Bayer, R. D. 1979. Intertidal zonation of Zostera marina in the Yaquina Estuary, Oregon. Syesis 12:147-154.

Intertidal zonation of *Zostera marina* in the Yaquina Estuary, Oregon

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Accepted April 10, 1979

The growth of *Zostera marina* L. was studied in the Yaquina estuary, Oregon. Shoots of *Z. marina* were found in three zones. The upper intertidal zone (above MLW) was characterized by annual growth from seeds, mainly reproductive shoots, and an absence of shoots in winter. The lower intertidal zone (below MLLW) was characterized by shoots from rhizomes, mainly vegetative shoots, and an eelgrass bed that persisted throughout the year. The transition zone between MLLW and MLW was characterized by shoots that were typical of either the upper or lower zones with shoot persistence throughout the year varying from site to site. Temperature, light, success of seed germination, and waterfowl grazing were discussed as factors that could result in the observed zonation.

KEY INDEX WORDS: *estuary, intertidal zonation,* Zostera marina.

Syesis, **12**:147–154 (1979)

Introduction

Growth of *Zostera marina* L. on the Pacific coast of North America has been examined for Alaska (McRoy 1966, 1970*a, b*); Puget Sound, Washington (Phillips 1972); Humboldt Bay, California (Keller and Harris 1966); and a southern California lagoon (Backman and Barilotti 1976. These studies demonstrated that eelgrass varies in growth form at different tidal elevations.

This study examines the growth of *Z. marina* in the Yaquina estuary, Oregon. Emphasis is placed on elevational differences in *Zostera* growth form.

Study Area and Methods

The 15.8 km^2 Yaquina estuary (44°38′N, 124°03′W) is a drowned river valley located on the central Oregon coast. The climate is typified by dry summers and mild wet winters with winter temperatures seldom below freezing.

The tidal regime of Oregon estuaries is semidiurnal mixed with approximately 6 h between tides. Mean Higher High Water (MHHW), Mean High Water (MHW), Mean Tide Level (MTL), and Mean Low Water (MLW) are 2.55, 2.32, 1.40, and 0.47 m above Mean Lower Low Water (MLLW) respectively (Oregon State Land Board 1973). "Subtidal" will be considered to be below the lowest predicted tide (0.88 m below MLLW) (Oregon State Land Board 1973).

In May and June 1974, transects were established to monitor the growth of *Z. marina* (Fig. 1). At each transect there were 5–15 stations 8–24 m apart. The transects were oriented perpendicularly to the shore edge. Using a hand level and surveyor's rod, I measured the elevation of each transect station relative to water level. The elevation of each station relative to MLLW was calculated by measuring the tide height at the tide recorder in the public wing of the Oregon State University Marine Science Center (Fig. 1) for the same time that the height of a station relative to water level was determined. This method of determining station elevation is probably accurate to within 0.2 m, since Goodwin *et al.* (1970) found that a tide difference of less than 0.1 m exists between Newport and River Bend and less than 0.3 m between Newport and the Georgia Pacific dock (Fig. 1). The lowest station was at −1.1 m, but SCUBA divers have reported eelgrass as deep as −4.6 m at the Yaquina.

From May 1974 to April 1975, the heights of five *Z. marina* shoots were measured from

