ABSTRACT

Charles Edward Proffitt. ATMOSPHERIC INPUTS AND FLUX OF CHLORIDE, CALCIUM, AND MAGNESIUM IN A MARITIME FOREST ON BOGUE BANK, NORTH CAROLINA. (under the direction of Dr. Vincent J. Bellis) Department of Biology, East Carolina University, February 1977.

A transect from the Atlantic Ocean to Bogue Sound was established in November of 1974 in the Roosevelt Natural Area at Salter Path, North Carolina. Stations, designated by their distance in meters from the ocean, were studied from 8 December 1974 to 2 July 1976. Chloride (Cl), calcium (Ca), and magnesium (Mg) were monitored in bulk precipitation, throughfall, humus leachate, soil, standing water, and ground water. Quantities of water in gross rainfall and throughfall were determined as was the soil moisture. Vegetation at stations across the island was described in terms of canopy species composition and diversity.

Quercus laurifolia and _Q. virginiana_ dominated the forest canopy in non-innundated areas, while _Fraxinus tomentosa_ dominated the canopies at swale stations. Canopy height was inversely correlated with inputs of chloride ($r = -0.87$, $P = 0.05$).

Atmospheric inputs of rain and dissolved Cl, Ca, and Mg into the forest and adjacent shrub thicket were collected by placing rain gages at the canopy surface over two study years (8 December 1974 to 6 December 1975 and 26 June 1975 to 7 June 1976). The gages were located at canopy level at nine stations along the transect and at one site in the Juncus-Distichlis

salt marsh that borders the forest on the sound side. Samples were analyzed for chloride over both study years and for calcium and magnesium over the second study year. Inputs of chloride ($g \cdot m^{-2}yr^{-1}$) over the first year ranged from 107 (at Station 57) to 16.5 (Station 325). Stations 680, 848, and 879 showed increasing chloride inputs resulting from salt spray from Bogue Sound.

For the second year maximum atmospheric inputs were recorded at Station 124. These inputs ($g \cdot m^{-2}yr^{-1}$) were Cl = 104, Ca = 3.07, and Mg = 6.67. Station 396 had the lowest annual inputs, these were; Cl = 20.0, Ca = 1.38, and Mg = 0.99.

It was possible to describe the patterns of salt spray inputs across the island from ocean to sound by linear regression equations. Regression analysis of atmospheric inputs as a function of a topographical factor (calculated from the distance from the ocean, the distance from the sound, and elevation above mean sea level) resulted in equations for the prediction of atmospheric mineral inputs at any site along the transect where the topography is known. The equations were found to be: (1) Cl, $Y= 21.9\ X - 5.48$, (2) Ca, $Y= 0.40\ X + 0.98$, and (3) Mg, $Y= 1.11\ X - 0.26$ (where Y is the atmospheric inputs in $g \cdot m^{-2}yr^{-1}$ and X is the topographical factor). This method of prediction also yielded good results for chloride data from the first year ($r= 0.80$, $P= 0.05$) and for data on topography and salt spray inputs gathered from a previously published study by another author.

The patterns of Cl and Mg in throughfall paralleled those in bulk precipitation. Both Ca and Mg were enriched in throughfall relative to bulk precipitation because of additional ions leaching from the foliage and the washing off of aerosols impacted on foliage.

Soil along the transect was found to contain low quantities of water soluble minerals either in the upper 30 cm or at the water table depth. The maximum annual means of soluble Cl and Mg in the upper 30 cm of soil were found at Station 57 (Cl= 8.24 and Mg= 3.03 $g \cdot m^{-2}$). The lowest quantities of Cl and Mg were found in soils from Station 396 (Cl= 5.09 and Mg= 0.09 $g \cdot m^{-2}$). For Ca there was little variation among the soils of the four stations monitored. The range of Ca for these soils was 0.57 to 0.29 $g \cdot m^{-2}$.

To develop a working model of mineral cycles on a barrier island, intersystem transfers and storages must be coupled with the gradient of atmospheric inputs across the island. Data presented here constitutes an important contribution toward the development of Cl, Ca, and Mg budgets for Bogue Bank. Also prediction of atmospheric inputs from a calculated topography factor provides a method for estimating the input gradients needed to develop models for Cl, Ca, and Mg on Bogue Bank.

ATMOSPHERIC INPUTS AND FLUX OF SOLUBLE CHLORIDE, CALCIUM, AND MAGNESIUM IN A MARITIME FOREST ON BOGUE BANK, NORTH CAROLINA

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INTRODUCTION

The study of elements essential to life contributes to our understanding of community structure and energetics. Additionally, if a toxic form of an element is present in the environment in sufficient amount, its role in the functioning of the community should also be evaluated. Sound management of an ecosystem can result from first enumerating and quantifying the ecological processes affecting the ecosystem (Johnson and Swank 1973).

Vegetational zonation, community structure and individual plant morphology on barrier islands depend greatly on the concentration and pattern of deposition of the toxic chloride ion in salt aerosols (Oosting and Billings 1942, Boyce 1954, Martin 1959, Bourdeau and Oosting 1959, Wells and Shunk 1937 and Art 1971). Paradoxically, the salt spray that stunts and shapes trees also comprises a major source of several nutrients essential for plant growth and development on the impoverished soil of barrier islands.

Atmospheric inputs of mineral salts have been studied since early this century. Over the decades, there has been a shift in emphasis from exclusive concern over the toxic effects of salt spray on coastal vegetation, to studies dealing with nutrient cycling and soil storage levels of certain minerals. Lately, work has been aimed at quantification of mineral input-output budgets, with salt spray inputs replacing the rapid leaching loss from the nutrient depleted coastal soils.

Boyce (1954) reviewed the literature dealing with determination of environmental factors limiting species composition, growth, and morphology.

He discussed three major theories used to explain the stunted and espalier trees of the maritime strand. These theories were (1) increased transpiration on the windward side of trees, due to frequent onshore coastal winds, resulting in death of exposed foliage from dessication, (2) injury caused by sandblasting of vegetation, and (3) the toxic effects of wind-born salt spray. There have been many proponents of each theory, but the effects of salt spray are now widely accepted as the most important limiting agent in many maritime systems (Boyce 1954 and Martin 1959).

Emphasizing the importance of salt spray, Wells and Shunk (1938) concluded that the most salt tolerant woody species on coastal dunes were wax myrtle (Myrica cerifera) and yaupon (Ilex vomitoria). Live oak (Quercus virginiana) was somewhat less tolerant and loblolly pine (Pinus taeda) was found to be the least tolerant to salt spray of any canopy species. Wells (1939) described the live oak dominated forest of Smith Island, North Carolina as a "salt spray climax community." Salt spray was found to eliminate competition by salt sensitive hardwoods thereby allowing the slower growing, salt tolerant live oak to achieve dominance.

Oosting and Billings (1942) and Wells (1942) also ascribed zonation of coastal vegetation to the pattern of salt spray depositation. The environmental parameters measured by Oosting and Billings (1942) were soil moisture, soil salinity, soil temperature, air temperature, evaporation rate, salt spray, and relative humidity. There was no correlation found between vegetation zonation and any factor other than salt spray.

Convincing evidence concerning the ecological role of toxic salt spray resulted from studies by Boyce (1951a, 1951b, and 1954) who investigated the origin, atmospheric transport, deposition of oceanic salt aerosols, and their subsequent entry into plant tissues, translocation, and physiological effects. He determined that necrosis induced by chloride ion accumulation in leaves and shoots was the most important negative effect of salt spray on vegetation. Chloride enters aerial portions of woody vegetation, at points where wind damage has produced small abrasions, and is translocated to the tips of leaves and meristematic shoot tissue. If high levels of chlorides result, necrosis and death of the tissues follow. Boyce explained the espalier forms of maritime trees by demonstrating that new shoots extending above canopy level on the windward side of a tree are more efficient collectors of salt spray and therefore more subject to toxic concentrations of chloride than shoots on the lee side.

Other workers have reported correlations between changes in coastal terrain, salt spray deposition patterns, and effects on vegetation (Oosting 1954 and Martin 1959). Variations in strand topography, resulting in gradients of several environmental factors, were found to produce a "mosaic" vegetational zonation pattern at Island Beach State Park in New Jersey (Martin 1959). Martin also reported that gradients in salt spray, soil moisture, and ground water salinity all varied directly with island topography.

Most research on oceanic salt aerosols has been in coastal areas. However, Juang and Johnson (1967), working in the Hubbard Brook Experimental Forest in New Hampshire, reported that even at a considerable distance from the ocean (116 km) and the 229 - 1006 m range of elevation above mean sea level, one-third of the chlorine input into the system was from impaction of aerosols on foliage rather than dissolved in rainfall or by gravitational sedimentation.

Early in the 1960's, research emphasis shifted to studies concerning the distribution of mineral nutrients within dune soils and nutritional relationships with plants. Serious deficiencies of nitrogen and phosphorous were found in dune soils at Braunton Burrows in England (Willis and Yemm 1961), with deficiencies of these nutrients occurring also in plants grown in these soils (Willis 1963). Wagner (1964), working with Uniola paniculata in North Carolina, reported increased growth with addition of nitrate to dune soils but noted little change in growth with applications of phosphate.

