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Estimates of Vascular Plant Primary Production in a West Coast Saltmarsh-Estuary Ecosystem

Abstract

Vascular plant primary production studies were undertaken in six Coos Bay, Oregon, salt marshes differing in plant associations, substrate, period of inundation, and degree of human interference. In each marsh, monthly samples were taken along permanent transect lines to determine aerial and root standing crop values. Estimation of death due to shedding and herbivory were included when assessing primary production values. Salt marshes with a predominance of giant bulrush, *Scirpus validus*, showed the greatest productivity (1200 G/M^2/year); disturbed marshes showed least productivity (400 G/M^2/year). Salt marshes with a predominance of *Carex lyngbei* and *Distichlis spicata* showed high intermediate characteristics (1081 G/M^2/year). Root standing crop values appear quite large (20,000 G/M^2). Further study needs to be undertaken in order to determine the importance of this plant material to estuarine food chains.

Introduction

Salt marshes are important components of estuarine ecosystems, playing a critical role in providing organic detrital material to estuarine food webs (Fenchal, 1969; Newell, 1965). They serve as a breeding ground and nesting site for many species of fish and wildlife (Hoffnagle *et al*, 1976), as settling basins for silt and organic material as well as pollutants of marine, terrestrial, and freshwater origin, and as stopover areas for many species of migratory birds (Magwire, 1976).

Salt marshes have received considerable attention on the North American Atlantic coast where low energy coastlines and barrier beaches create conditions which favor formation of extensive salt marsh systems. On the Pacific coast, however, due to the high energy nature of the coastline, salt marshes are restricted to estuaries and sheltered bays (Chapman, 1960). Little research has been done on these ecosystems. Notable exceptions include the work of MacDonald (1969) on the mollusk assemblages of the entire Pacific coast, and the work of Jefferson (1974) concerning plant community structure on the Oregon coast.

In this paper vascular plant primary production in the salt marshes of the Coos Bay estuary is assessed as a first step toward measuring organic detrital influx into the estuary.

Site Description

The Coos Bay estuary is located in southwestern Oregon 165 km north of the California border. It is approximately 5799 ha in extent, the largest estuary wholly within the state of Oregon (Akins and Jefferson, 1973).

The climate is mild, mid-latitude marine with warm summers and wet, cool winters. Average rainfall ranges from 125 cm on the coast to 250 cm at the headwaters of the Millicomma River, some 40 km inland (Oregon State Water Board, 1963). Little rain falls from June through September. Temperatures are moderate, averaging 7°C in January and 15°C in July.

Six study marshes were selected within the estuary for primary production studies on the basis of their plant communities, salinity, substrate, and degree of human interference (Figure 1, Table 1). Plant communities were classified according to the scheme of Jefferson (1972). The South Slough marsh was selected because of its location near the upland end of the South Slough Estuarine Preserve. The site is virtually undisturbed; adjacent uplands were logged near the turn of the century and used since as low-intensity dairy farms. The Henry Metcalf Estuarine Preserve marsh is a low, marine salt marsh near the ocean entrance to Coos Bay, with an unusual diversity of plant species. Twenty species of plants inhabit the marsh from its highest to its lowest reaches. Pony Slough marsh is located adjacent to the North Bend Airport. It is within a state bird sanctuary and is an important stopover for migrating waterfowl during winter storm tides. North Slough is a long, north-south running marsh following the edge of Highway 101 north of North Bend. The study site was located in a pure *Scirpus validus* stand, a species which tolerates salt water concentrations as low as three to five parts per thousand. The Bull Island site is a highly dissected marsh across the bay from the town of Coos Bay. This location contains the largest contiguous section of salt marsh in the estuary, unaltered in the past seventy years (Herbert Lillienthal, pers. comm.). The Coalbank Slough site is enclosed on three sides by upland and enclosed on the bayward side by a recently constructed road placed upon stone. Bay water circulation into the marsh is exclusively through a 4 ft. culvert placed underneath the roadway. The impaired circulation of this marsh gives rise to a disturbed, low-productivity condition which favors invasion of terrestrial species.

TABLE 1. Characteristics of six study marshes.