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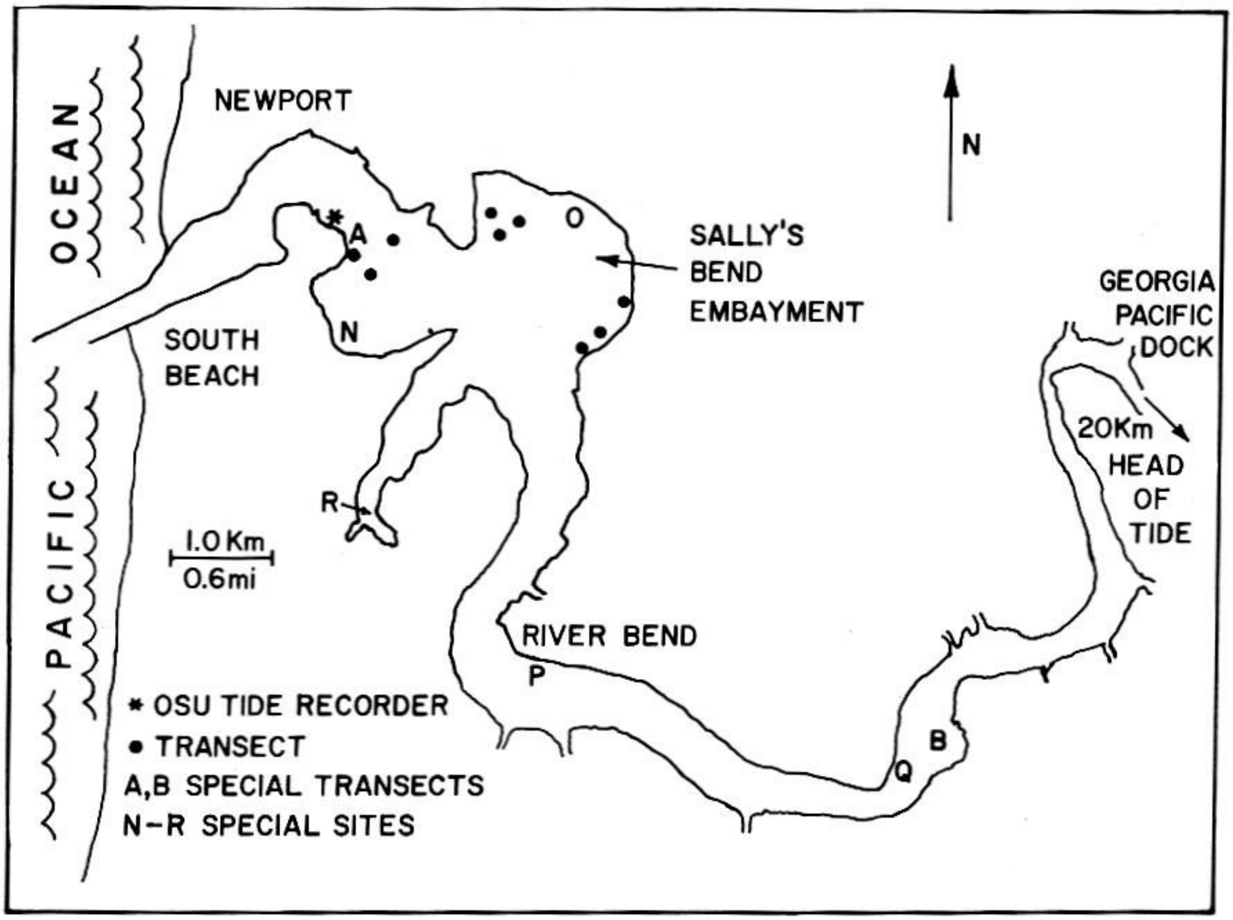

FIGURE 1. Map showing the location of study areas within the Yaquina estuary.

tip of the longest blade to substrate level at each transect station. Thum (1972) found that sediment elevation changed less than 0.10 m per month with changes generally less than 0.05 m from May 1970 to June 1971 at eight stations from −0.61 m to +2.56 m along a transect within 50 m of transect A (Fig. 1). Thus, large (>0.10 m) differences in average shoot height between months would probably not reflect changes in substrate level. Shoot densities were recorded for a square 0.1 m^2 plot for five plots at each station. The proportion of reproductive shoots was determined in a sample of 50 shoots at each station. I differentiated reproductive from vegetative shoots when lateral spathes began appearing on a reproductive shoot which was when the shoot was about 0.25 m long. Blade width was measured at the widest part of a blade. Transects were checked either monthly or bimonthly.

Transect **A** was chosen to illustrate the relationship between shoot length, shoot densities, tide elevation, and season. Eelgrass seasonality at other transects appeared similar to that at Transect **A**. Transect **A** was also located within 0.5 km of where temperature, tidal elevation, sedimentation, and other environmental variables have been measured (Gonor *et al.* 1970, Thum 1972).