Investigations began into the origins of nutrients in coastal soils. In his study of a dune grassland in South Wales, Etherington (1967) determined potassium losses from soils via water percolation. Such losses, he believed, must be balanced by compensatory inputs from salt spray, since he found that atmospheric potassium inputs (the major source of potassium for the system) correlated best with onshore winds.

Around this time new techniques were developed for studying biogeochemical cycles and energy flows in terrestrial systems. Bormann and Likens (1967) discussed the need for studies of mineral inputs and outputs in terrestrial ecosystems to complement the large amount of work on intersystem cycling and nutrient compartmentalization already accomplished. They presented the idea of relating the hydrologic cycle to nutrient fluxes for small watersheds with water-tight bedrock basins.

Most mineral cycling studies, using these hydrologic parameters, have been carried out in inland ecosystems where weathering of soil constituted the major input of elements having sedimentary cycles (Ovington 1965, Carlisle et al 1966, Bormann and Likens 1967, Likens et al 1967, and Bormann et al 1969). Recently, however, there have been several studies of mineral cycling in coastal ecosystems (where weathering of the soil provides negligible nutrients) employing many of the same hydrological techniques previously applied mainly to inland watersheds (Art 1971, Clayton 1972, Van der Valk 1974a, and Art et al 1974). Since there is little input of minerals into coastal soils via weathering and since soluble minerals are subject to rapid leaching through the sandy substrate, a steady supply of mineral nutrients transported from the ocean by atmospheric pathways is necessary for ecosystem maintenance (Art 1971, Clayton 1972, Van der Valk 1974 a and b).

Art (1971) monitored atmospheric cation inputs and intersystem cycling for a selected plot in a maritime forest on Fire Island, New York. From this data he was able to estimate that atmospheric inputs balance the losses of nutrients due to leaching by water percolation. He did not consider, however, the gradient of atmospheric inputs that occurs in the forest with increasing distance from the ocean. The gradient of inputs and outputs must be determined before a working model can be developed for the forest.

Atmospheric inputs of mineral cations into a Baccharis brushland in California were determined by Clayton (1972). He also studied leaching losses from the soils and uptake of ^{22}Na by the plants. He concluded a steady state existed for the ions investigated, with leaching losses balanced by atmospheric inputs.

In another study of macronutrient cations, Van der Valk (1974a) developed a budget of atmospheric inputs, intersystem cycling, and leaching outputs for mineral cations for a foredune grass community in North Carolina. He found that the inputs of all cations studied slightly exceeded the calculated percolation outputs.

The next step in coastal ecological studies is the determination of hydrological and mineral ion budgets for the entire forest and shrub system on barrier islands and mainland coastal areas. Many ecological and physiological parameters of intersystem nutrient cycling vary with the changing pattern of atmospheric inputs. Workers can attack this problem by either intensive studies of many ecological parameters for one part of the salt spray gradient, as done by Van der Valk (1974a) for a foredune grass community and Art (1971) for a single study plot in the maritime forest, or by monitoring fewer ecological factors but doing so over the entire gradient of atmospheric inputs. In the current study, the second approach was adopted, and it is hoped that the results reported here will be used as a "launching pad" for research projects concerned with determining various aspects of maritime strand mineral budgets. Through this type of research, a mechanically and descriptively valid working model of mineral inputs, cycling, and outputs can be developed for the entire salt spray gradient.

This work differs from other studies by examining the gradient of minerals in atmospheric inputs into the canopy, throughfall to the forest floor, and percolation losses along a transect from foredune to sound on a barrier island. This is also the first research concerning the inputs and outputs of minerals for a maritime forest in the southeastern United States.

Commercial development and highway construction, by removing vegetation cover, are undoubtedly exposing remaining forest species to environmental stress factors such as increased temperatures and levels of toxic ions not usually encountered. Increased deposition of toxic salts and greater temperatures at the forest floor may damage understory species and less tolerant canopy species. In areas where extensive clearing of vegetation has occurred, exposure of sandy soil to elevated temperatures would probably result in depletion of fresh water from surface soils owing to increased evaporation. The effect of such clearing of a maritime forest on a barrier island's water table needs to be investigated. Removal of protective vegetation can also cause substrate destabilization resulting in blowouts.

Components of maritime forest ecology that demonstrates the importance of the ecosystem to barrier island stability include: (1) the capacity of the trees to function as a buffering force against violent winds, (2) substrate stabilization, (3) the lower summer temperatures existing beneath the canopy which may reduce evaporation of ground water, and (4) the supply of organic matter to the sandy soils. These functions, in addition to the aesthetic quality of the seemingly sculptured contours of the canopy, make it clear that this ecosystem is one of the Outer Banks' most valuable natural resources. Therefore, an understanding the balance of forces controlling this community is a necessary prerequisite for ecologically sound management of the Outer Banks.

It has been pointed out that sedentary biogeochemical cycles in maritime strand areas are greatly influenced by oceanic salt spray. Since salt spray was known to form a gradient of inputs across a barrier island, a modification of the hydrological techniques employed in nutrient budget studies of inland forested watersheds was felt to be in order. It was the main purpose of this study to quantify the gradient of atmospheric inputs of several important minerals and to compare this salt spray gradient with storage of the minerals in the organic and inorganic soil compartments. With the forest assumed to be at steady state, such input and storage measurements would allow estimation of any leaching outputs from the ecosystem. In addition, it was felt that if regression equations for the prediction of atmospheric inputs across the island could be developed, then a means of monitoring the salt spray gradient using fewer stations would be available for other workers interested in salt spray driven biogeochemical cycles in the maritime strand.

ORIGIN OF BARRIER ISLANDS

As stated by Art (1971) there are two widely debated theories of barrier island origin. One is the deBeaumont theory of barrier island formation by emergent sand bars produced by a falling sea. The other theory ascribes the islands' formation to submergent shorelines based on the absence of marine sediments in the sounds and bays on the mainland side of barrier islands (Hoyt 1967). Although this question of emergent or submergent shorelines largely remains unresolved, two undeniably important processes of barrier island accretion and erosion are longshore currents and on-off shore currents (Art 1971). These processes probably account for most of the changes in barrier islands over geologically short time periods.

Olson (1958) related the characteristic dune and swale system of beaches to interaction between vegetation and sand laden winds. Pioneer beach grasses must continue to grow even with intermittant burial, until an equilibrium between dune height and the capacity of the wind to carry sand is reached. At this equilibrium point, the dunes will cease to increase in height from wind carried sands.

Once such a balance between dunes, vegetation, and wind is reached; community succession guided by edaphic soil factors and patterns of salt spray inputs proceeds to a series of polyclimax communities (Oosting 1954). Where environmental factors allow establishment of shrubs and forest, increased stability of dune sands and addition of organic matter to the generally nutrient poor dune soils results.

The groundwater of barrier islands is described as a lens of fresh water suspended on salt water due to differences in specific gravity. The flow of water in the lens is down at the center, then up along the lens edge, with subsequent discharge into the ocean (Harris 1967). Such water flow prevents the inward diffusion of sea water and its associated mineral nutrients into the vegetation zone of barrier island soils (Art 1971).

Coarse dune sands allow high water percolation rates which may result in water stress in many of the vegetation communities of barrier islands (Oosting and Billings 1942, Oosting 1954, and Art 1971). However, without rapid vertical movement of water, it is conceivable that toxic quantities of salts from atmospheric inputs, could accumulate in soils. Harris (1967) found a wedge of low permeability sediment on the ocean side of Hatteras Island, North Carolina to contain as much as 1500 ppm chloride.

DESCRIPTION OF STUDY SITE

The Roosevelt Natural Area at Pine Knoll Shores, North Carolina is a 8.9 ha tract of land extending from U.S. Highway 58 to Bogue Sound. This study was conducted in the shrub thicket bordering the Natural Area on the ocean side and in the maritime forest of the Natural Area.

Bogue Banks has a south facing beach with the foredune elevation averaging 4.9 m above mean sea level in the vicinity of the study site. The width of the island from the ocean to the last sampling station on the edge of Bogue Sound is 881 m. The area is a series of parallel relict dunes with intervening swale areas that are inundated with fresh water much of the year. The highest point of elevation along the study transect is 6.1 m occuring on a relict dune 260 m from the ocean. Therefore, the study area conforms to the typical concept of the dune-swale system of a relatively low foredune with gradiation to a somewhat higher secondary dune(s) (Oosting 1954).

The annual mean temperature at Beaufort, near the study site, is 17.6°C. July has the highest mean temperature of any month at 26.6°C. Prevailing winds are onshore from the southwest, except for the months of September, October, and November when winds come from the north or northeast (Oosting and Billings 1942). The mean annual rainfall for the Morehead-Beaufort area is 137.4 cm (Hardy and Hardy 1971).

A shrub thicket extends from immediately behind the foredune to about 165 m from the storm beach scarp. From that point on for about 515 m a _Quercus laurifolia_, _Q. virginiana_ maritime forest dominates the dry areas while *Fraxinus tomentosa* dominates flooded swales. There is an abrupt transition from forest to *Juncus-Distichlis* salt marsh about 700 m back from the ocean and this extends the remaining 181 m out to Bogue Sound. Part of the Natural Area, including the study transect, has a strip of maritime forest directly bordering the Sound.

