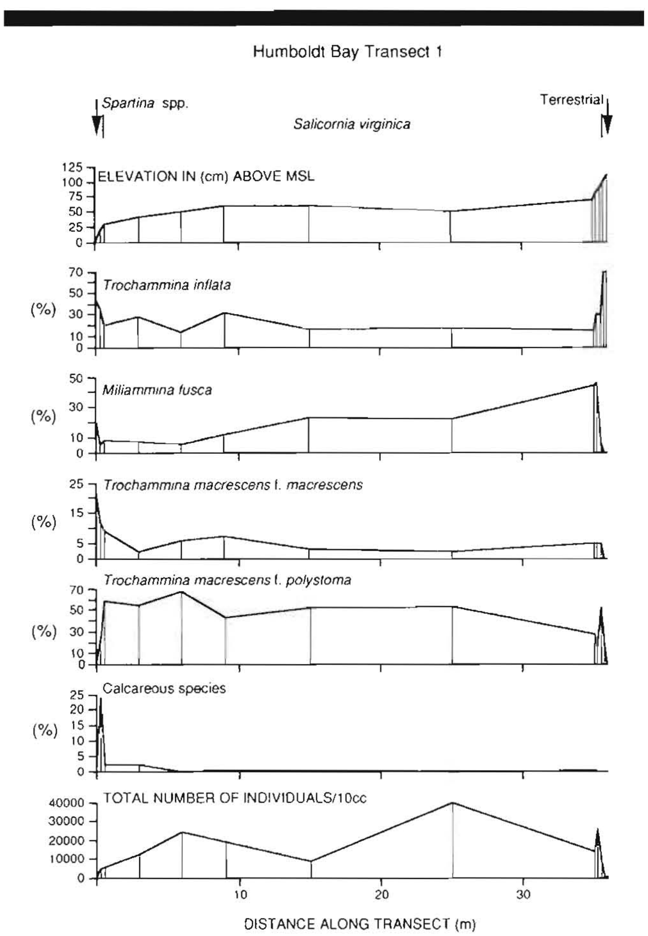

Figure 6. Northern California, Humboldt Bay, Transect 1. Same format as Figure 4. Foraminiferal data are detailed in Table 5.

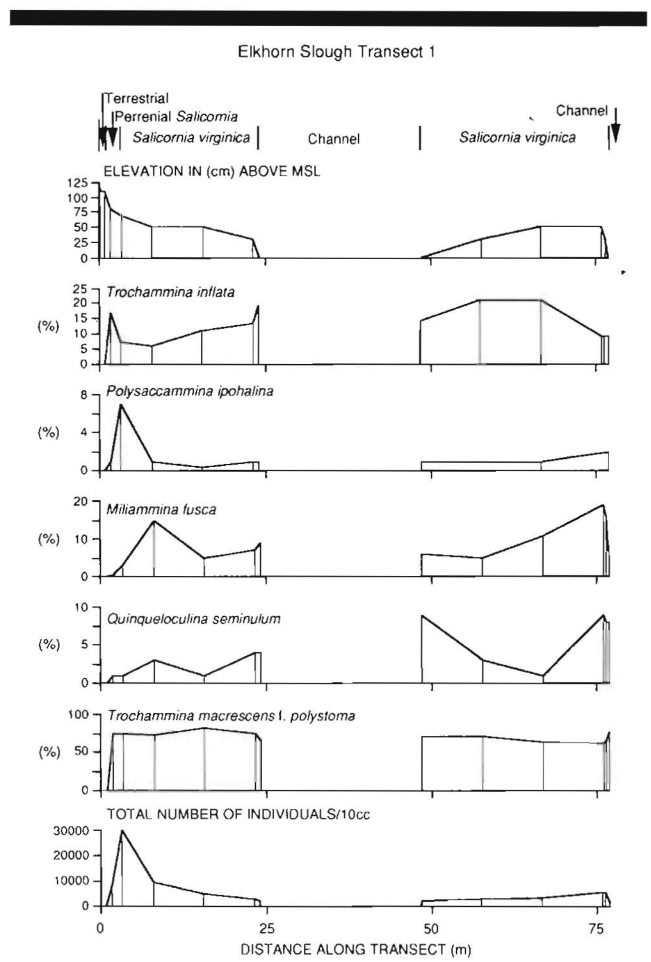

Figure 7. Central California, Elkhorn Slough, Transect 1. Same format as Figure 4. Foraminiferal data are detailed in Table 6.