Results

Three zones were recognized. In the upper intertidal zone (salt marsh to MLW), *Z. marina* shoots could be present in the spring through fall (Table I) but disappeared at some areas (*R*, Fig. 1) by August and in all the upper intertidal by January (Fig. 2*A*). By July in the upper intertidal, all shoots longer than 0.25 m were reproductive (Fig. 2*B*). In the transition zone between MLW and MLLW,

TABLE I

Mean densities (shoots/0.1 m^2) for five plots at seven stations along Transect **A** in the upper intertidal (UP), transition (TR), and lower intertidal (LO) zones. ND=No Data

Eel-grass Zone	Eleva-tion (m)	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
UP	+1.13	0.0	0.4	0.6	0.6	0.0	ND	0.0	0.0	0.0	0.0	0.0	0.0
UP	+0.82	8.6	5.8	3.6	8.6	1.8	ND	0.0	0.0	0.0	0.0	0.0	0.0
UP	+0.52	10.8	8.6	11.6	6.4	2.0	ND	2.0	0.0	0.0	0.0	6.0	10.6
TR	+0.16	13.0	14.2	9.2	11.4	5.8	ND	7.0	9.8	11.6	13.8	5.6	10.0
LO	−0.24	7.6	9.8	7.6	14.0	6.4	ND	7.2	13.8	16.4	15.4	8.4	16.0
LO	−0.40	6.6	9.0	4.6	5.4	3.0	ND	6.0	8.0	11.4	4.8	5.6	11.4
LO	−1.01	1.4	4.8	4.8	2.0	ND	ND	8.2	ND	4.6	4.0	4.0	6.2