TOPOGRAPHY OF THE STUDY TRANSECT

Materials and Methods

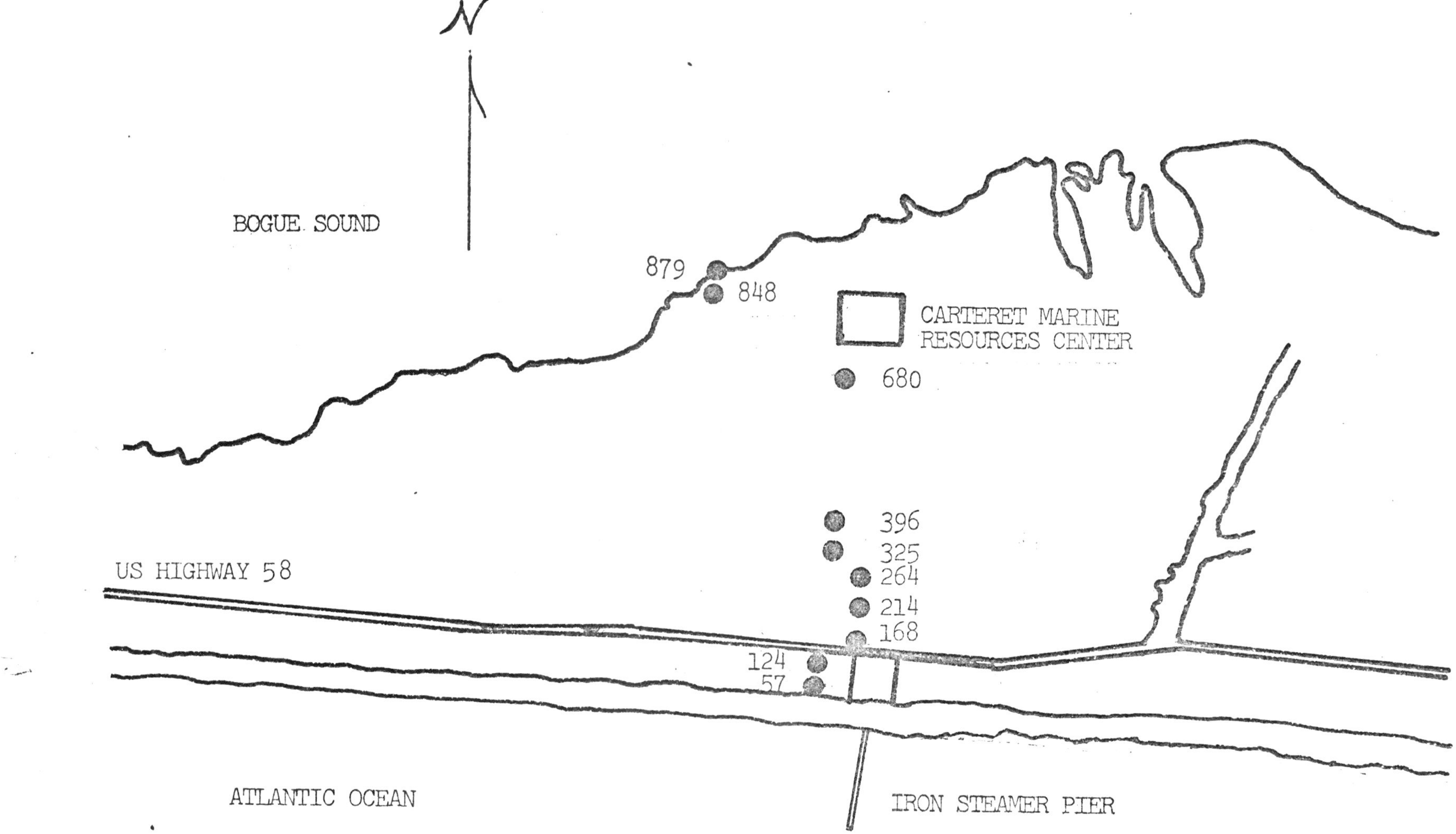
In June of 1975 elevations above mean sea level and distances from the ocean were determined at the stations along the study transect using standard surveying techniques and equipment. By comparing the surveyed distances and elevations to a topographical map of the study area compiled by Piedmont Aerial Services, Inc. in 1964 the stations were accurately located on the map (see Fig. 1).

Results and Discussion

Distances from the ocean and elevations above mean sea level are given for all stations in Table 1. For the remainder of this report, stations will be identified by their distance from the ocean in meters. Behind the foredune there are a series of parallel relict dunes of varying elevation. Between the dunes there are three swale areas (Stations 325, 488, and 625) which are innundated by standing water much of the year, especially during the colder months.

As noted by Oosting (1954) and Martin (1959), topography is a major ecological factor in barrier island plant community ecology since important environmental parameters, such as soil moisture, temperature, and salt spray change in accordance with topographical variation. The topographic information presented in Table 1 will be discussed in a later section concerning atmospheric inputs in order to evaluate the relationship between inputs of chloride, calcium, and magnesium and island topography.

Fig. 1. Location of study stations. Numbers indicate the distance of the station from the ocean in meters.



SCALE 0.8 CM = 100 M

Table 1. Distance from the ocean and elevation above mean sea level (MSL) of all stations along the transect

Distance from ocean (m)*	Elevation above MSL (m)
57	2.13
124	4.58
168	5.28
214	2.78
264	6.30
325	0.41
396	1.35
488	0.29
564	1.70
625	0.32
680	3.65
747	0.14
848	0.14
879	0.71

*Stations are numbered according to their distance from the ocean in meters.

ATMOSPHERIC INPUTS OF RAIN WATER AND DISSOLVED MINERALS

Materials and Methods

In November 1974 bulk precipitation collectors were installed at canopy level at seven stations along a transect across Bogue Island from the foredune to the sound. Also two bulk precipitation gages were placed in the Juncus-Distichlis salt marsh on the sound side of the maritime forest. The collectors consisted of a 7.0 cm diameter funnel connected to a one-liter polyethylene bottles by tygon plastic tubing. This apparatus was attached to a wooden stand that was subsequently nailed and/or lashed into a tree in such a manner that the funnels were at canopy level. In the salt marsh, the wooden frames were driven into the peat until the funnels were approximately 1.5 m above the marsh surface.

On 3 February 1975, bulk precipitation collectors were mounted at two new stations, one in the shrub thicket 124 m from the ocean and the other in the maritime forest 264 m from the ocean. Another gage was installed at canopy level 396 m from the ocean in August 1975. The location of all stations where bulk precipitation inputs were monitored are shown in Fig. 1. The displacement of the transect between Stations 680 and 747 was necessary because of the Carteret Marine Resources Center construction site in the Natural Area.

After the first year of sampling, collections at Stations 214, 325, and 625 were discontinued since the collection trees at these stations were extremely difficult to climb, and therefore nearly impossible to sample without assistance. In fall 1975 one of the collectors in the *Juncus-Distichlis* marsh was destroyed during a storm and this station (747) was not replaced. Vandals destroyed the collector nearest the ocean at Station 57 in October 1975 forcing relocation to another tree approximately the same distance from the ocean.

Rainfall volume and chloride content were monitored throughout the study from 3 November 1974 to 7 June 1976. Calcium determinations were made on samples taken over the second study year, 26 June 1975 to 7 June 1976. Analyses of magnesium were made on collections taken from 25 October 1975 to 7 June 1976.

As reported by Gambell and Fisher (1966), microbiological alteration of chemical composition in bulk precipitation is significant for nitrate and ammonium but not for dissolved macronutrient cations. Based on these findings no action was taken to retard microbial growth within the bulk precipitation gages.

Due to wind damage to collectors during storms, occasional partial blockage of a funnel with organic matter, and acts of vandalism, the number of gages sampled for rainfall on any given date varied over the study period. Samples were still taken for chloride, calcium, and magnesium (hereafter referred to as Cl, Ca, and Mg respectively) analysis when possible from the damaged collectors and the mean rainfall volume for all other gages during the particular period was used to estimate total ion inputs. When samples could not be collected, the mean concentration of the dissolved minerals over the study year for that collector and the mean volume of rainfall over the particular sampling period were used to compute mineral inputs. The same general procedure of mean concentration and mean volumes was used to extrapolate Mg inputs from the 224 days actually measured to an annual figure.

Total volume of rainfall in bulk precipitation gages was measured in the field and samples were transferred to polyethylene bottles that had been washed in 2% HNO_3 and rinsed three times with distilled water. Upon return from the field all samples were filtered to remove particulate matter and were refrigerated at 0-4 C until chemical analyses could be carried out.

Chloride was determined by the Mohr titration method (Harris and Kratochvil 1969). In this technique, 10 ml of the sample solution was titrated with 0.014 N $AgNO_3$ using a 0.01 N K_2CrO_4 as an indicator. Cations were determined using a Perkin-Elmer 305B atomic absorption spectrophotometer. To minimize interferences from other minerals, appropriate amounts of La_2O_3 were added to the aliquots to be tested for cations (Perkin-Elmer Corp. 1968).