Study location	Area ha	Substrate	Elevation above zero tidal datum	Species richness	Predominant plant species in order of abundance by weight
South Slough	1.1	silt/ organic	3.5 M	9	Carex lyngbei, Distichlis spicata, Triglochin maritima, Salicornia virginica
Henry Metcalf Estuarine Preserve	.8	sandy	.8 M	19	Salicornia virginica, Triglochin maritima, Distichlis spicata, Carex lyngbe, Deschampsia caespitosa
Pony Slough	21.5	sandy	.5 M	12	Salicornia virginica, Distichlis spicata, Deschampsia caespitosa, Triglochin maritima, Jaumea carnosa
North Slough	14.3	organic	1.5 M	1	Scirpus validus
Bull Island	12.2	silt/ organic	1.75 M	11	Carex lyngbei, Deschampsia caespitosa, Triglochin maritima, Salicornia virginica, Distichlis spicata
Coalbank Slough	3.8	organic/ silty	2.4 M	8	Carex lyngbei, Deschampsia caespitosa, Grindelia integrifolia, Atriplex patula, Glaux maritima

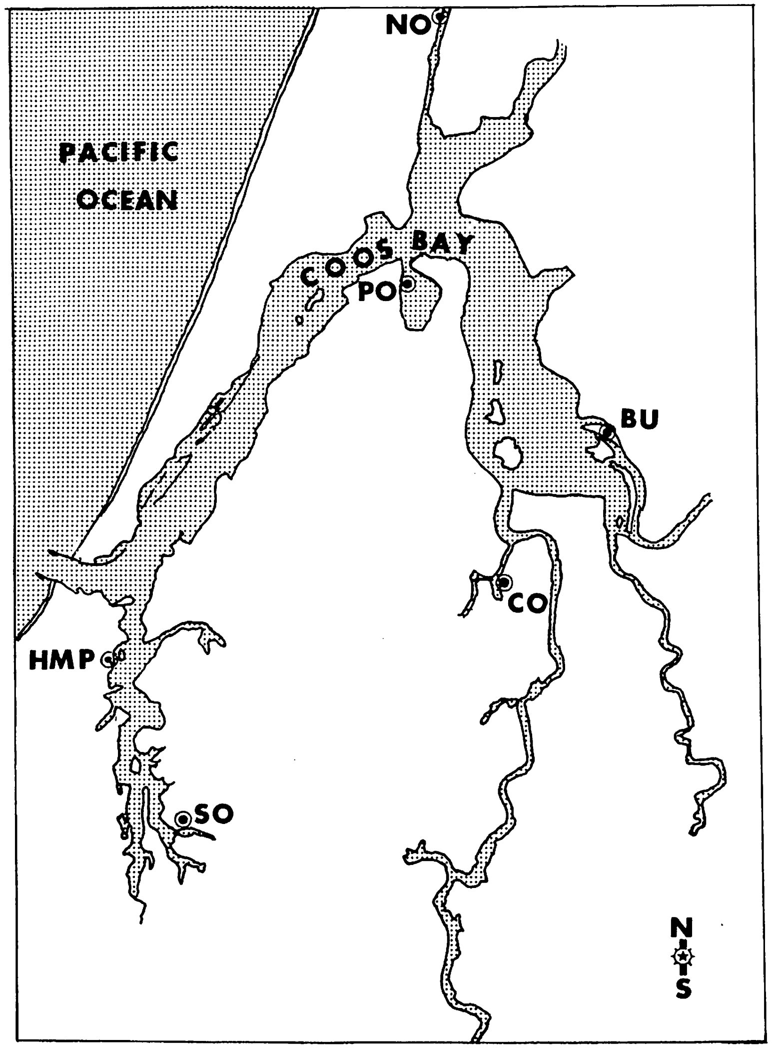

Figure 1. Coos Bay, Oregon, location of study. SO=South Slough, HMP=Henry Metcalf Estuarine Preserve, PO=Pony Slough, NO=North Slough, BU=Bull Island, CO=Coalbank Slough.

