Reports

Barrier Island Forest Ecosystem: Role of Meteorologic Nutrient Inputs

Abstract. *The Sunken Forest, located on Fire Island, a barrier island in the Atlantic Ocean off Long Island, New York, is an ecosystem in which most of the basic cation input is in the form of salt spray. This meteorologic input is sufficient to compensate for the lack of certain nutrients in the highly weathered sandy soils. In other ecosystems these nutrients are generally supplied by weathering of soil particles. The compensatory effect of meteorologic input allows for primary production rates in the Sunken Forest similar to those of inland temperate forests.*

Terrestrial ecosystems are open systems; their maintenance and development are dependent on a constant source of nutrients to compensate for losses and to allow for net increases in biomass. For many ecosystems, the principal sources of nutrients are weathering of soil minerals and meteorologic inputs (*1*). Carbon, nitrogen, oxygen, and sulfur tend to enter ecosystems as meteorologic inputs. The usual source of Ca, K, Mg, P, and other metallic cations is weathering of soil and rock minerals (*2*).

If the rate of weathering is low, or if certain minerals are absent, patterns of ecosystem function and development may be preeminently influenced by meteorologic inputs of the nutrients that are usually supplied through the weathering process. Study of such a system adds new dimensions to the importance of meteorology in the regulation of ecosystems.

The forest ecosystem (dominated by *Ilex opaca, Sassafras albidum,* and *Amelanchier canadensis*) behind the secondary dune on the barrier island at Fire Island, New York, represents one end of a gradient of ecosystems ranging from one almost wholly dependent on weathering as a source of K, Ca, Na, and Mg (Hubbard Brook, New Hampshire) (*3*), through one of intermediate dependence on weathering (Brookhaven, New York) (*4*), to the Sunken Forest, which is heavily dependent on meteorologic input (*5*).

Table 1. Cation budgets for the Sunken Forest. Rain was measured with the automatic collector open only during rain; for bulk precipitation the collector was continuously open, measuring rain plus dry fallout. Impaction includes dry fallout. The average meteorologic input is one-half the sum of rain, impaction, and bulk precipitation. Exchangeable nutrients and soil minerals were measured to a depth of 30 cm. Weathering is based on the difference between the cation concentration of the soil layer minerals from 0 to 15 cm and from 15 to 30 cm. Leaching is stemflow plus throughfall, exclusive of meteorologic inputs. Uptake is incorporated in current growth and measured by dimension analysis.

Components	Cations (g/m^2)			
	K	Na	Ca	Mg
Annual inputs				
Rain	0.22	4.29	0.36	0.68
Dry fallout	0.40	5.41	0.50	0.47
Bulk precipitation	0.62	9.70	0.86	1.15
Impaction	0.62	14.30	0.74	1.98
Average meteorologic input	0.73	14.15	0.98	1.91
Compartments				
Organic				
Living biomass	36.3	21.3	46.4	17.8
Debris	1.1	0.7	5.3	1.5
Exchangeable nutrients	6.8	6.7	28.6	9.7
Soil minerals	461.8	465.2	629.1	286.3
Annual transfers				
Weathering*	0.01	0.06	0.04	0.01
Leaching	3.20		1.13	0.17
Litterfall	0.87	0.69	6.11	1.35
Uptake	5.11	1.85	4.92	1.88

* Not significant at $P = .05$.

Mineralogical analyses of sands in the Sunken Forest on Fire Island indicate that soil minerals are extremely poor as a source of plant nutrients; 98 percent of the substrate is quartz sand. The remainder is predominantly magnetite, garnet, and tourmaline (*6*).

Fire Island is underlain by a lens of fresh water maintained by an excess of precipitation over evapotranspiration. This lens theoretically extends to a depth of 40 m below sea level (*7*). The fresh water in the lens moves downward at the center and upward along the edges, ultimately discharging into the Atlantic Ocean and Great South Bay (Fig. 1). This movement of fresh water prevents intrusion of nutrients from the ocean through the ground water system (*5, 8*).