Results and Discussion

Rainfall and Dryfall Inputs

Rainfall was relatively uniform along the 881 m transect as shown by a mean percent deviation of the standard error from the mean volume of only 5.4 (Table 2). Some workers recommend that shields be used on rain collectors located at canopy level to prevent (or reduce) variation in amounts of water collected when high winds occur (Leyton et al 1969). However, the low percent deviation reported in the present study seems to confirm the conclusion of Helvey and Patric (1965) that no significant difference in collection efficiency occurs between gages on the ground and ones situated at canopy level.

Over the first study year, 8 December 1974 to 6 December 1975, 138 ± 8.3 cm of rainfall were recorded. For the second year, 26 June 1975 to 7 June 1976, the annual rainfall was 124 ± 7.2 cm. A mild drought which occurred in the spring of 1976 may account for the smaller quantity of total rainfall and certainly reduced the frequency of collections over the second year. These values for rainfall agree well with the mean precipitation over seventy years for the Morehead-Beaufort, North Carolina area of 137 cm or 54.1 in of rainfall (Hardy and Hardy 1971).

Table 2 shows patterns of rainfall in the study area over the first and second study years respectively. The greatest amounts of rainfall were found in summer and early fall, winter months have the lowest, and spring has quantities somewhat intermediate between those of summer and winter.

Table 2. Mean quantities of rainfall in bulk precipitation gages over each sampling period.

Date collected	Number of gages	Number of days	Mean cm rain	Standard error as % of mean	mm rain per day
28 Dec 74	9	20	4.98(0.23)*	4.7	2.49
2 Feb 75	8	36	13.29(0.60)	4.5	3.69
2 Mar 75	9	28	15.13(0.51)	3.4	5.40
23 Mar 75	11	21	4.75(0.22)	4.6	2.26
27 Apr 75	11	35	11.56(0.45)	3.9	3.30
3 Jun 75	10	37	14.49(0.76)	5.2	3.92
26 Jun 75	10	23	12.18(0.84)	6.9	5.30
13 Jul 75	10	17	20.21(1.29)	6.4	11.89
1 Sep 75	9	39	11.41(0.88)	7.7	2.93
28 Sep 75	5	27	16.72(1.87)	11.2	6.19
25 Oct 75	7	27	8.63(0.55)	6.4	3.20
6 Dec 75	10	42	4.74(0.23)	4.8	1.13
21 Jan 76	8	46	18.94(0.86)	4.6	4.11
11 Feb 76	6	21	10.75(0.71)	6.6	5.12
6 Apr 76	8	57	8.58(0.32)	3.4	1.48
7 Jun 76	7	62	24.10(0.48)	2.0	3.89
			Average % deviation of Standard error from mean	5.4	

*Values in parentheses are one standard error from the mean.

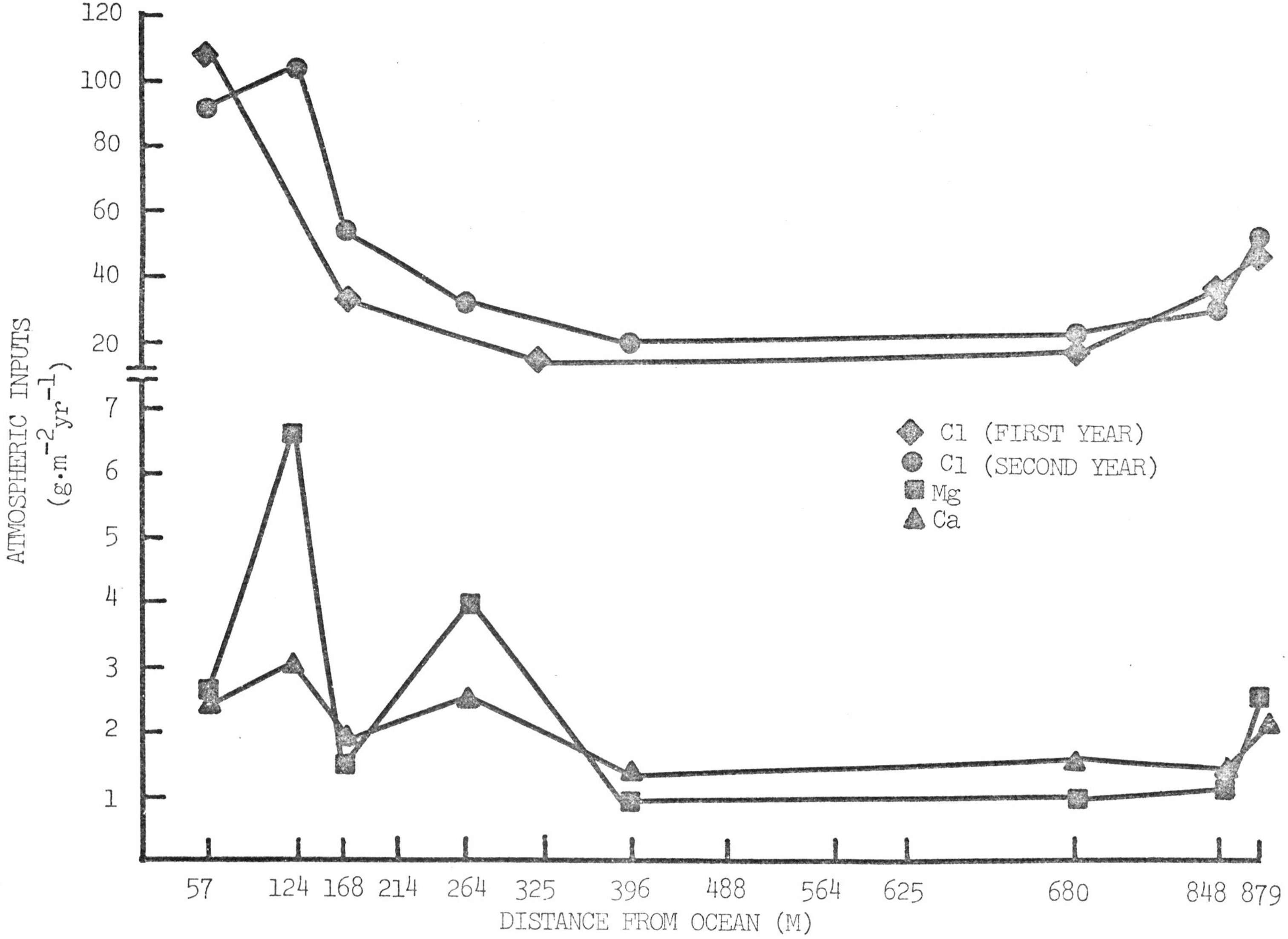
The mineral content of rainfall collected by continuously open gages represents bulk precipitation since dry fallout in the forms of dust and aerosols enters the collector along with the rain (Whitehead and Feth 1964). In coastal ecosystems most of the dryfall is in the form of salt spray aerosols (Art 1971 and Van der Valk 1974a).

The ionic concentrations in bulk precipitation at each station over the two study years are given in the Appendix, Table A. The highest concentrations of Cl, Ca, and Mg occurred near the salt spray sources, the Atlantic Ocean and Bogue Sound. Total annual concentrations of Cl for the two years agree well.

The annual atmospheric inputs of Cl for the study periods 8 December 1974 to 6 December 1975 and Cl, Ca, and Mg for the year 26 June 1975 to 7 June 1976 are given in the Appendix, Table B and illustrated in Fig. 2. The annual patterns of atmospheric inputs show generally decreasing trends with increasing distance from the ocean back to Stations 325 and 396. Then increasing mineral inputs for Stations 680, 848, and 879 were observed as Bogue Sound became increasingly more important as a salt spray source.

The small peak of salt inputs at Station 264 occurred because this station was located on the highest point of elevation of the transect, 6.3 m above mean sea level. Although salt spray inputs decrease with increasing distance from the ocean, they also increase to a point with increasing height in the air column due to greater wind velocities (Boyce 1954). The height in the air column at which salt intensities cease to increase further was not known, but is evidently higher than any point of elevation

Fig. 2. Annual meterologic inputs of Cl along the transect (over both study years) and of Ca and Mg (over the second study year).