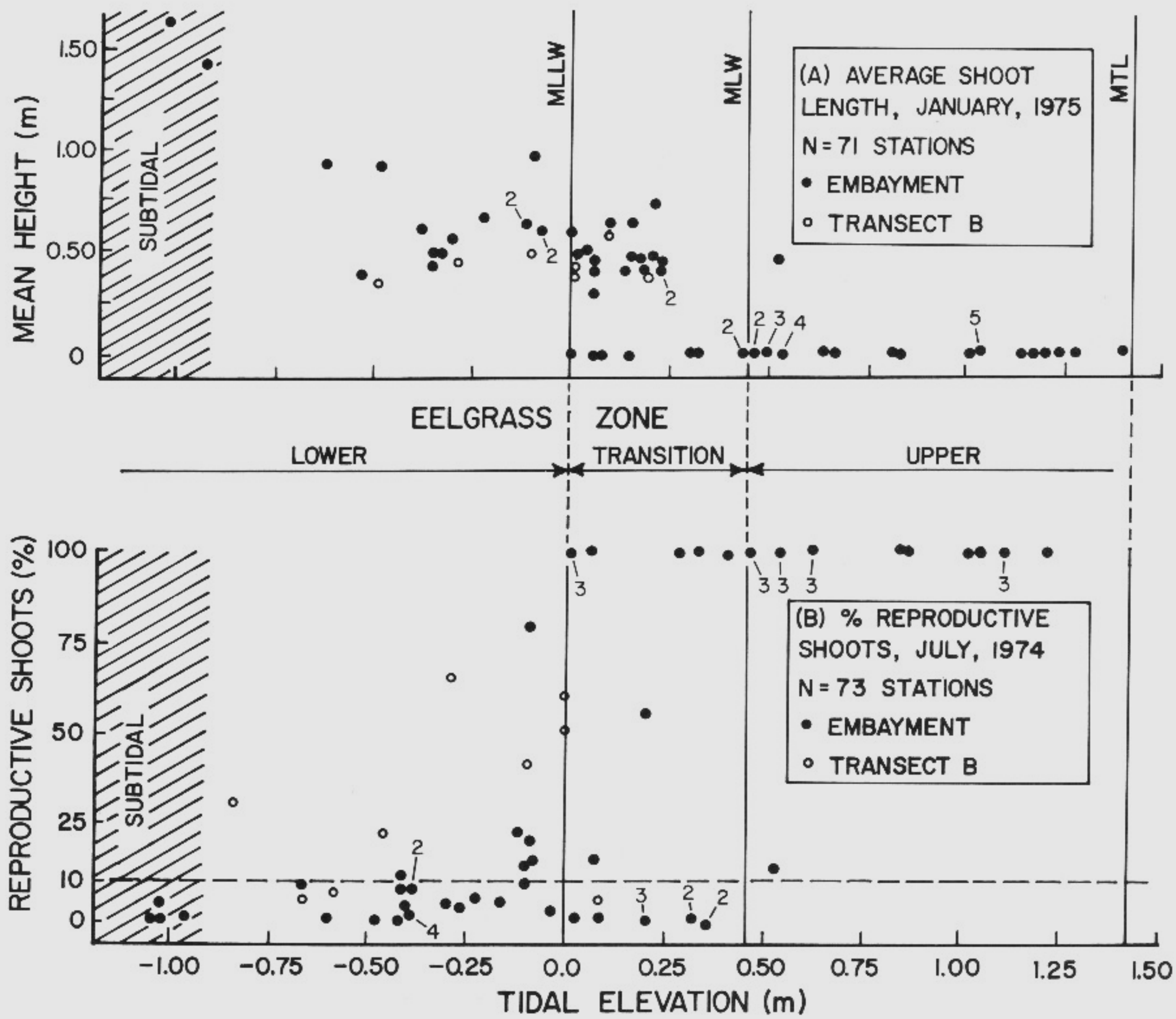

FIGURE 2. Criteria of Yaquina *Z. marina* zones. Numbers in **A** and **B** refer to numbers of coincident points. (**A**) Mean height above substrate of longest blade of five randomly selected *Z. marina* shoots in January 1975. (**B**) Percentage of shoots than can be distinguished as reproductive (i.e., longer than 0.25 m) at transect stations in July 1974.

the persistence of eelgrass in winter varied from site to site as did the proportion of reproductive shoots (Fig. 2). The low zone occurred below MLLW and was characterized as a persistent bed with mainly vegetative shoots (Fig. 2).

Most Yaquina eelgrass sites could be classified into the above zones. However, exceptions existed (Fig. 2) and included a persistent eelgrass bed that occurred at about 0.9 m above MLLW at **P** and scattered vegetative shoots from rhizomes that have been found as high as 1.37 m above MLLW.

Of 25 reproductive shoots dug up in the upper zone at Transect **A**, all had developed from seeds. At Sally's Bend embayment and in some upper estuary locations above **B** (Fig. 1), I found a few scattered reproductive and vegetative shoots growing from the same rhizome at about 1.25 m above MLLW in December. These upper intertidal rhizomes were present only where freshwater flowed out over the mudflats at low tide. In the low zone, both reproductive and vegetative shoots were observed to arise from rhizomes.

At Transect **A**, average shoot length was shortest in winter, began to increase by April, and by October or November had reached its maximum (Fig. 3). However, shoots did not appear to be synchronized in their growth because 0.25 m long shoots were found throughout the year in the low zone.

The longest vegetative (2.80 m) and reproductive (4.00 m) shoots were observed in the low zone. Shoots at stations in the low zone were longer that in the transition and upper zones (Fig. 3). The longest reproductive shoots occurred at Transect **B** in the low zone, but vegetative shoots at Transect **B** were about the same length as at lower estuary transects. At stations where both reproductive and vegetative shoots occurred, the longest reproductive shoots were longer than the longest vegetative shoots in July for 76 per cent of the stations (N = 17) in the low zone, for 90 per cent of the stations (N = 11) in the transition zone, and all of the stations (N = 23) in the upper zone. At most upper zone stations, shoots were shorter than 1.0 m (Table II).