Observations made over 1 year suggest that the input of nutrients to the ecosystem by animals is not great. Sea birds import nutrients to areas surrounding their nesting sites; however, neither nests nor guano was detected in the portion of the Sunken Forest where this research was conducted. Input of detritus was not measured, but observations indicate that it was very low, most of the oceanic organic debris being trapped by the dune ridges and swales. These facts suggest meteorologic input as the principal source of nutrients available to the vegetation.

Following established procedures, K, Na, Ca, and Mg were measured in various meteorologic inputs, biomass, net primary production, soil minerals, organic debris, throughfall, and stemflow, and as nutrients on exchange sites in the soil (*5, 9*). Since time was limited, we did not analyze for P, S, or N.

Measurements of nutrients in bulk precipitation collected in the open (that is, rain plus dry fallout) may underestimate the total meteorologic input (Table 1) because they do not account for the impaction of salt spray on the upper canopy (*10, 11*). Winds coming off the ocean over the secondary dune

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carry oceanic salts. The airstream impinges on the uppermost part of the canopy. In the zone of contact between vegetation and wind, there is a steep vertical gradient in salt-carrying capacity of the airstream (*10*). As branches grow upward into the zone, they are periodically killed back during intervals of intense salt impaction. This leads to an enormous proliferation of lateral branches just below the contact zone, and the production of a branch surface (9.5 m^2 per square meter of land surface) which is several times larger than that found in inland forests (*5*). This finely divided forest canopy plays a major role in the entrapment of salt spray and its transfer to the forest floor.

The meteorologic input of K, Ca, and Mg by impaction on vegetative surfaces (including dry fallout) was estimated by measuring the Na content of rain after it passed through the canopy (throughfall and stemflow), subtracting the Na content of rain in the open, and multiplying the excess Na by the K/Na, Ca/Na, and Mg/Na ratios of aerosols deposited during dry periods on acrylic-coated leafy twigs in the uppermost canopy (*5, 12*). This method may provide an overestimate of the impaction input because some Na in throughfall might be derived from inside leaves, even though there is less Na than K, Ca, or Mg in foliar tissues (*5*). Therefore, the total meteorologic input was also estimated by averaging inputs from bulk precipitation (rain plus dry fallout) with those from impaction plus rain alone (Table 1).

The density of airborne aerosols of oceanic salts increases abruptly at wind speeds greater than 7 m/sec due to the formation of whitecaps (*10*). Impaction and precipitation inputs are highly correlated with the speed of onshore winds that prevail during the growing season (*13*).

The retention and cycling of nutrients within the ecosystem is affected importantly by the distribution of organic matter. Living biomass accounts for most of the K, Ca, and Mg, while lesser amounts of these elements are held in, or adsorbed on, soil organic matter (Table 1). Large amounts of Na enter the ecosystem, but uptake and retention of this ion are low. Soil organic matter provides virtually all the exchange surface within the soil, as shown by the strong relation between soil organic matter, exchangeable cations, and cation exchange capacity (*14*). A mull humus is localized in the surface 15 cm, and root systems occur predominantly within this zone.

Table 2. Annual cation sources for several temperate forest ecosystems.

Ecosystem	Distance from ocean (km)	Source	Cation ($g\ m^{-2}$) K	Na	Ca	Mg	Reference
Sunken Forest	0.3	Meteorologic input	0.73	14.15	0.98	1.91	(*5*)
		Weathering					
		Total	0.73	14.15	0.98	1.91	(*4*)
Brookhaven Forest	15	Meteorologic input	0.24	1.70	0.33	0.21	
		Weathering*	1.11	0.68	2.43	0.83	
		Total	1.35	2.38	2.76	1.04	
Hubbard Brook Forest	116	Meteorologic input	0.14	0.15	0.26	0.07	(*3*)
		Weathering	0.4	0.61	0.80	0.8	
		Total	0.54	0.76	1.06	0.87	
Cedar River Forest	310	Meteorologic input	0.08		0.28		(*21*)
		Weathering*	1.52		1.74		
		Total	1.60		2.02		

* Weathering = output + immobilization in biomass — input.