Table 2. *Foraminiferal and thecamoebian percentage occurrence in Hokkaido Transect 2. L = living, T = total, x = <1%. These data are plotted in Figure 3.*

Station number	1		2		3		4		5		6		7	
Distance along transect (m)	0		1		2.5		4.5		5		9		12.5	
(live/total)	L	T	L	T	L	T	L	T	L	T	L	T	L	T
No. of species	4	8	3	6	2	7	3	6	2	5	7	7	3	7
No. of individuals	1,632	11,712	3,792	11,216	944	11,312	4,224	27,968	2,048	14,272	5,776	11,056	4,864	25,344
Ammobaculites exiguus		1				x				1	x	x		x
Ammonia beccarii		x												
Haplophragmiodes manilaensis	2	1		x										
Miliammina fusca	4	7	3	3		4	2	x		2	3	9	1	3
Polysaccammina ipohalina														
Pseudothurammina limnetis								1		x	x	x		x
Quinqueloculina seminulum											x	x		
Tiphotrocha comprimata						x		1						
Trochammina inflata			2	1	12	22	36	31	28	25	1	2	3	5
Trochammina inflata (sipho-type)	1	3												
T. macrescens f. *macrescens*	93	86	95	93	88	71	62	65	72	71	95	85	96	86
T. macrescens f. *polystoma*														
Centropyxis aculeata		1		2		2		2			x	4		5
C. constricta		x		1		1								x
Difflugia globulis														
D. proteiformis														
Lesquereusia spiralis														
Nebella collaris														

Station number	8		9		10		11		12		13		14	
Distance along transect (m)	16		26		31.5		32.8		35.3		37.3		40.3	
(live/total)	L	T	L	T	L	T	L	T	L	T	L	T	L	T
No. of species	3	6	4	7	2	4	3	5	4	5	4	6	5	5
No. of individuals	6,528	31,872	4,032	11,856	9,664	21,120	5,136	16,736	3,904	10,304	596	6,454	9,776	16,064
Ammobaculites exiguus	1	3		1							50	25	2	3
Ammonia beccarii														
Haplophragmiodes manilaensis												4	x	1
Miliammina fusca		4	8	20	2	2	2	2	6	15	29	18	78	72
Polysaccammina ipohalina				x										
Pseudothurammina limnetis														
Quinqueloculina seminulum			x	x										
Tiphotrocha comprimata														
Trochammina inflata	11	8	1	2		1	9	10		x				
Trochammina inflata (sipho-type)														
T. macrescens f. *macrescens*	88	74	90	76	98	93	89	85	92	67	14	46	19	21
T. macrescens f. *polystoma*														
Centropyxis aculeata		10		1		5		2	1	13		6	1	3
C. constricta		1						0	2	5	7	2		
Difflugia globulis														
D. proteiformis														
Lesquereusia spiralis														
Nebella collaris														

Station number	15		16		17		18		19	
Distance along transect (m)	45.3		48.8		50.8		55.8		59.8	
(live/total)	L	T	L	T	L	T	L	T	L	T
No. of species	3	6	6	6	3	6	1	4	1	5
No. of individuals	5,664	10,464	1,400	2,976	66	498	6	828	72	342
Ammobaculites exiguus						1				
Ammonia beccarii										
Haplophragmiodes manilaensis			5	13						
Miliammina fusca	6	11	40	28	27	6				2
Polysaccammina ipohalina										
Pseudothurammina limnetis		4	10	12		1				
Quinqueloculina seminulum										
Tiphotrocha comprimata										
Trochammina inflata		1				1				

Table 2. *Continued.*

Station number	15		16		17		18		19	
Distance along transect (m)	45.3		48.8		50.8		55.8		59.8	
(live/total)	L	T	L	T	L	T	L	T	L	T
Trochammina inflata (sipho-type)										
T. macrescens f. *macrescens*	93	74	42	33	55	10		1		2
T. macrescens f. *polystoma*			1	x						
Centropyxis aculeata	1	11	2	13	18	81	100	97		63
C. constricta										
Difflugia globulis										2
D. proteiformis		1								
Lesquereusia spiralis								1		
Nebella collaris								1	100	32

areas. However, *Spartina foliacea* dominated the low marsh and *Grendilla* sp. the high marsh. *Sphagnum* moss fringed the marsh on the landward end. Salinities measured here were 25‰ at the channel and 19‰ at station 7 in the middle. Other areas were too dry to take measurements.