Aboveground plant production

Permanent transect lines were staked across each marsh outward from the shore. Monthly (May-August) samples of aerial biomass were taken every 5 or 10 m along the transect line in order to obtain from fifteen to twenty-five samples from each marsh. At each sample location 1/8 sq m quadrats were laid out and all standing vegetation was clipped down to 2 cm. Each sample was bagged separately in the field and refrigerated until sorted, in order to minimize weight loss by fermentation and respiration as recommended by Boyer (1958) and Milner and Hughes (1968). Cuttings were sorted into living and dead material for each species present. Positive species identification could almost always be made. Sorted samples were then dried at 100°C to constant weight (24 hr).

The following formula (Wiegert and Evans, 1964) is used to calculate primary production from our monthly standing crop figures obtained from each marsh.

$$P_n = \sum_{n=1}^{N} (B_n - B_{n-1}) + L + P_a + G$$

where P_n = net primary production

B_n = aboveground standing crop at time n

L = losses from death and shedding

P_a = biomass added after peak accumulation

G = direct grazing due to consumers

This classic formula becomes complicated in a community of many different plant species reaching their peak biomass at different times, thus the maximum standing crop of each species in each study site has been substituted for $(B_n - B_{n-1})$, as in Eilers (1975). Eilers reasoned that in a nonwoody perennial, maximum standing crop would include only growth that had occurred during that year (excluding death due to shedding and consumption by herbivores). This alteration also in effect removes P_a (biomass added after peak biomass) since peak biomass is being measured for each species. Therefore:

$$P_n = \sum_{n=1}^{N} S + L + G$$

where S = maximum standing crop of each plant species in the study location.

A unique problem occurred in the case of *Salicornia virginica*, a woody perennial. In this case $B_n - B_{n-1}$ was resubstituted for S and April standing crop values were used as the beginning of the growing season, since at that point no green vegetation was visible.

L (the loss due to death and shedding) is calculated by assuming that the loss of dead material occurs at a constant rate throughout the year. In the early spring, before any new growth has occurred, the decrease in dead material from the past growing season is measured and projected forward linearly into the later summer months when dead material from the current growing season has begun to accumulate. This estimation of current and past dead material allows one to determine the amount of dead material attributable to the current growing season and provides an estimated value for L.

Herbivory in salt marshes is believed to be quite low, most energy being utilized as detrital material supplied to the estuary. Large herbivores are rarely present and small herbivores, primarily the deer mouse, *Peromyscus maniculata*, do not appear abundant enough to be causing significant grazing pressures on the salt marsh. Magwire (1976) studied small mammals in the same six study locations that were used for the primary production studies, and had capture success rates of 5.7 captures per 100 trap nights. Some 80 percent of these animals captured were insectivorous shrews, *Sorex vagrans*.

Insects may be the most important herbivores in the salt marsh. In an East Coast study, Smalley (1960) established that 10 percent of the biomass (*Spartina alterniflora*) in his study area was consumed by insects. Shrag (1976), working at the Oregon Institute of Marine Biology, found that leafhoppers (Cicadellidae) feeding on *Distichlis spicata* consumed 7.27 percent of total production. Utilizing this figure, our data might be somewhat in error if greater or lesser herbivory by terrestrial arthropods is taking place.

Ash-free dry weight

Subsamples of the dryweight samples were ignited in a muffle furnace at 600°C to determine ash-free dry weight (Boyd, 1971).

Root biomass

Root biomass was sampled at each point along the transect. A 4 cm diameter core of the upper 40 cm of the marsh was obtained with a sharpened steel pipe sampler driven into the substrate. The root and soil core was extracted and removed from the pipe by insertion of a wooden ramrod. Soil cores were stored under conditions similar to aerial cuttings until processing. Soil cores were rinsed by hand over a 60-mesh-per-inch screen. A 35-mesh-per-inch screen was used for the samples originating from the Henry Metcalf Estuarine Preserve due to the coarse nature of the sandy substrate. Samples were dried to constant weight and subsamples were ashed similarly to aerial samples.

Estimates of primary production should include both above-ground and below-ground plant material. Unfortunately, it was not possible to distinguish between living and dead roots or to separate the roots by species (Schlesinger, 1977). Due to these difficulties, root biomass was not calculated, but is given, rather, in standing crop values.

Results and Discussion

Each salt marsh is a unique combination of plant species, substrate, tidal circulation, and nutrients. As a result of these variables one may expect one salt marsh to differ from another in many ways. In order to assess total primary production of salt marshes in the Coos Bay estuary ecosystem, the contribution from each representative site must be examined. Table 2 presents live and dead standing crop values for each study location during each month of the growing season. Standard deviations appear quite high due to the wide variability within each transect.