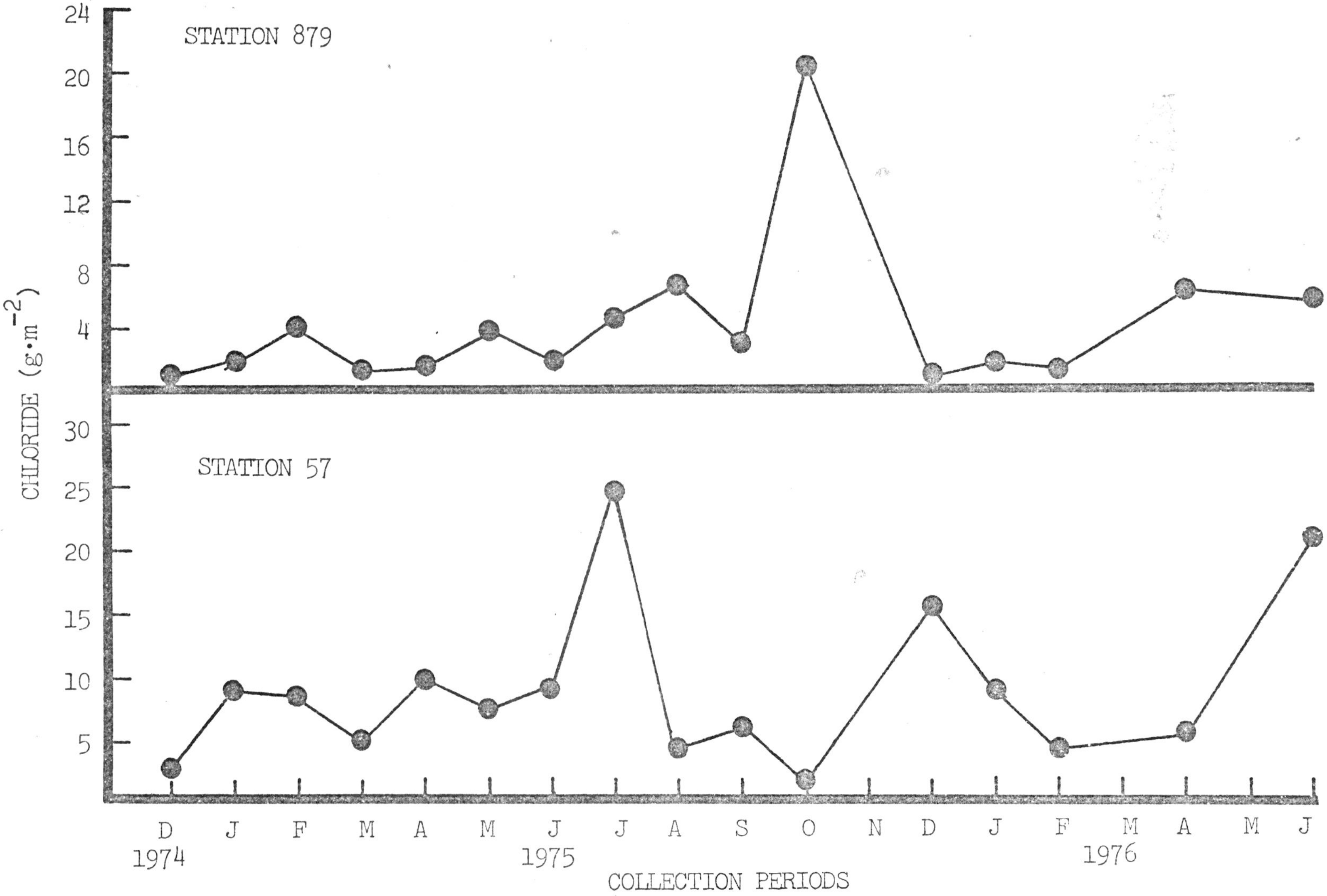

120
100
80
60
40
20
7
6
5
4
3
2
1
ATMOSPHERIC INPUTS
(g·m^{-2}yr^{-1})
57
124
168
214
264
325
396
488
564
625
680
848
879
DISTANCE FROM OCEAN (M)
◆ Cl (FIRST YEAR)
● Cl (SECOND YEAR)
■ Mg
▲ Ca

along the transect as will be shown by the prediction equations later.

It is important to note that much of the annual atmospheric input of salts into the system comes during relatively short intervals often associated with periods of high wind velocity. Because of the orientation of the island with the beach facing almost due south, winds off the ocean often come out of the south and southwest. Similarily, prevailing winds from the north and northeast come across Bogue Sound before reaching the island. Figure 3 shows the pattern of inputs of Cl into Station 57, the sampling station nearest the ocean, and Station 879, immediately adjacent to the sound. Peak inputs near the ocean generally corresponded to only small input from the sound side. This pattern occurred because inputs at Station 57 are dependent on winds from the south or southwest such as occurred during collection periods 26 June 1975 to 13 July 1975 and 6 April 1976 to 7 June 1976. However, winds from the north can form salt spray from the sound and thus Station 879 had its highest input of Cl during sampling period 28 September 1975 to 25 October 1975 while for Station 57 this same period produced the lowest inputs of Cl recorded.

Figure 2 reveals that all three ions monitored also followed the same general pattern of deposition across the island. The patterns for Cl, the major anion in the sea, and Mg, the second most abundant cation in sea water, were very similar. Ca, being a minor constituent of sea water, exhibited only small fluctuations in meterologic input between stations close to a salt spray source and stations more isolated from oceanic aerosols.

Fig. 3. Atmospheric inputs from December 1974 to June 1976 at Stations 57 (station nearest the ocean) and 879 (station nearest the sound).


STATION 879
STATION 57
CHLORIDE (g·m^{-2})
24
20
16
12
8
4
30
25
20
15
10
5
D
J
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
1974
1975
1976
COLLECTION PERIODS

In inland systems atmospheric inputs of Ca are often greater than those of Mg since there are larger amounts of Ca in rainfall and agricultural dust than Mg (Gambell and Fisher 1966, Likens et al 1967, and Johnson and Swank 1973). However, near the sea, the greater absolute amount of Mg in salt spray causes this ion to occur in higher concentration in bulk precipitation (Van der Valk 1974a). The results graphed in Fig. 2 illustrate the variation in inputs from Stations 57-264, where Mg and thus salt spray dominate the cation inputs to Station 396, 680, and 848 where Ca inputs are greater than the Mg inputs possibly because of agricultural dust dry fallout. These data agree with the results of Gambell and Fisher (1966), who report a mean Mg concentration of less than 0.2 ppm in the rainfall of eastern North Carolina and southeastern Virginia. However, their data from coastal stations show Mg concentrations equal to or slightly higher than those of Ca.

Based upon the concentrations of Cl, Ca, and Mg in rainfall given by Gambell and Fisher (1966) quantities of ions resulting from rainfall and salt spray in bulk precipitation at each station were determined. Gambell and Fisher believe that their data was not influenced to a great extent by dryfall because little variation was encountered in concentrations of samples collected over their study and since their data provided values similar to those reported by Juang and Werby (1958) who used collectors that were open only during rainfall and thus excluded most dryfall.

By averaging the concentrations in rainwater given by Gambell and Fisher (1966) for several selected sites on the North Carolina Outer Banks, values of 7.49, 0.75, and 0.76 $mg \cdot l^{-1}$ (for Cl, Ca, and Mg respectively) were obtained. Near the sea, bulk precipitation tends to have a higher concentration of Mg than Ca. Therefore rainfall alone cannot account for the relatively higher inputs of Ca than Mg observed at some stations somewhat isolated from salt spray sources. This anomaly will be discussed below.

Appendix Table B compares the relative concentrations of ions in bulk precipitation arising from rainfall and dryfall. The concentration of each ion derived from rain was calculated from the rainfall concentrations given above and the mean annual volume of rainfall as recorded in the present study. The annual rainfall inputs of Cl, Ca, and Mg were thus estimated to be 9.28, 0.93, and 0.94 $g \cdot m^{-2}$ respectively. For the first year the annual amount of Cl derived from rainfall was 10.4 $g \cdot m^{-2}$.

From the Appendix Table B it is evident that the percent Cl derived from salt spray at each station varied little between the two study years. However, in response to an intense early summer storm in 1976, stations near the ocean accumulated greater quantities of salts the second year.

The distinct increases in Ca input near the ocean and the sound indicated that salt spray inputs of Ca increased the total Ca inputs above the base line agricultural dryfall for these parts of the forest. However, the quantities so derived from salt spray were small compared to Cl and Mg inputs. For Mg, the total atmospheric inputs due to dryfall dropped from 64.6% of the total at Station 57 to only 4.8% at Station 396. This implies that salt spray and rainfall are the sources for most of the Mg input into the forest. Conversely, at Station 396 where there was only 4.8% dryfall input of Mg, the amount of Ca from dryfall sources was 32.7% of the total Ca input. This implies either another source of Ca, such as agricultural dust, or lends support to the hypothesis that fractionation of sea salts occurs in salt spray, which is supported by data given by Clayton (1972) who reported increases of Ca relative to Mg. Also supporting fractionation of sea salt nuclei theory is the finding that at Station 396, 53.7% of the Cl was due to dryfall, which for Cl is undoubtly salt spray aerosols. However, even though there may be some increase in Ca relative to Mg resulting from salt spray fractionation, the uniformity of Ca inputs across the transect indicates that another source of Ca exists which provides for more even distribution across the island. Agricultural dust (Gambell and Fisher 1966), is probably the extra source responsible for most of the dryfall inputs of Ca.

Van der Valk (1974a) proposed that mollusk shell fragments may have accounted for increased levels of Ca found in his bulk precipitation gages; however, Van der Valk's collectors were located behind the foredune with funnels close to the ground, whereas in the present study the funnels were at canopy level and gages were never observed to contain any shell or sand particles.