Central California

This transect was in Elkhorn Slough, just south of Santa Cruz and just behind the Moss Landing Oceanographic Station. The salt-marsh zone was completely occupied by *Salicornia virginica*. Above the highest astronomical tide (Stations 1–3) the perennial *Salicornia* sp. and *Suaeda* sp. were found. Salinities ranged from 32‰ (Station 4, high marsh) to 30‰ at the channel edge.

METHODS

Samples were collected with a small 3.5 cm diameter corer—only the upper 1 cm of sediment was collected to obtain a 10 cm^3 sample. Material was wet-sieved within 1 week using a .063 mm sieve (mesh 230) as the lower size to retain foraminifera and 0.5 mm as the upper size to catch roots and large plant fragments. Samples were preserved in buffered formalin and Rose Bengal (to detect living specimens). Samples were retained in liquid suspension and examined in liquid under a dissecting microscope (20 to 40 ×). Large samples were split to aliquots of 300–500 specimens using a modified plankton splitter (SCOTT and HERMELIN, 1993). Organic material was not decanted away as in some earlier studies (e.g., SCOTT and MEDIOLI, 1980a); in some cases, most of the living would have been washed away by decanting. Salinity was determined using an American Optical handheld salinity refractometer.

FORAMINIFERAL RESULTS

Hokkaido Marshes

Transect 1: Abundances of both living and total numbers/10 cc were among the highest ever recorded in marsh sequences (Fig. 2, Table 1). Although *Miliammina fusca* and *Trochammina macrescens* f. *macrescens* co-varied in the total abundance, largest living numbers were of *T. macrescens* with relatively low numbers of *M. fusca* living even though it dominated many of the samples. This suggested the same situation as observed in Nova Scotia, Canada, where *M. fusca* living populations occurred in the winter but still dominated total populations year round (SCOTT and MEDIOLI, 1980b). Vertical zonation was difficult to see here but it appeared that the higher stations (25–30) had higher percentages of *Haplophragmoides manilaensis*. At the treeline above the tidal limit (samples 28–30), thecamoebians (freshwater rhizopods) replaced the foraminifera. The other reason that vertical zonation was difficult to see was that the marsh surface was very hummocky—unfortunately we could not measure the elevation accurately or we might have been able to see better zonations.

Transect 2: Although this transect was close to Transect 1, the fauna was somewhat different (Figure 3, Table 2). First of all, *M. fusca* was common only just below the highest marsh and *Trochammina inflata*, a rare species along Transect 1, was quite abundant in the lower part of Transect 2. *Trochammina macrescens* f. *macrescens* was the dominant species at almost all levels, and this may be the reason the numbers of living were high along this entire transect. However, as at Transect 1, *H. manilaensis* was common in the highest marsh just below the upland plants and thecamoebians become the dominant forms above tidal levels.

Washington State Transects

QPF TRANS 1: This marsh exhibited a strong vertical zonation, coincident with plant zones (Figure 4, Table 3). The low marsh was dominated by *Ammotium salsum* and *M. fusca*. At the low/high marsh boundary, *Haplophragmoides wilberti* dominated and a little higher up *Trochammina inflata* and *T. macrescens* f. *polystoma* also become prominent. Just at the boundary between grasses and trees, *T. macrescens* f. *macrescens* becomes prominent but this may be illusionary since total populations drop to almost nothing here. Across this transect, both living and total numbers are moderately high below Station 11.