The Henry Metcalf Estuarine Preserve and Pony Slough sites both contain a high proportion of *Salicornia virginica*. On these sites the growing season begins with a good deal of "aerial" biomass already present in the form of woody non-photosynthesizing stems. Other study sites with predominately non-woody perennials show little growth at this time. As the growing season progresses, however, the *Salicornia virginica*-rich marshes, while maintaining their dominance over the lower sites, do not grow to the extent that the marshes predominated by *Carex lyngbei* and *Scirpus validus* do. The *Salicornia*-rich sites, Pony Slough and Metcalf Preserve, put on only 300 G/M² of aerial biomass during the growing season.

TABLE 2. Live and dead shoot standing crops for each study location during each month of the growing season.

	Marsh	April	May	June	July
Live	Metcalf Preserve	337.36 ± 320.64	442.24 ± 286.72	491.2 ± 320.8	560.24 ± 256.88
	Pony Slough	287.76 ± 123.36	324.16 ± 152.4	516.72 ± 151.2	689.12 ± 217.68
	South Slough	(63.86 ± 17.52)	571.2 ± 199.6	699.76 ± 148.	550.96 ± 183.68
	Bull Island	63.36 ± 17.52	236.72 ± 83.52	687.28 ± 196.2	596.32 ± 160.4
	North Slough	45.92 ± 24.40	204.96 ± 100.00	717.92 ± 235.04	795.36 ± 204.32
	Coalbank Slough	40.16 ± 53.13	56.96 ± 55.36	151.68 ± 153.20	205.2 ± 143.84
Dead	Metcalf Preserve	208.8 ± 166.24	162.96 ± 123.52	136.48 ± 112.42	295.28 ± 322.56
	Pony Slough	62.4 ± 92.48	35.28 ± 31.94	90.00 ± 53.12	120.08 ± 73.76
	South Slough	(106. ± 135.92)	104.00 ± 5.92	134.72 ± 133.36	126. ± 86.88
	Bull Island	106. ± 135.92	101.68 ± 108.4	283.68 ± 201.04	107.04 ± 90.32
	North Slough	316.08 ± 84.4	261.44 ± 146.00	325.12 ± 98.48	524.45 ± 119.6
	Coalbank Slough	480.16 ± 408.16	76.16 ± 67.88	98.3 ± 134.64	71.84 ± 71.92

In contrast, *Scirpus validus*-rich sites, such as North Slough, begin the growing season with stores of available nutrients and energy in roots and rhizomes. At this time they possess no live above-ground biomass. As the growing season progresses, bulrush-rich sites exhibit dramatic growth, in large part due to the nutrient and energy stores present in these roots and rhizomes. Bulrush puts on the bulk of its growth in June and July. By July, *Scirpus validus* marshes attained a standing crop of 800 G/M²

Study sites with *Carex lyngbei* predominating possess intermediate growth rates. They grow through June, at which time their biomass declines, probably due to a temperature controlled increase in respiration or a loss of lower leaves through breakage or tidal action.

Disturbed marshes, of which Coalbank Slough site is an example, show normal but stunted growth patterns. Growth occurs well into July, but never attains an appreciable standing crop.

Figure 2 illustrates the method utilized to differentiate dead material from the current growing season and past growing seasons. Dead standing biomass is plotted for each month. As the dead biomass begin to increase near the end of the growing season, due to increased death of currently growing plants, the descending line is extended in a straight line to the month of peak dead biomass. All material underneath this line is thought to be dead material from the previous year. If the line does not intersect the perpendicular to the greatest month's dead standing crop, all material is assumed to be derived from the current growing season. In all cases except the Coalbank Slough site, in which dead material has completely decomposed, the continuation of the line does not intersect the maximum dead standing crop perpendicular.

Figure 3 separates live matter by species rather than by study site. Examination of this figure illustrates the close relationship between characteristics of marsh growth and the predominant species in a salt marsh. Well over 50 percent of the biomass in each marsh is produced by one or two species, thus sites strongly reflect the growth characteristics of the predominant species.