The uptake of nutrients, as measured by the midsummer nutrient content of net primary production, is about balanced by returns to the forest floor through canopy leaching and litter fall (Table 1). Calcium transfer by litter deposition appears to be greater than Ca uptake, probably because the latter was sampled in midsummer, while Ca in leaf tissues would be expected to increase up to the onset of litter fall (*15*). This suggests that the ecosystem is nearing a steady state and that meteorologic inputs balance losses to ground water. Patterns of intrasystem nutrient cycling in the Sunken Forest are quite similar to those inferred for some moist tropical forests (*16*). Both have highly weathered soil mineral substrates and, hence, low inputs from weathering, large proportions of cations held within the living biomass, and a dependence on rapid circulation of nutrients between soil and vegetation. The litter layer in the Sunken Forest is converted to humus annually, transferring six times more Ca than the meteorologic input, while canopy leaching annually transfers more than four times the meteorologic input of K.

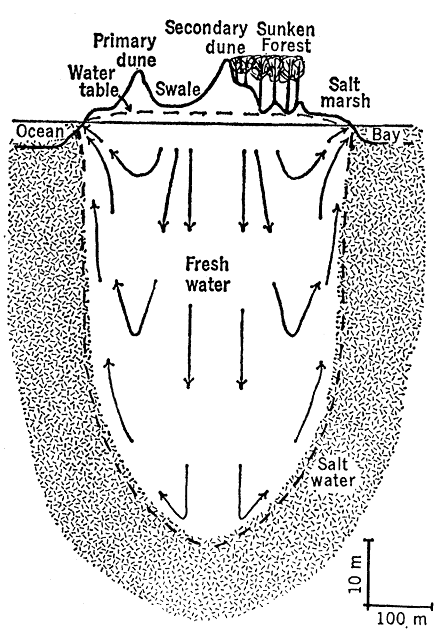

Fig. 1. Cross section of Fire Island (looking west) in the vicinity of the Sunken Forest, showing topography and hydrologic patterns. [Hydrologic flow patterns after (*7*).]

The interactions between the organic matter of the Sunken Forest and meteorologic nutrient inputs have played a primary role in the development and maintenance of the ecosystem. Primary production is substantially dependent on meteorologic inputs acquired over a period of time through precipitation, dry fallout, and the impaction of aerosols on living biomass. Retention of nutrients within the ecosystem is almost wholly a function of their accumulation in living biomass and on soil organic matter, both of which are related to primary production. However, the Sunken Forest ecosystem has not developed solely in the context of a positive feedback loop in which greater biomass leads to a greater ability to trap and retain nutrients, which in turn leads to greater biomass. Rather, a subtle relationship exists between living biomass and salt spray aerosols that on one hand limits further increase in biomass, but on the other hand facilitates the entrapment of aerosols.

Growth of the forest beyond the shelter of the secondary dune subjects the shallowly rooted trees to high-intensity wind and wind-borne salt particles. The system is stabilized by the development of an aerodynamically smooth upper surface of the canopy. This is brought about by the wellknown toxic effects of salt spray on the twigs that grow into the higher-velocity portions of the airstream flowing off the ocean and over the secondary dune (*10*). The growth response of the forest trees simultaneously adapts the ecosystem to the wind-salt conditions and limits further biomass accumulation resulting from upward growth. However, proliferation of branches at the airstream-canopy interface guarantees a large surface area that probably strains aerosols from slower, nontoxic portions of the airstream. Thus, there are continual adjustments between the restriction of the system by toxic effects of salt spray and dependence of the system on salt spray as a source of nutrients.