California Marshes

Humboldt Bay—Transect 1: The low marsh section of this transect is difficult to define because of the steep bank (Figure 6, Table 5), but the California transects are the only ones where we see significant percentages of calcareous species, in this case Miliolids, but only in the lowest samples. Stations

Table 3. *Foraminiferal and thecamoebian percentage occurrences in Washington QPF Transect 1. L = living, T = total, x = <1%. These data are plotted in Figure 4.*

Station number	1		2		3		4		5		6		7	
Distance along transect (m)	0		1		2		3		7		11		15	
(live/total)	L	T	L	T	L	T	L	T	L	T	L	T	L	T
No. of species/10 cc	7	8	7	8	7	8	7	8	6	7	7	8	6	8
No. of individuals/10 cc	48	92	67	138	1,260	2,800	1,496	3,404	895	1,814	455	1,809	600	2,069
Ammotium salsum	6	3	6	3										
Haplophragmoides manilaensis					1	x		x		x	3	1		x
H. wilberti	4	7	2	4	13	13	40	31	22	24	10	16	30	27
Miliammina fusca	44	34	73	64	73	69	50	52	33	25	10	8	7	12
Polysaccammina ipohalina												x		x
Tiphotrocha comprimata		2	6	7		2	x	1			x	x	x	x
Trochammina inflata	38	33	8	12	2	2	6	8	29	31	69	51	45	36
T. macrescens f. *macrescens*	2	7		2	6	6	1	4	10	7	6	7	9	12
T. macrescens f. *polystoma*	4	14	2	7	4	7	3	4	6	13	2	17	9	12
T. ochracea							x	x						
T. pacifica	2	1	5	2	1	x			x	x				

Station number	8		9		10		11		12	
Distance along transect (m)	16		20		25		26		30	
(live/total)	L	T	L	T	L	T	L	T	L	T
No. of species/10 cc	8	8	8	8	6	7	4	6	0	1
No. of individuals/10 cc	1,203	2,799	287	1,965	65	2,201	52	218	0	1
Ammotium salsum										
Haplophragmoides manilaensis	1	1	x	x				1		
H. wilberti	20	14	27	20	54	18		3		
Miliammina fusca	16	16	2	8	3	6				
Polysaccammina ipohalina	1	x	x	1	2	4	2	1		
Tiphotrocha comprimata	x	x	x	x		x				
Trochammina inflata	38	29	37	41	29	66	6	4		
T. macrescens f. *macrescens*	6	14	27	21	2	4	75	50		100
T. macrescens f. *polystoma*	18	25	7	8	11	3	17	42		
T. ochracea										
T. pacifica										

3–10 were more or less on a plateau and that is reflected in a relatively monotonic fauna until we get to the steep high marsh boundary where the *Trochammina* spp. suddenly jump in abundance together with total numbers. This could be an extremely accurate level indicator in this area.

Elkhorn Slough—Transect 1: As in the Humboldt Bay transect, there is little vegetation change and a *Spartina* low marsh zone is absent (Figure 7, Table 6). The foraminifera reflect this also; the only detectable change in this transect again occurs near the high marsh boundary where total abundances increase and *T. macrescens* f. *macrescens* becomes more abundant. The upper three samples above tidal level were barren of any microfossils which is common to most California marshes where tidal water is the only water available.

COMPARISON WITH OTHER PACIFIC RIM MARSHES

The data presented here fill in some large gaps that existed so that now we have data from the western Pacific (Japan), British Columbia (PATTERSON, 1990), Washington State, Oregon (JENNINGS and NELSON, 1992), northern California, central California, southern California (SCOTT, 1976a,b), Chile (JENNINGS *et al.*, 1995), and New Zealand (HAYWARD and HOLLIS, 1994). We do not include PHLEGER's (1967) data because it was not quantitative and even the plant zones were incorrect. All the data are not completely comparable because the previous studies of SCOTT (1976), JENNINGS et al. (1992, 1995), and PATTERSON (1990) measured the elevations precisely; whereas, here we simply sampled the plant zones and estimated elevations. However, we are confident that our data, although not measured precisely, still reflect fairly accurate elevations, to within 20 cm (depending on local tidal ranges).

The comparison zone by zone for each marsh is summarized in Table 7. Highlights are that *Trochammina macrescens* f. *macrescens* dominates or subdominates high marsh faunas in Japan, British Columbia, Washington and Oregon but is replaced by *T. macrescens* f. *polystoma* and *Trochammina inflata* in the more arid California marshes. In Chile and New Zealand, *Trochamminita salsa* dominates the high marsh faunas. However, the high marsh faunas in New Zealand are much more diverse and more similar to those in the northern hemisphere than to those in the Chilean area (HAYWARD and HOLLIS, 1994). As has been noted before, high marsh faunas are similar for almost all areas, but the low marsh faunas tend to reflect local variables except for consistent occurrences of *Miliammina fusca* and, to a lesser extent, *Ammotium salsum*.