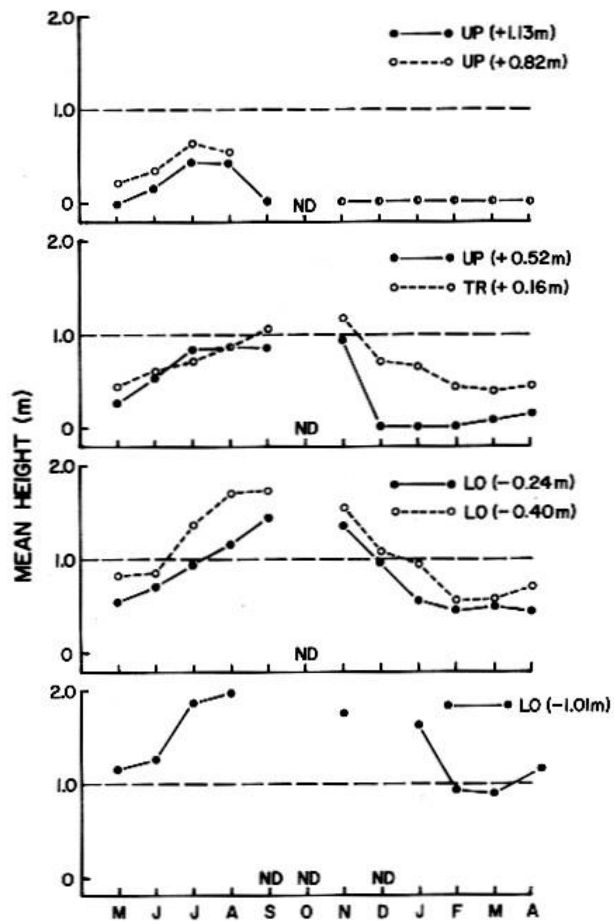

FIGURE 3. Mean height of longest blades of five *Z. marina* shoots at seven stations in three zones along Transect **A** from May 1974 to April 1975. Abbreviations as in Table I. ND=No Data.

Maximum blade widths were greater in the low zone (9.0 and 11.5 mm for reproductive and vegetative shoots respectively) than in the transition zone (8.5 and 10.5 mm) or in the upper zone (7.0 and 5.5 mm). For 26 blades of reproductive shoots from 1.75 to 3.95 m long, the mean blade width of 7.2 mm (range 5.0–9.0 mm) was significantly narrower than the mean of 10.8 mm (range 9.0–11.5 m) for 26 blades of vegetative shoots 1.75 to 2.25 m long ($t = 14.40$, $P < .001$).

In the upper zone density changed seasonally, since eelgrass was not present in winter. Seasonal changes in density were great in the low zone, but a seasonal trend was not evident (Table I). For each month there was an increasing density with increasing depth until

TABLE II

July shoot characteristics of *Z. marina* in three intertidal zones for reproductive (REPRO) and vegetative (VEG) shoots. Shoot densities calculated from five plots at each station

Eelgrass Zone	Stations N	% Stations With Shoots ≥ 1.0 m		Plots N	Densities (Shoots/0.1 m^2)	
		REPRO	VEG		Max. Density	% Plots ≤ 5
UP	23	26	0	115	20	84
TR	22	18	18	110	16	79
LO	34	47	79	170	25	61

+0.16 m or −0.24 m and then density began generally decreasing with decreasing elevation (Table I). In July, the majority of plots (five plots/station) in all zones had densities less than five shoots/0.1 m^2, but the proportion of plots with densities less than five was lowest in the low zone (Table II).

Discussion

Growth and Zonation

The longest shoots and widest blades were found below MLLW in Alaska (McRoy 1966) and in the Yaquina estuary. In Puget Sound, Phillips and Grant (1965) and Phillips (1972) found that leaf length and blade width increased with increasing depth below MLLW. In Humboldt Bay (Keller and Harris 1966), the longest shoots were present below MLLW, but blade widths were not measured. Where standing stocks were calculated above and below MLLW, the greatest standing stocks were found below MLLW (Keller and Harris 1966, Backman and Barilotti 1976). In Puget Sound (Phillips 1972) and at the Yaquina, shoot densities generally decreased with decreasing tidal elevation below MLLW. However, in the upper intertidal at the Yaquina, densities increased with increasing depth to about MLLW.