The rates of development, biomass accumulation, and net primary production approach the means for temperate forests (*5*). Dimension analyses (*17*) indicated a biomass of 17,000 g/m^2, a net primary production of 1110 g/m^2, and a leaf area index of 5.9, all of which fall well within the range for temperate forests. This is in part because nutrients from meteorologic sources alone are about equivalent to nutrients from meteorologic plus weathering sources in a variety of other ecosystems (Table 2).

The development of an ecosystem may be extremely slow if low weathering rates are coupled with low rates of meteorologic input. These factors may be important along Lake Michigan, where fresh water dune ecosystems take thousands of years to reach the tree stage (*18*). Radiocarbon dates and geological evidence suggest that the Sunken Forest has reached a comparable stage of development in only 200 to 300 years (*19*).

Our results also suggest that the high levels of biomass accumulation and primary production found in some coastal regions (*5, 17, 20*), may be in part due to high weathering inputs plus high meteorologic inputs.

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13. The relation between kilograms Na impacted per hectare (Y) and thousands of kilometers of wind blowing onshore (between 79° and 238°) at speeds of <7 (X_1) and >7 (X_2) meter/sec is given by $Y = 2.49X_1 + 3.57X_2 - 0.264$ (multiple correlation coefficient, .84; F value of the regression, 39.4; 2 and 34 degrees of freedom; significant at $P < 0.1$ percent). The amounts of K, Ca, and Mg impacted are calculated by multiplying the amount of Na by the K/Na, Ca/Na, and Mg/Na ratios, 0.0435, 0.0519, and 0.139, respectively.
14. The relation between cation exchange capacity in milliequivalents per 100 g of soil (Y) and organic matter expressed as percentage loss on ignition (X) is given by $Y = 1.51X - 0.24$ (multiple correlation coefficient, .97; F value of the regression, 300.5; 1 and 22 degrees of freedom; significant at $P < 0.1$ percent). The relation between total exchangeable K + Na + Ca + Mg in milligrams per kilogram of soil (Y) and organic matter expressed as percentage loss on ignition (X) is given by $Y = 67.44X - 19.56$ (multiple correlation coefficient, .88; F value of the regression, 72.8; 1 and 22 degrees of freedom; significant at $P < 0.1$ percent).
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Radiohalos in a Radiochronological and Cosmological Perspective

Abstract. *New photographic evidence, data on halo ring sizes, and x-ray fluorescence analyses provide unambiguous evidence that polonium halos exist as a separate and distinct class apart from uranium halos. Because of the short half-lives of the polonium isotopes involved, it is not clear how polonium halos may be explained on the basis of currently accepted cosmological models of Earth formation.*

I have examined some 10^5 or more radiohalos, mainly from Precambrian granites and pegmatites located in several continents. In addition to U and Th halos, originally studied (*1, 2*) for information on the constancy of the α-decay energy E_α and the decay constant λ, I have discussed X halos (*2, 3*), dwarf halos (*3*), and giant halos (*4*), and explained how these remain prime candidates for identifying unknown α-radioactivity and, not impossibly, unknown elements as well.

I have also reported (*5*) on a class of halos which had been tentatively attributed (*6, 7*) to the α-decay of ^{210}Po, ^{214}Po, and ^{218}Po. Earlier investigators (*2, 7–10*), possessing only a sparse collection of Po halos, at times confused them with U halos or invented spurious types such as "emanation" halos (*2*) or "actinium" halos (*8*) to account for them. (Figure 1, a to d, is a schematic comparison of U and Po halo types with ring radii drawn proportional to the respective ranges of α-particles in air.) To explain Po halos, Henderson (*7*) postulated a slow accumulation of Po isotopes (or their respective β-decay precursors) from U daughter product activity. I demonstrated that this secondary accumulation hypothesis was untenable and showed, using the ion microprobe (*3*), that Po halo radiocenters (or inclusions) exhibit anomalously high $^{206}Pb/^{207}Pb$ isotope ratios which are a necessary consequence of Po α-decay to ^{206}Pb.

Recently, these ion microprobe results have been questioned, Henderson's results misinterpreted, Po halos con-