Table 4. *Foraminiferal and thecamoebian percentage occurrences in Washington LLR Transect 1. L = living, T = total, x = <1%. These data are plotted in Figure 5.*

Station number	1		2		3		4		5		6		7		8	
Distance along transect (m)	0		1		2		10		20		30		40		50	
(live/total)	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T
No. of species/10 cc	6	8	5	5	6	8	7	8	5	5	6	6	6	8	5	7
No. of individuals/10 cc	1,169	2,158	2,880	9,672	2,272	9,120	988	9,656	1,361	8,773	1,833	9,821	1,147	4,431	902	5,914
Ammotium salsum																0
Eggerella advena														x		
Gaudryina exilis														x		
Haplophragmoides manilaensis	x	x			x	x		x			x	x				
H. wilberti	2	2	13	7	19	14	26	44	24	49	26	44	37	47	20	23
Miliammina fusca	95	91	83	90	70	78	23	22	3	5	12	21	5	10	2	8
Polysaccammina ipohalina													x	x		x
Pseudothurammina limnetis																
Siphotrochammina lobata																
Tiphotrocha comprimata		x				x	1	x								
Trochammina inflata	1	2	3	2	6	3	45	21	56	28	47	20	46	32	72	57
T. macrescens f. *macrescens*	1	2	1	1	4	2	3	10	14	14	8	9	9	9	5	10
T. macrescens f. *polystoma*	1	3	1	1	x	2	3	3	2	4	6	5	2	2	1	2
T. ochracea		x					x	x								
T. pacifica						x										
Centropyxis aculeata																
C. constricta																
Oopyxis sp.																

Station number	9		10		11		12		13		14		15	
Distance along transect (m)	60		70		80		90		100		110		120	
(live/total)	L	T	L	T	L	T	L	T	L	T	L	T	L	T
No. of species/10 cc	6	8	7	7	5	6	5	6	5	8	4	8	1	4
No. of individuals/10 cc	527	3,768	792	2,684	149	935	1,430	4,470	38	153	32	52	16	122
Ammotium salsum														
Eggerella advena														
Gaudryina exilis														
Haplophragmoides manilaensis		1	x	x										
H. wilberti	19	40	32	32	32	18	10	17	61	26	38	29		
Miliammina fusca	13	19	2	6	3	3	6	8		1		2		
Polysaccammina ipohalina														
Pseudothurammina limnetis								x	11	14	6	8		
Siphotrochammina lobata			x	x	1	x								
Tiphotrocha comprimata	2	x				x								
Trochammina inflata	59	18	19	16	44	54	43	25	5	3				1
T. macrescens f. *macrescens*	7	19	44	44	20	26	41	49	21	22	47	40		
T. macrescens f. *polystoma*	1	3	3	2			1	1	3	31	9	6		
T. ochracea														
T. pacifica														
Centropyxis aculeata												6		2
C. constricta										3		6		2
Oopyxis sp.		x								1		4	100	96

PHLEGER's (1967) work was a pioneering study based on a limited number of samples (except for the Mission Bay, California, samples) and hence it is not a fair comparison with the material since that time. However, PHLEGER's data have little resemblance to the data of JENNINGS and NELSON (1992) from Coos Bay, Oregon or PATTERSON (1990) from the Fraser River Delta, B.C. PHLEGER's total abundances were very low and not diagnostic for vertical zonations, unlike the more recent data. PHLEGER made no attempt to differentiate zonations and had low sample density. If his samples were not freshly collected, they might also have degraded (SCOTT and MEDIOLI, 1986) as was almost certainly the case in his Alaska material which was collected from a marsh that had been supratidal for a year after being uplifted by the great 1964 Alaska earthquake. Hence, the new data from others and those presented here have greatly enhanced our knowledge of Pacific Rim marsh faunas.