Other areas along the eastern Pacific coast have not been reported to have intertidal eelgrass zonation similar to the Yaquina estuary. McRoy (1966, 1970*a*) did not mention if eelgrass occurred above MLLW in Alaska. However, he found eelgrass growing in tidepools to be shorter, have narrower blades, have a higher proportion of reproductive shoots, and have less rhizome biomass than eelgrass growing subtidally. But Alaskan tidepools eelgrass grew from rhizomes and the percentage of reproductive shoots was much less in either shallow (19%) or deep (6%) tidepools than that found in the upper intertidal in the Yaquina. Phillips (1972) stated that eelgrass in Puget Sound grew mainly below MLLW but mentioned that scattered shoots occurred up to 1.5 m above MLLW. He did not state if shoots above MLLW were mainly vegetative or reproductive. At Netarts Bay, Oregon (Stout 1976), Humboldt Bay (Keller and Harris 1966), and in a southern California lagoon (Backman and Barilotti 1976), the upper extent of eelgrass was near MLW. However, Stout (1976) noted single plants in water-filled depressions at higher elevations. The Netarts Bay and Humboldt Bay studies were limited to the summertime, so the upper elevation of a persistent eelgrass bed was not determined in either study. A high proportion of annual reproductive shoots in the upper intertidal has been found not only at the Yaquina (this study) but also in Nova Scotia (Keddy and Patriquin 1978). In most Pacific areas the percentage of reproductive shoots has been reported to be less than 20 per cent (McRoy 1966, 1970*b*), but in the Gulf of California, Felger and McRoy (1975) found that 100 per cent of the shoots were reproductive.

Zonation Factors

Physical factors. Eelgrass growing in the upper or lower intertidal are exposed to different physical environments. Eelgrass growing at +0.76 m in the upper intertidal was exposed at least 4.6 times as long as eelgrass growing at 0.0 m at the upper boundary of the low zone during the current study (calculated from unpublished OSU tide data). The amount of exposure markedly varied seasonally in the upper intertidal, but in the lower zone seasonal changes in exposure were not as great (calculated from unpublished OSU tide data).

At the Yaquina in 1970–71, the upper intertidal was more exposed to greater temperature extremes, higher daily maximum temperatures, a greater number of days reaching 15 C, and more months in which 15 C was attained (Fig. 4) than the lower intertidal. No temperature data were available during the present study.

Within the Yaquina estuary, water temperatures could be 5 C to about 8 C higher in summer in the upper estuary than in the lower estuary (calculated from Krygier and Horton 1975). Transect **B** had a higher proportion of reproductive shoots (Fig. 2**B**) and longer reproductive shoots in the lower intertidal than did stations in the lower estuary. Similarly, McRoy (1966) found that eelgrass beds that were exposed to warmer temperatures had a higher proportion of reproductive shoots than beds exposed to cooler temperatures.

Temperature (Fig. 4) and light intensity (Thum 1972) concurrently reach maxima in summer, so light as well as temperature may influence eelgrass growth (McRoy 1970*a*; Phillips 1972, 1974). Further, using canopies over eelgrass growing at −1.5 m, Backman and Barilotti (1976) found that the proportion of reproductive shoots and shoot density decreased in shaded areas. At the Yaquina, the upper intertidal was exposed to stronger illumination than lower in the intertidal, since the lower intertidal was more often and more deeply covered by water, and thus would be expected to and did have a higher proportion of reproductive shoots. Similarly, in the Gulf of California where water temperatures and light intensities are greater than in more northerly areas, the proportion of reproductive