Primary production estimates

Table 3 presents primary production figures for each study site. These production figures integrate standing crop, litter material, and grazed material for the entire growing season.

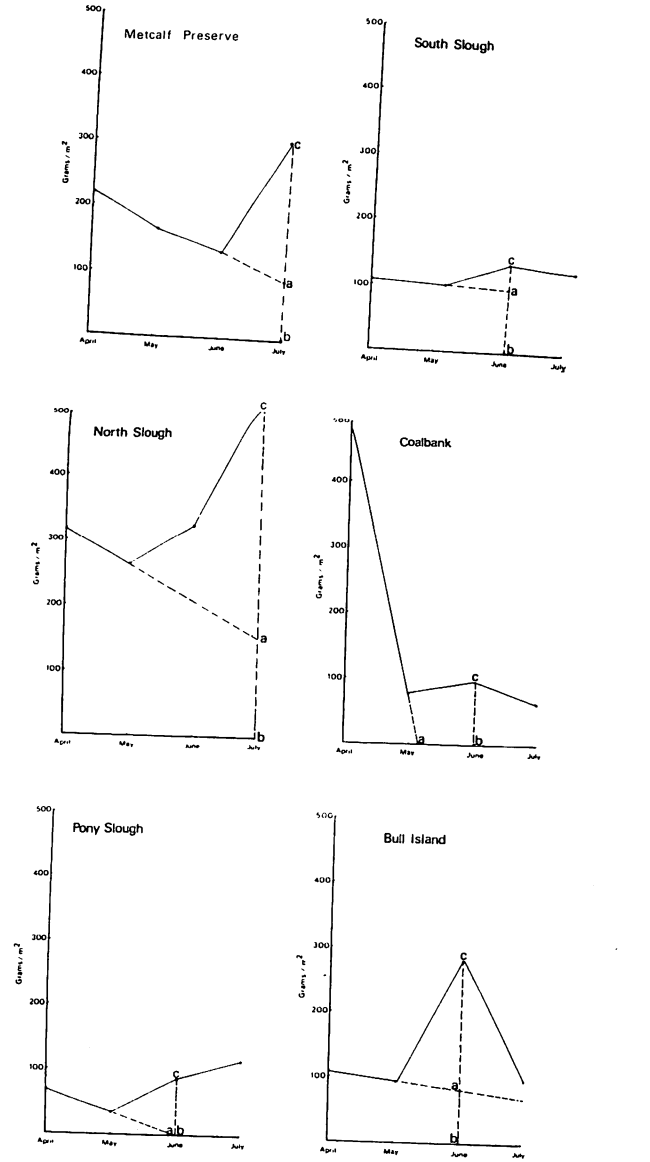

Figure 2. Changes in dead standing biomass from April to July. Estimated portion of dead shoot material (CB) derived from previous season's growth (AB).

North Slough, the bulrush-dominated stand, clearly shows the highest production over the growing season. This production, while in large part contained in the live aerial portion of the plants, is also influenced by large amounts of dead litter material lost during the growing season, perhaps due to the marsh's low tidal character. The two *Carex lyngbei* marshes, Bull Island and South Slough, which are elevated above the tide level, differ in their productivity. While comparable amounts of living material are present in each site, the amount of litter transported into the estuary during the growing