JENNINGS and NELSON (1992) provided a nice comparison of North American west coast data with data from the Atlantic Coast (SCOTT and MEDIOLI, 1980a, Nova Scotia; SCOTT, D.K. and LECKIE, 1990, Massachusetts) indicating that some of the most common species on the east coast are either not present or rare on the Pacific Coast (e.g. *Tiphotrocha comprimata, Ammoastuta inepta*). This is still valid even with the additional data presented in this paper—*T. comprimata*, a common high-middle marsh species, is rarely present in any

Table 5. *Northern California, Humboldt Bay, Transect 1 foraminiferal percentage occurrences. L = living, T = total, x = <1%. These data are plotted in Figure 6.*

Station number	1		2		3		4		5		6		7	
Distance along transect (m)	0		0.3		0.6		3		6		9		15	
(live/total)	L	T	L	T	L	T	L	T	L	T	L	T	L	T
No. of species	0	4	6	7	5	6	6	7	5	5	4	7	3	6
No. of individuals	0	18	642	4,566	384	5,874	912	12,396	2,340	24,156	2,016	18,972	270	8,298
Haplophragmoides wilberti							4	3			5	4		5
Miliammina fusca		22	3	5	2	8	5	7	2	5		12		23
Polysaccammina ipohalina						3		2	3	8		1		
Planktonics		11												
Quinqueloculina seminulum			45	13	10	2	3	2				x		x
Spirillina vivipara			42	11										
Tiphotrocha comprimata				x										
Trochammina inflata		44	6	36	16	20	16	28	8	13	43	32	33	16
T. macrescens f. *macrescens*		22	1	12	16	9	3	2	11	6	4	7	7	3
T. macrescens f. *polystoma*			4	22	57	58	70	55	77	68	48	43	60	52

Station number	8		9		10		11		12		13	
Distance along transect (m)	25		35		35.2		35.5		35.7		36.9	
(live/total)	L	T	L	T	L	T	L	T	L	T	L	T
No. of species	5	6	5	6	4	6	6	7	0	2	0	1
No. of individuals	3,120	40,704	2,136	13,896	1,980	25,380	1,104	8,280	0	10	0	2
Haplophragmoides wilberti	3	3	8	9	4	3	11	4				
Miliammina fusca	31	22	55	44		46		6				
Polysaccammina ipohalina	2	1				1	4	1				
Planktonics												
Quinqueloculina seminulum				x								
Spirillina vivipara												
Tiphotrocha comprimata							7	3				
Trochammina inflata	9	18	13	15	64	31	11	29		80		100
T. macrescens f. *macrescens*		2	7	5	13	5	11	5				
T. macrescens f. *polystoma*	55	53	17	27	20	16	57	52		20		

Table 6. *Central California, Elkhorn Slough, Transect 1 foraminiferal percentage occurrences. L = living, T = total, x = <1%. These data are plotted in Figure 7.*

Station number	1	2	3	4		5		6		7		8		9	
Distance along transect (m)	0	0.3	0.9	1.8		3.4		7.9		15.6		23.2		24.1	
(live/total)	B	B	B	L	T	L	T	L	T	L	T	L	T	L	T
No. of species				5	6	5	6	6	6	3	7	2	6	4	7
No. of individuals				1,212	8,220	1,332	30,024	1,800	9,018	408	4,644	114	2,346	234	2,172
Haplophragmoides wilberti											x				1
Miliammina fusca					x	5	3	9	15	3	5		7		9
Polysaccammina ipohalina				1	1		7	1	1		x		1		1
Quinqueloculina seminulum				2	1	3	1	11	3		1		4	3	4
Trochammina inflata				15	17	3	7	7	6	18	11	16	13	28	19
T. macrescens f. *macrescens*				5	7	5	7	1	1		1		1	3	1
T. macrescens f. *polystoma*				76	74	84	75	71	73	79	82	84	74	67	66