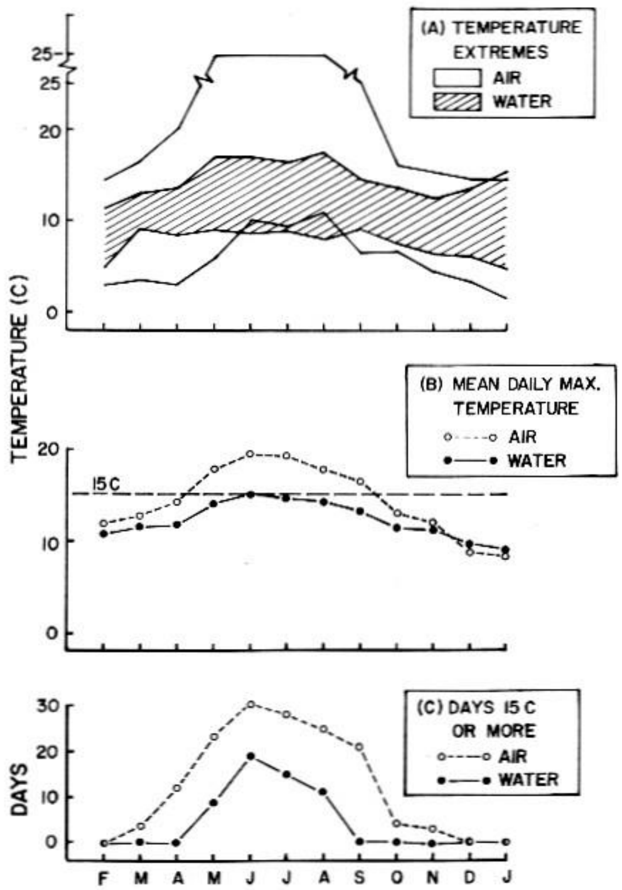

FIGURE 4. Monthly air (0.50 m above water surface) and water (0.10 m below surface) temperatures at low tide near Transect **A** from February 1970 through January 1971. Temperature data calculated from Gonor *et al.* (1970) and Gonor (unpubl. data). (**A**) Temperature extremes. (**B**) Mean daily maximum temperatures. (**C**) Number of days 15 C or more.

shoots was high (100%) (Felger and McRoy 1975. However, Yaquina shoot density was not greatest in the upper intertidal but increased with increasing depth until about MLLW and then began decreasing with decreasing elevation.

Phillips (1972) found that seeds germinate best at low salinities of about 10‰. In winter and spring when seed germination in the upper intertidal occurs (personal observations) during periods of high freshwater run-off, the Yaquina estuary develops a vertical salinity gradient with less dense, lower salinity water on the surface (Burt and McAlister 1959). Thus, the growth of shoots from seeds in the upper intertidal may result from salinities suitable for seed germination.

Shoots from rhizomes are rare in the upper intertidal, perhaps because few rhizomes become established. Rhizomes may not be able to become established in the upper intertidal because of the warmer temperature régime (Fig. 4) and because of uprooting. Both Keller (1963) and McRoy (1966, 1970*a*) have mentioned waterfowl grazing as well as wave action as factors that may result in the uprooting of rhizomes.

Biotic factors. Most herbivorous waterfowl forage by upturning or while walking on the mudflats. Because of tidal action, eelgrass in the upper intertidal would be available several times as long as eelgrass in the low zone. Thus, rhizomes would be more subject to uprooting by waterfowl in the upper intertidal.

Herbivorous waterfowl may also be important in intra-estuarine differences in *Z. marina* zonation by selectively grazing in embayment areas. In the upper estuary (**P**, Fig. 1), a persistent eelgrass bed with rhizomes extended into the upper intertidal to about 0.9 m above MLLW, which was higher than persistent eelgrass beds found in the lower estuary. At **P**, no Black Brant (*Branta nigricans*) were observed during five years of avian research and other herbivorous waterfowl were not frequently seen (personal observations).

Additionally, while herbivorous waterfowl have been the only birds assumed to harvest eelgrass, I have recently observed that gulls, scoters, scaups, and other diving ducks in winter and early spring ingest eelgrass covered with herring (*Clupea harengus*) eggs. Thus, some of the patchiness in eelgrass distribution may result from uprooting by normally nonherbivorous birds.