Results given in Fig. 3 indicate that for Stations 57, 124, 168, 214, and 264 inputs of Cl and Mg were dominated by oceanic salt spray. At Stations 325 and 396, salt spray from the ocean was still the main source of Cl, but rainfall dominated the Mg inputs. Salt spray from Bogue Sound contributed the majority of Cl at Stations 680 and 848 while rainfall still dominated the Mg input. Salt spray from Bogue Sound was the major source of both Cl and Mg at Station 879. For Ca, rain and dust were responsible for most of the inputs except for those stations most directly under the influence of salt spray (57, 124, and 879).

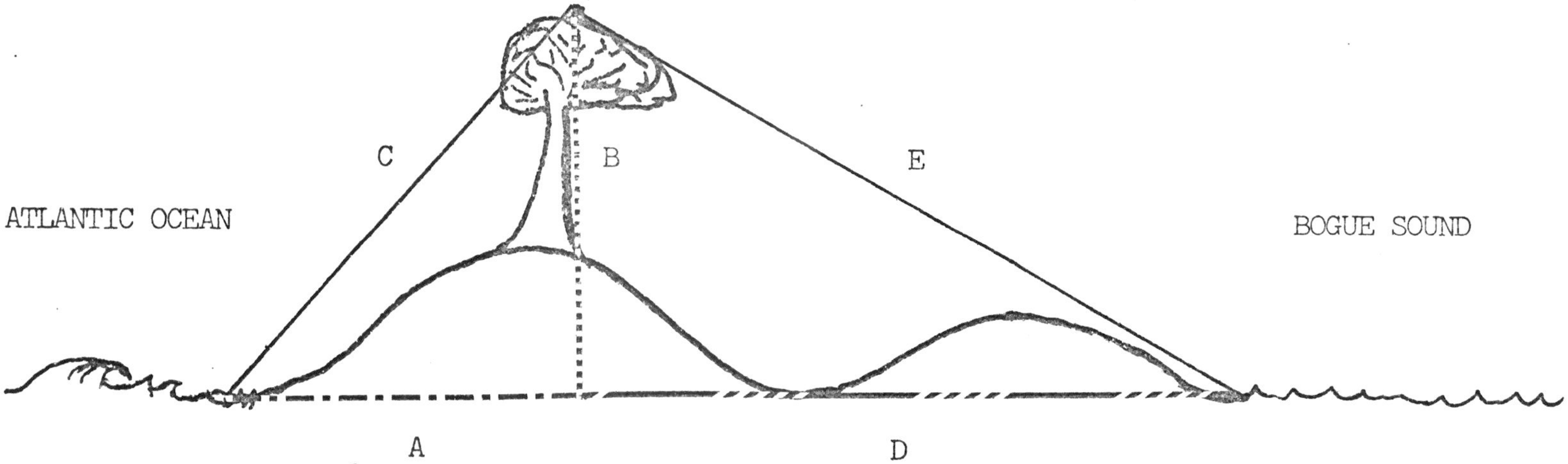
Prediction of Salt Spray Inputs

Although the relationship between atmospheric inputs of salt and barrier island topography is exceedingly complex, equations that describe the pattern of inputs across a barrier island would be of great help in studies of salt spray driven biogeochemical cycles. Regression equations were developed in this study that predict annual atmospheric inputs of salts for any station along the study transect when the station's distances from the ocean and sound, and elevation above mean sea level are known. Although the equations are valid only for the transect studied, they probably could be used to obtain reasonable estimates of inputs at most locations on Bogue Banks. Prediction equations could be developed for other barrier islands using methods comparable to those of this study.

To calculate the topographic index, each station was depicted by two triangles having sides ABC and DBE (Fig. 4). In the first of these triangles "A" was the distance of the station from the ocean in meters, "B" was the elevation of the collector above mean sea level (expanded by 100 X), and "C" was the hypotenuse of the triangle (calculated from "A" and "B"). In the second of the triangles at each station "D" was the distance of the station from the sound in meters, "B" again was the elevation X 100, and "E" was the resulting hypothenuse. Elevations were expanded by 100 X in order to accent the differences between distance of stations from salt spray sources and the resultant hypothenuse.

The topographic index for a station was described by the equation $C/A + 0.078\ E/D = TI$. The C/A term is a partial topographic index that

Fig. 4. Diagram of barrier island profile illustrating how the topographic index (TI) for a particular station was calculated.



TOPOGRAPHY INDEX AT A STATION = C/A + 0.078E/D

A= DISTANCE OF THE STATION FROM THE OCEAN (M)

B= ELEVATION OF GAGE ABOVE MEAN SEA LEVEL (M) X 100

D= DISTANCE OF THE STATION FROM THE SOUND (M) will be shown to be linerally related to the influx of salt spray into a station from the Atlantic Ocean (Table 3). The E/D term will be shown to be directly related to the input of salt spray along the transect from Bogue Sound. When the two partial topographic indices for a station are combined to yield the TI for that station, it is necessary to have a term that relates the intensities of salt spray from the ocean and the sound.

The relative intensities of salt spray from the ocean and sound were not directly measured in this study and thus have been estimated in the following manner. The transect was divided into two parts based on which salt spray source (ocean or sound) dominated the annual inputs of Cl. Stations 57, 124, 168, and 264 observed over the second study year fell mainly under the influence of oceanic salt spray (Fig. 2), while Stations 879, 848, 747, and 680 probably received a major portion of Cl from Bogue Sound salt spray. Station 396 had the lowest annual salt spray inputs and so probably receives little Cl from either source.

The first portion of Table 3 gives the linear regression analysis of annual Cl inputs with the partial topographic indices (C/A) for stations mainly under the influence of oceanic salt spray. The next part of Table 3 is similar regression analysis for stations under the major influence of the sound, for these stations the partial topographic indices are defined by E/D. Results significant at P = 0.05 were obtained from both sets of analyses.

The relative intensities of salt spray from the ocean and the sound were estimated by comparing the annual inputs of Cl at two sites, one

Table 3. Regression analyses between topography and atmospheric inputs are given. Part 1 considers Stations 57, 124, 168, 264, and 396 (under the major influence of salt spray from the Atlantic Ocean). Part 2 considers Stations 879, 848, 747, 680, and 396 (influenced mainly by salt spray from Bogue Sound). Elevations are in meters X 100. Atmospheric inputs are in g $Cl \cdot m^{-2}yr^{-1}$.

Part 1

Station DIST. OCEAN	ELEVATION	HYPOTENUSE OF ABC	PARTIAL TI (C/A) x	Second year ATMOS. INPUTS y
57	213	220.5	3.8683	92.2
124	458	542.4	4.3740	104.0
168	528	554.1	3.2981	54.6
264	630	683.1	2.5874	32.9
396	135	418.4	1.0565	20.0

r = 0.93, b = 0.0329, m = 1.0390, t = 4.405, P = 0.05

$Y_p = 60.79 + 0.0329(X - 3.3069)$ EQUATION ONE, x = partial TI
y = Atmos. inputs

Part 2

DIST. SOUND	(STATION)	ELEVATION	HYPOTENUSE OF ABC	PARTIAL TI (E/D) x	Second year ATMOS. INPUTS y
3	(879)	71	71.1	23.6880	53.6
34	(848)	14	36.8	1.0814	31.9
134	(747)*	14	134.7	1.0054	19.3
202	(680)	365	417.2	2.0652	24.0
486	(396)	135	504.4	1.0379	20.0

r = 0.94, b = 1.3315, m = 22.08, t = 4.6090, P = 0.05

*This station was not monitored over the second study year so atmospheric inputs are for the first year.

immediately adjacent to Bogue Sound and the other next to the Atlantic Ocean. The site next to the sound was Station 879 (E/D = 23.6880, annual Cl inputs = 53.64 $g \cdot m^{-2}$). However, no comparable station near the ocean existed for comparison of inputs with those near the sound. Thus it was necessary to estimate the atmospheric Cl inputs for a site near the ocean having a partial topographic index (defined by C/A) equal to 23.6880. In other words, a site was picked near the ocean that had a partial topographic index (C/A) equal to the partial topographic index of Station 879 (defined by E/D) which is immediately adjacent to the sound. The annual Cl inputs for this station near the ocean were calculated from the prediction equation (equation 1, Table 3) developed in part one of Table 3, $Y_p = 60.79 + 0.0329(X - 3.3069)$. E/D = 23.6880 was substituted into the prediction equation (above) for X which resulted in the estimated annual inputs for the site near the ocean being $Y_p = 689\ g \cdot m^{-2}$. Thus the ratio of intensities of salt spray from the ocean and the sound can be estimated as follows:

Site near ocean (C/A = 23.6880)	Site near sound (E/D = 23.6880)	ratio
689 g $Cl \cdot m^{-2} yr^{-1}$	53.6 g $Cl \cdot m^{-2} yr^{-1}$	0.078

The equation for calculating the TI of Bogue Banks stations thus is C/A + 0.078 E/D. From this equation, the TI for each station was computed. The results of linear regression for the entire transect between atmospheric inputs of Cl over the second study year and TI were: $r = 0.94$, $P = 0.05$, $Y = 21.91 X - 5.48$ (Appendix, Table C). In all regression equations given in analysis of the relationship of topography and atmospheric inputs, "X" is the independent variable TI and "Y" is the dependent variable atmospheric inputs.