Station number	10		11		12		13		14		15	
Distance along transect (m)	48.5		57.7		66.8		75.9		76.5		76.9	
(live/total)	L	T	L	T	L	T	L	T	L	T	L	T
No. of species	4	6	4	5	5	7	5	5	5	6	4	6
No. of individuals	245	1,862	828	2,598	462	3,060	828	5,016	1,314	5,472	381	1,644
Haplophragmoides wilberti						x				x		
Miliammina fusca		6	2	5	5	11	10	19	5	16	3	4
Polysaccammina ipohalina		1				1						2
Quinqueloculina seminulum	3	9	4	3	1	1	16	9	21	8	9	8
Trochammina inflata	17	14	25	21	26	21	12	9	11	9	9	9
T. macrescens f. *macrescens*	3	2		1	3	1	6	2	1	1		x
T. macrescens f. *polystoma*	77	70	69	71	65	64	57	61	62	65	80	76

Table 7. *Summary of all Quantitative Pacific Coast salt marsh foraminiferal data. Species listed in order of importance. Species in parentheses occurred at only one transect in area.* Trochammina m. f. *refers to* Trochammina macrescens f. *either* macrescens *or* polystoma.

	High Marsh	Low Marsh
Hokkaido	*Trochammina m.* f. *macrescens* *Haplophragmoides manilaensis* *Miliammina fusca*	*Miliammina fusca* *Trochammina m.* f. *macrescens* (*Trochammina inflata*)
British Columbia	*Trochammina m.* f. *macrescens* *Trochammina inflata*	*Miliammina fusca* *Ammonia beccarii* *Ammobaculites exiguus* *Elphidium* spp.
Washington State	*Trochammina m.* f. *macrescens* *Trochammina inflata* *Haplophragmoides wilberti* *Trochammina m.* f. *polystoma*	*Miliammina fusca* *Ammotium salsum*
Oregon	*Trochammina m.* f. *macrescens* *Trochammina inflata* *Haplophragmoides* spp.	*Miliammina fusca* *Reophax nana* *Ammotium salsum* *Ammobaculites exiguus*
N. California	*Trochammina inflata* *Trochammina m.* f. *polystoma* *Miliammina fusca*	*Miliammina fusca* Calcareous spp.
C. California	*Trochammina m.* f. *polystoma* *Trochammina inflata*	*Miliammina fusca*
S. California	*Trochammina inflata* *Trochammina m.* f. *polystoma*	*Polysaccammina hyperhalina* *Miliammina fusca* Calcareous spp.
Chile	*Trochamminita salsa* *Haplophragmoides* spp. *Pseudothurammina limnetis*	*Miliammina fusca*
New Zealand	*Trochammina inflata* *Trochamminita salsa* *Haplophragmoides wilberti* *Trochammina m.* f. *macrescens* (*Miliammina fusca*)	*Elphidium* spp. *Haynesina depressulum* other Calcareous spp.

marsh samples yet examined from the Pacific. Also it is not common in the Southern Hemisphere in either ocean (SCOTT *et al.*, 1990; HAYWARD and HOLLIS, 1994). One low marsh species, *Ammoastuta inepta,* common to abundant in brackish warm marshes of the Atlantic in both hemispheres, has never been reported from the Pacific. In summary, there appear to be a few endemic marsh species. Differences between the east and west coasts of North America (and maybe South America although we have limited data from the west coast of South America) might be attributed to the different climatic regimes. However, it is also true that the migratory bird pathways from the two ocean basins do not cross. This could be a greater factor than climate, since birds can transport foraminefera over considerable distances and most species of marsh foraminifera appear to be able to tolerate extreme ranges of temperature.

It is apparent from examining all these data, however, that there is a characteristic high marsh fauna that is almost universally made up of *Trochammina* spp. and sometimes *Haplophragmoides* spp., if the area is brackish. There are few calcareous high marsh species and these only occur in hypersaline marshes (e.g., *Discorinopsis aguayoi*) and in low marshes. However, these are usually not preserved in the subsurface. Although the high marsh foraminiferal zones in the Pacific do not appear to provide the absolute accuracy found in Atlantic marshes, particularly Nova Scotia, the vertical range resolution is always at least as accurate as ±30 cm, since that is the maximum range of upper marsh areas that have been measured. Hence, for the studies of rapid sea-level changes caused by earthquakes or other factors, marsh foraminiferal zonations appear to be the most accurate indicators.

TAXONOMY

We include no taxonomy here but refer the reader to SCOTT *et al.* (1990, 1991) and SCOTT and MEDIOLI (1980a) where all species discussed here are illustrated with taxonomic listings.

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