I thank S. Pokes, M. Amspoker, M. Guin, L. D. Johnston, D. Ransom, M. Mallon, and the people at the Oregon State University Marine Science Center and Ore-Aqua Foods, Inc., for encouragement and assistance that aided in completing this project. Constructive criticism on various drafts of this manuscript were given by M. Amspoker, M. Kentula, R. C. Phillips, J. A. Wiens, and two anonymous reviewers. Unpublished data were provided by J. J. Gonor. Most field research was conducted while I was a graduate student at Oregon State University.

BACKMAN, T. W., and D. C. BARILOTTI. 1976. Irradiance reduction: effects on standing crops of the eelgrass *Zostera marina* in a coastal lagoon. Mar. Biol. **34**:33–40.

BURT, W. V., and W. B. MCALISTER. 1959. Recent studies in the hydrography of Oregon estuaries. Res. Briefs, Fish Comm. Oreg. **7**:14–27.

FELGER, R., and C. P. MCROY. 1975. Seagrasses as potential food plants. *in* G. F. Somers, ed., Seed-bearing halophytes as food plants. Proc. of a Conference at the Univ. of Delaware. NOAA Office of Sea Grant, Dept. of Commerce, pp. 62–74.

GONOR, J. J., A. B. THUM, and D. W. ELVIN. 1970. Inshore sea surface temperature and salinity conditions at Agate Beach, Yaquina Bay, and Whale Cove, Oregon. Tech. Rep. Off. of Naval Res., Dept. of Oceanography, Data Rep. No. 45, Ref. 70–44, Oreg. State Univ. 30 pp.

GOODWIN, C. R., E. W. EMMETT, and B. GLENNE. 1970. Tidal study of three Oregon estuaries. Bull. No. 45, Oreg. State Univ. Eng. Exper. Sta. 32 pp.

KEDDY, C. J., and D. G. PATRIQUIN. 1978. An annual form of eelgrass in Nova Scotia. Aquat. Bot. **5**:163–170.

KELLER, M. 1963. The growth and distribution of eelgrass (*Zostera marina* L.) in Humboldt Bay, California. M.S. thesis, Humboldt State College, Arcata, Calif. 54 pp.

——— and S. W. HARRIS. 1966. The growth of eelgrass in relation to tidal depth. J. Wildl. Manage. **30**:280–285.

KRYGIER, E. E., and H. H. HORTON. 1975. Distribution, reproduction, and growth of *Crangon nigricauda* and *Crangon franciscorum* in Yaquina Bay, Oregon. Northwest Sci. **49**:216–240.

MCROY, C. P. 1966. The standing stock and ecology of eelgrass, *Zostera marina*, Izembek Lagoon, Alaska. M.S. thesis, Univ. of Washington, Seattle. 138 pp.

——— 1970*a*. On the biology of eelgrass in Alaska. Ph.D. thesis, Univ. of Alaska, College, Alaska. 156 pp.

——— 1970*b*. Standing stocks and other features of eelgrass (*Zostera marina*) populations on the coast of Alaska. J. Fish. Res. Board Canada **27**:1811–1821.

OREGON STATE LAND BOARD. 1973. Oregon estuaries. State of Oregon, State Land Board, Division of State Lands, 46 unnumb. pages.

PHILLIPS, R. C. 1972. Ecolological life history of *Zostera marina* L. (eelgrass) in Puget Sound, Washington. Ph.D. thesis, Univ. of Wash., Seattle. 154 pp.

——— 1974. Temperate grassflats. *in* H. T. Odum, B. J. Copeland, and E. A. McMahan, eds., Coastal ecological systems of the United States. Conservation Foundation and NOAA, Off. of Coastal Environ., pp. 244–299.

——— and S. GRANT. 1965. Environmental effect on *Phyllospadix scouleri* and *Zostera marina* leaves. Am. J. Bot. **52**:644.

STOUT, H. (ed.). 1976. The natural resources and human utilization of Netarts Bay, Oregon. NSF Student Originated Studies Program. Oregon State Univ., Corvallis. 247 pp.

THUM, A. B. 1972. An ecological study of *Diatomovora amoena,* an interstitial flatworm, in an etuarine mudflat on the central coast of Oregon. Ph.D. thesis, Oreg. State Univ., Corvallis. 185 pp.