Analyses of Cl over the first study year and Ca and Mg over the second year are given in Tables D - G.

Only stations that were monitored over an entire year were used in regression analyses with the topographic indices. This practice eliminated the loss of accuracy associated with extrapolation of inputs to an annual figure at stations which for one reason or another were not monitored for a full year. Since it has been shown that much of the annual inputs for stations in the major zone of salt spray come in storm pulses, it would be difficult to estimate annual atmospheric inputs using mean concentrations and yearly volume totals of rainfall. Therefore Stations 124 and 264 were not considered in the first study year's Cl regression analysis, while Stations 214, 325, and 848 which were monitored over the first study year were included. The results of the first study year Cl analysis were: $r = 0.80$, $P = 0.05$, $Y = 20.77X - 3.12$ (Appendix, Table D). Although the correlation coefficient is not as high for the first year as for the second, the slopes of the regression lines are similar.

Regression analyses also yielded significant results for atmospheric inputs of Ca and Mg (Appendix, Tables E and F). For Ca, the results were: $r = 0.88$, $P = 0.05$, $Y = 0.40 X + 0.98$. For Mg, findings were as follows: $r = 0.75$, $P = 0.05$, $Y = 1.11 X - 0.26$.

In order to further test the relationship between the topographic factors and atmospheric inputs of salts, data given by Martin (1959) including distance from the ocean, elevation above mean sea level, and salt input, were used in the same type of calculations as described above.

Martin, however, only had his salt collectors in operation for short periods of time and only when winds were onshore. Therefore the TI is defined by C/A alone since any inputs from the sound were negligible under these conditions.

Data on elevation, given by Martin in feet, was converted to meters and expanded by 100 X. Atmospheric inputs were converted from $mg \cdot dm^{-2}$ to $g \cdot m^{-2}$ in order to facilitate comparison with the present study. The topographic indices and linear regression analyses are presented in the Appendix, Table G for Martin's transects I, II, IV, and VI where collections of salt were made at canopy level. Transects III and V (in non-forested areas) had dual collectors one foot and three feet above the ground at each station. The total salt catches of six "runs" for both heights were used in the regression analyses. The correlation coefficients of TI with atmospheric inputs at canopy level for Martin's transects were: Transect I ($r = 0.89$, $P = 0.01$), Transect II ($r = 0.75$, $P = 0.05$), Transect IV ($r = 0.95$, $P = 0.01$), and Transect VI ($r = 0.94$, $P = 0.01$). Correlation coeffieients for transects with dual collectors at one foot and three feet above the ground (in areas where there were no trees) were significant at each height at $P = 0.05$ except the one foot height for Transect III which was significant only at $P = 0.10$. The total salt catch of six "runs" was used for Transects III and V. These data reveal that the relationship between the TI described here and atmospheric inputs is not limited to any unique situation existing on Bogue Banks but can be applied to other barrier islands.

The equation for calculation of the topographic index ($TI = C/A + 0.078\ E/D$) must be adapted to each barrier island individually. The intensity factor (0.078) will vary with the degree of fetch across a bay or sound, salinity of the water and the direction and intensity of the prevailing winds. Therefore, the ratio of the intensity of salt spray from the sound (or bay) to that from the ocean must be determined for each island. Also by the same reasoning, the regression equations presented here for predicting the atmospheric inputs of Cl, Ca, and Mg on Bogue Banks would not accurately describe the inputs on many other barrier islands. For islands where the coastal orientation and annual wind patterns are similar to Bogue Banks, the equations would probably provide adequate estimates of inputs. However this method of developing the prediction equations is relatively simple. Therefore, equations capable of predicting the atmospheric input gradients should be developed for any barrier island where mineral cycling work is to be attempted.

The importance of this simple mathematical relationship between the topographic indices and atmospheric inputs of salts is its use for rapid calculation of salt spray inputs along a transect across a barrier island. By monitoring a few points along a transect from ocean to sound and knowing the topography of the transect, the pattern of atmospheric inputs along the rest of the transect can be estimated. The relationship between TI and atmospheric inputs can only apply to systems where two general rules hold: (1) with increasing height in the air column, there is also an increase in salt content of the air stream and (2) the elevations of the stations considered do not exceed the point in the air column at which there is no longer an increase in salt content with increasing height. Any mainland coastal ecosystem falling within the rules outlined above can probably have its atmospheric inputs estimated by the same technique. The relationship possibly holds also for other mineral constituents of salt spray (e.g. sodium and potassium). As stated by Zar (1974) equations are often used in science that are known to inaccurately represent natural processes, but are still helpful in prediction.

SOIL AND FRESH WATER TABLE ANALYSIS

Materials and Methods

From November 1974 through June 1975 mineral soil samples were taken at stations along the transect in order to determine the variation of Cl at different depths in the soil column in relation to atmospheric inputs of this ion. The humus and litter layers were removed and a soil auger, shielded by a length of graduated polyvinylchloride pipe 5 cm in diameter, was used to extract the soil in 15.2 cm (6 in) core segments. The maximum depth sampled in this manner was 152 cm (5 ft). In addition, samples of soil were taken from the fresh water table at several stations over this time period. In dry areas the water table was monitored using a PVC well, and at innundated swale stations standing water was sampled.

Soil samples selected for analyses were returned to the laboratory sealed in plastic bags. Wet weights were either measured immediately upon arrival at the laboratory or the samples were frozen until the analyses could be performed. Dry weights were measured after allowing soil to air dry for at least two weeks at room temperature in an air conditioned room. Samples were passed through a 2.0 mm mesh sieve to remove coarse debris. For Cl analysis, 200 g of dry sieved soil were mixed with 200 ml of distilled water, covered, and allowed to stand at room temperature for 24 - 48 h until solubility equilibrium was established. The water was filtered out and a 10 ml subsample titrated with 0.014 N $AgNO_3$ using 0.01 N K_2CrO_4 as an indicator (Harris and Kratochvil 1969).

On 2 February 1975 an experiment was performed to estimate the rate at which a large quantity of salt would be flushed through the forest soil. A 2.27 kg (5 lb) quantity of crushed rock salt was placed beneath the humus mat on the surface of the mineral soil over an area of one square decimeter at Station 264. The humus mat was replaced over the salt to minimize loss of Cl by above ground run off and to keep soil conditions as close to natural as possible. Initial and subsequent soil cores were taken at points termed 264 A, B, and C. Samples taken within a radius of 0.25 m of the site of salt emplacement were considered to be from site 264 A. Site 264 B was located 0.61 m down the dune slope from 264 A on the ocean side. Site 264 C was placed laterally 0.61 m equidistant from both 264 A and B. These sites were then monitored for a period of time following salt placement.

During the period 1 July 1975 to 2 July 1976, triplicate soil samples were taken as intact 30 cm deep cores, since this depth encompasses the major root zone of the maritime forest (Art 1971), at Stations 124, 264, 396 and 680. Also occasional soil samples from the fresh water table were taken at Station 214 and standing water at Stations 324 and 625. Individual soil samples were allowed to air dry and then were stirred to assure uniform mixture of a sample. Soil was then tested for dissolved Cl and dissolved and total available Ca.

One hundred grams of dry soil was mixed with 100 ml of deionized water.

After allowing 24 h for equilibrium to occur, the water was filtered and then assayed for soluble Cl using the method described previously. The water was also tested for soluble Ca using a Perkin-Elmer 305B atomic absorption spectrophotometer employing the same procedure discussed in the section on atmospheric inputs. A 5.0 g sample of the dry soil was mixed with 1 N ammonium acetate (adjusted to pH = 7) for determination of exchangeable Ca. As with the soluble samples, 2% LaO_3 was added to the exchangeable and soluble solutions.

In order to observe the storage of soluble Cl, Ca, and Mg in the humus and litter layer, a 10 dm^2 surface portion of the humus mat was collected at Stations 124, 264, 395, and 680 over the same time period that the intact 30 cm cores were taken. Upon return to the laboratory, the mats were placed in large bowls, pulled apart, and mixed with 1000 ml of deionized water. The bowls were covered and 24 h was allowed for equilibrium to occur. Then the water was removed, filtered, and analyzed for dissolved ions using methods described for bulk precipitation samples.

Results and Discussion

Chloride content of soils along the transect collected from various depths over the period 3 November 1974 to 29 May 1975 is presented in Table 4. There was seldom any appreciable amount of this element in the surface soils except in soils taken from the front of the foredune. The quantities of surface Cl remained at constantly low levels at the other stations. Atmospheric inputs presumably replaced losses by percolation.

There was no increase in Cl in soils at depths sampled. The absence

Table 4. Variation in soluble chloride with soil depth at selected stations. Values reported are μg chloride per g dry weight of soil.