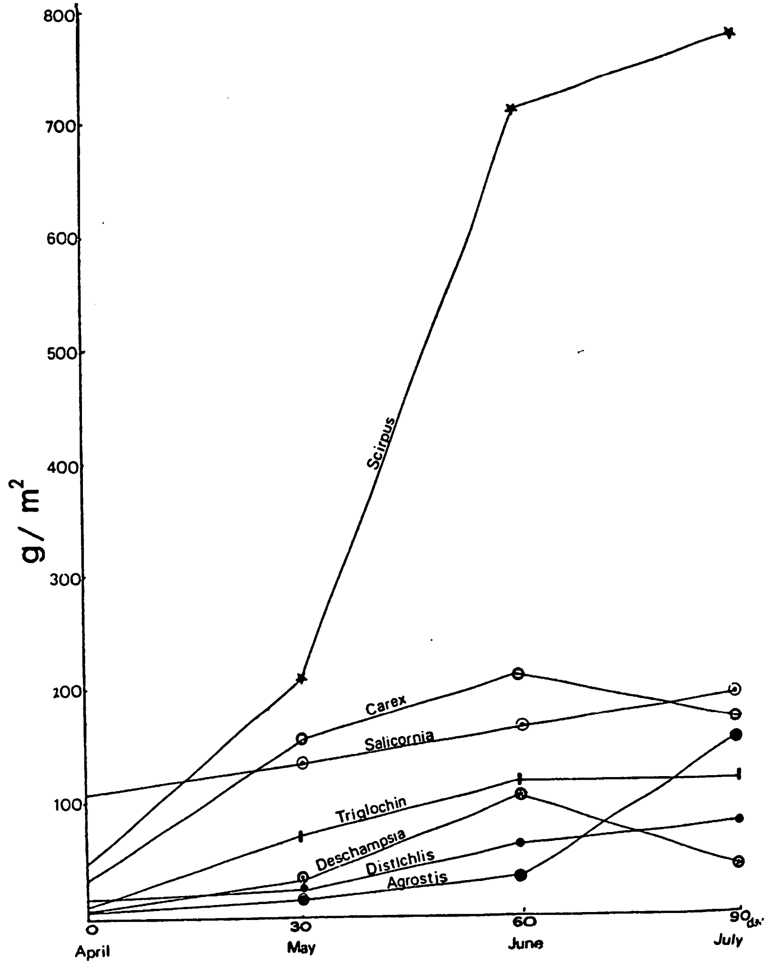

Figure 3. Biomass of seven plant species as the growing season progresses.

season seems much larger in the Bull Island site. The low marshes, Metcalf and Pony Slough, are characterized by rather low production values. Litter is relatively high for these two species, perhaps as a result of their more frequent inundation. Coalbank Slough has production values only one-third as great as those of the most productive marshes. These low values are possibly a result of restricted water circulation.

TABLE 3. Calculation of total aerial productivity for each of the study sites. S=shedding, L=litter, G=grazing.

Marsh	S	+	L	+		= Total G/M²
NO	749.4		369.4		81.7	= 1200.5
BU	815.2		192.7		73.5	= 1081.4
SO	734.8		30.0		55.8	= 820.6
PO	479.0		120.1		43.7	= 624.8
HMP	360.1		200.3		40.9	= 601.9
CO	280.6		98.3		27.7	= 406.6

Figures derived for each salt marsh community in Coos Bay compare favorably with data for other types of ecosystems shown in Table 4. Several factors unique to the estuarine environment contribute to high productivity in salt marshes. The moderating effect of ocean waters on marine climates and locally on the micro-climate of the salt marsh allows a longer growing season (Keefe, 1972). Vertical orientation of leaves in salt marsh plants reduces intense heating (Palmer, 1941), and enables the plant to expose maximum leaf surface to sunlight over the course of the day and minimizes mutual shading (Jervis, 1964).

TABLE 4. Comparison of primary productivity in different world ecosystems. Daily values for marshes based upon 200 day growing season (USDA).

Plant community From Odum (1960)	Net primary productivity G/M²/year	G/M²/day
Wheat (areas of highest yield)	1250	3.43
Corn (world average)	412	1.13
Hay (areas of highest yield)	940	2.58
Forest (pine during years of most rapid growth)		
Forest (deciduous, same as pine)	3180	6.0
Spartina salt marsh (Georgia)	1560	3.0
Infertile open ocean	3300	9.0
Shallow inshore waters (Long Island)	182	.5
From Harding et al (1970)	1168	3.2
Eelgrass (Zostera marini)		
	4500	5.17
Immature high marsh		
Bulrush marsh	1087	5.43
Low sandy marsh	1201	6.00
	622	3.11

Due to the high water table in marshes, soil water is usually abundant and enriched in dissolved nutrients from the soil-water equilibrium. This high nutrient content of marsh soils and water helps maintain high productivity. As freshwater flows into the marsh, silt from upstream is trapped by marsh plants (Ranwell, 1964). In addition, the tide moves nutrients from marine sources into the salt marsh. The watery marsh environment hastens decomposition of organic matter and leads to the formation of organic colloids that absorb exchangeable ions necessary for plant growth (Keefe, 1972).

Estuary production

Assessment of vascular plant productivity in the entire estuary must consider the community level. In this analysis, different salt marsh types are grouped according to the plant species present. The extent of each marsh type present in the estuary is taken from Hoffnagle and Olson (1974). These acreages are multiplied by production figures from the preceding to obtain the total production of the estuary by vascular salt marsh plants. Using this technique, total productivity for the 7.86 x 10^6 sq m of salt marsh in the Coos Bay estuary is 7.35 x 10^9 g per year (see Table 5).

TABLE 5. Total productivity of salt marsh systems in Coos Bay based upon estimated productivity and estimated acreage.

Marsh type	Productivity (G/M²)	x	Area (M²) = Total
High Marsh	951	x	4.40 x 10^6 = 4.18x10^9
Low Marsh (silt and sand)	622	x	1.46 x 10^6 = 9.08x10^8
Sedge Marsh	1081.4	x	1.43 x 10^6 = 1.54x10^9
Bulrush Marsh	1200.6	x	6.06 x 10^5 = 7.27x10^8
Total			7.89 x 10^6 = 7.35x10^9 Grams

Root standing crop and ash weight

Root dry weight and ash-free dry weight values are given in Table 6. These root standing crop values suggest two important factors operating in the salt marsh ecosystem. Total contribution of roots and rhizomes to the standing crop of the entire plant is well over 10 times that of aerial production. The sharp decline of root dry weight as the growing season progresses, and the accompanying increases in aerial growth, suggest that roots and rhizomes may function as a storehouse for aerial growth.

Root ash-free dry weights point to the important contribution made to inorganic nutrient stores by plant roots (taken here to mean both plant roots and rhizomes). At the beginning of the growing season 50 percent of the plant roots are organic and 50

TABLE 6. Dry weight and ash-weight of roots during each month of the growing season.

Marsh	April dry wt. g/m²	April ash-free dry wt. g/m²	May dry wt. g/m²	May ash-free dry wt. g/m²	June dry wt. g/m²	June ash-free dry wt. g/m²	July dry wt. g/m²	July ash-free dry wt. g/m²
Coalbank Slough	38232.08 ± 30063.38	18198.95 (47.6%)	19179.73 ± 9056.66	12213.25 (47.22%)	12213.25 ± 5390.07	8549.27 (70.%)	13375.66 ± 4697.4	11733.13 (87.72%)
North Slough	20915.38 ± 7762.66	13825.06 (66.1%)	9124.11 ± 1441.07	7517.35 (82.39%)	8877.29 ± 5206.96	7261.62 (81.8%)	6305.66 ± 2364.52	5745.9 (91.14%)
Metcalf Preserve	34474.16 ± 12133.63	10535.3 (30.56%)	11552.43 ± 4697.4	5750.79 (49.78%)	10827.91 ± 4522.24	7200.56 (66.5%)	9370.92 ± 5437.84	8905.18 (95.03%)
South Slough	No data		7205.34 ± 1950.62	4908.48 (68.12%)	5374.14 ± 3152.83	4245.57 (79.%)	7937.81 ± 3869.29	7513.13 (94.65%)
Pony Slough	12125.64 ± 6226.05	8329.1 (68.69%)	15549.2 ± 6329.55	8241.08 (53.%)	13329.49 ± 5326.39	9503.92 (71.3%)	9155.95 ± 3264.29	8419.81 (91.96%)
Bull Island	11233.95 ± 3192.6417	5028.32 (44.7)%	13853.36 ± 2794.56	5991.58 (44.%)	10748.29 ± 1291.05	8296.18 (77.%)	9554.04 ± 3821.62	9033.34 (94.55%)

percent are inorganic. By the end of the season, 90 percent is organic material. As the growing season progresses, inorganic materials are utilized and replaced by organic stores. An absolute decrease in root weight occurs during the growing season.

This paper has assessed the primary production of vascular plants in an estuarine ecosystem, taking into account death due to shedding and herbivory. Primary production and root standing crop values for five different estuarine marshes have been established. The more fundamental question concerning the fate of the photosynthetic material has not been looked at due to its complexity. It may be presumed that a large portion of the material produced in the salt marsh decomposes and enters the estuary in some form as detritus destined for further consumption by estuarine organisms (Odum and de la Cruz, 1963).

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