STATION	DEPTH (cm)	1974		1975			
		3 Nov	8 Dec	2 Feb	3 Mar	27 Apr	29 May
57	surface	39.9	24.8	20.9	156.0	50.0	36.0
	15-31	31.4	19.9	49.7	14.9		32.3
	46-61	40.3			16.4	11.0	
	61-76	50.6					
	91-107					25.0	
	107-122	44.8					
	137-152	33.9					
168	surface			37.7	21.5	45.0	37.5
	0-15			11.9	4.0		
	15-31		26.3	13.4	4.0	29.0	20.9
	31-46			22.4	4.9		
	46-61		29.8	13.4	3.5	25.0	42.7
	61-76		28.3	14.4			
	76-91		34.8	19.9	13.4		
	91-107		29.8	27.3			
	107-122		39.8	30.3			
	122-152		37.3				
214	surface				39.3		34.7
	0-15				32.8		
	15-31				13.9		48.7
	31-46				19.9		
	46-61				14.9		

STATION	DEPTH (cm)	1974		1975			
		3 Nov	8 Dec	2 Feb	3 Mar	27 Apr	29 May
396	surface				48.2		31.8
	15-31				9.9		14.4
	46-61				9.9		30.3
680	surface				19.9		24.9
	0-15	12.4					
	15-31	11.9			11.9		17.4
	31-46	12.4					
	46-61	14.9					
	61-76	17.4					
	76-91	7.5					
	91-107	14.9					
	107-122	14.9					
879	surface		72.1		35.8		
	15-31		44.7		20.4		
	46-61				15.9		

of Cl accumulation in soils agrees with findings reported by Wells and Shunk (1938), Oosting (1954), Boyce (1954) and Martin (1959) who considered rapid leaching through a porus substrate as the explanation for low salt levels in coastal strand soils.

The elevation of water table depth above or below mean sea level and Cl content of soils taken from the fresh water table in non-flooded areas are presented in Table 5. The depth and ion content of standing water are given in Table 6. Most measurements of the water table at dry stations were taken over the period 3 November 1974 to 29 May 1975. Standing water depth and ionic content at Station 325 were monitored over the entire study. These data show that soils taken from the water table depth typically have only small amounts of Cl present. The Cl content of standing water in swale Stations 325 and 488 was generally higher than for stations where the water table was below the ground surface level. This was probably due to the direct exposure of standing water to atmospheric inputs of Cl, lower permeability of organic swale muds, concentration by evaporation, and aboveground runoff of Cl laden water from adjacent relict dunes. Swale Station 625 often exhibited unusually high Cl concentration compared to the rest of the fresh water table. The higher Cl content was likely due to a direct connection of this swale to Bogue Sound.

The depth of the ground water table on barrier islands fluctuates with rainfall, evaporation, and tidal activity (Harris 1967 and Art 1971). A net lowering of the water table over the period 3 November 1974 to 29 May 1975 was observed (Fig. 5).

Table 5. Elevation in meters above (+) or below (-) mean sea level of the fresh water table (and concentration of chloride) (at stations along the transect). The chloride content of soil from the water table of stations in non-flooded areas is given in μg· g soil $^{-1}$.

STATION		1974		1975						MEAN
		3 Nov	8 Dec	3 Mar	27 Apr	29 May	24 Jul	28 Sep	25 Oct	CONCENTRATION
57	DEPTH	-0.42	-0.12	+0.03						
	Cl	33.6		44.2					99.4	59.1
396	DEPTH	-0.76		+0.45	+0.45					
	Cl					34.8		32.3		33.6
564	DEPTH	-0.45	+0.53	+0.37		+0.35				
	Cl					19.9				19.9
879	DEPTH	-0.15		-0.20						
	Cl									

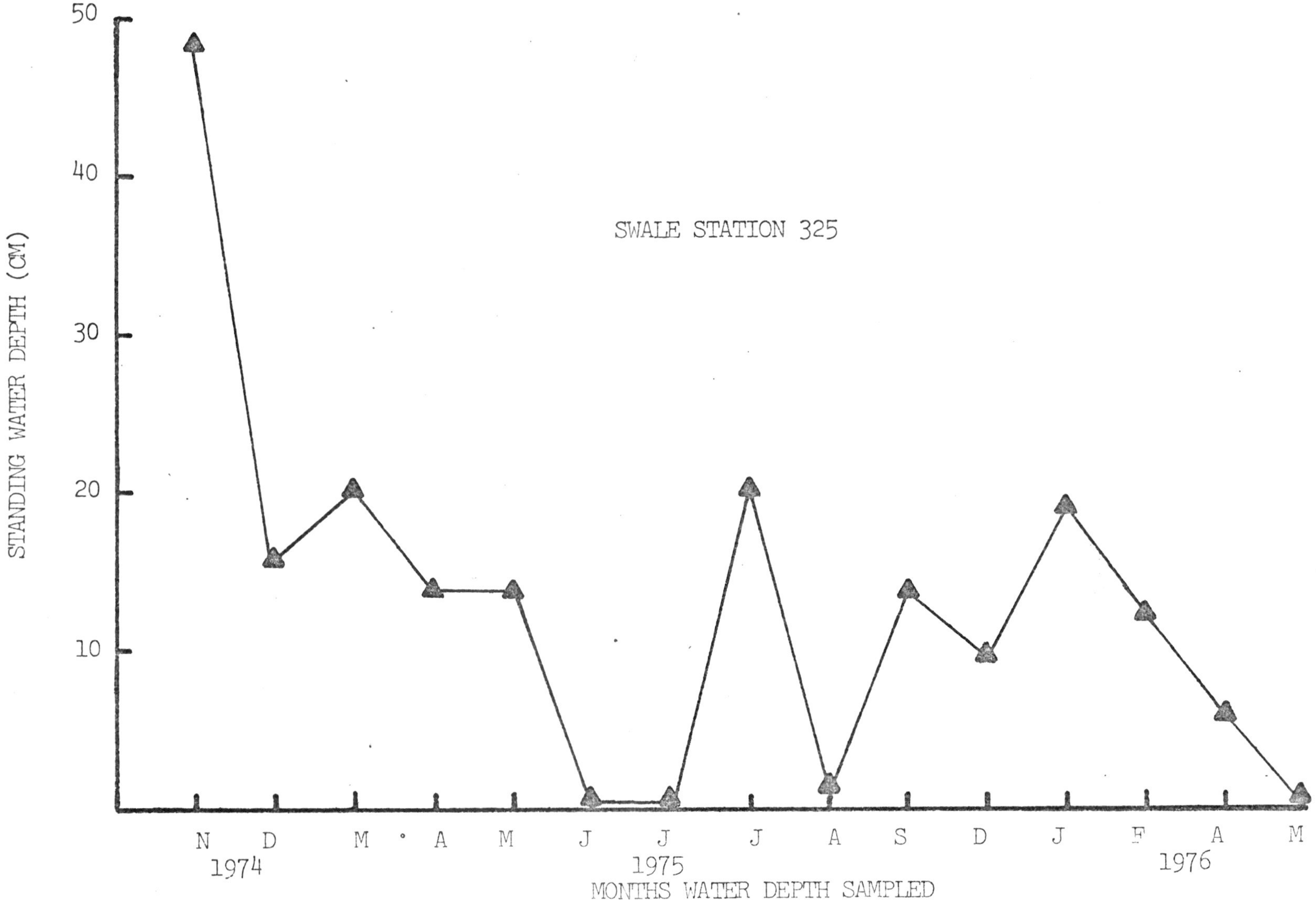
Table 6. The depth, chloride content, calcium content, and magnesium content of standing water swale Stations 325, 488, and 625. Water depth is in cm and all ion concentrations are in μg/ml.

Date sampled	Station 325				Station 488				Station 625			
	Depth	Cl	Ca	Mg	Depth	Cl	Ca	Mg	Depth	Cl	Ca	Mg
3 Nov 74	48.30				70.49				22.86			
8 Dec 74	15.75	94.43			31.75	112.8			11.43	1456.0		
28 Dec 74		96.42				94.4				705.7		
2 Mar 75	20.32	81.51			29.25	109.3			17.78	343.9		
27 Apr 75	13.97	86.98			22.86	106.9			8.89	678.4		
29 May 75	13.97				27.94				12.70			
3 Jun 75	0**				2.54				0			
26 Jun 75	0				0				0			
24 Jul 75	1.27	86.5	57.0						0	414.0	67.0	
28 Sep 75	13.97											
25 Oct 75		99.4	66.4	10.5						278.3	56.0	
6 Dec 75	9.53	120.3	60.0	10.1								
21 Jan 76	19.05	69.6	48.9	8.1								
11 Feb 76	12.4	82.5	48.0									
11 Mar 76									6.35			
6 Apr 76	6.0	91.0	52.2									
7 Jun 76		48.5	7.3								46.5	13.1
Mean		87.0	48.5	9.6								

*Blank spaces indicates not sampled

**0 indicates no standing water at the designated sampling site

Fig. 5. Depth (in meters) of standing water at Station 325.


SWALE STATION 325
STANDING WATER DEPTH (CM)
50
40
30
20
10
N
D
M
A
M
J
J
J
A
S
D
J
F
A
M
1974
1975
1976
MONTHS WATER DEPTH SAMPLED

The results of an experiment involving the release of 2.7 kg of rock salt at the surface of the soil at Station 264 are presented in Table 7. In the initial samples taken at points 264 A, B, and C before placement of the salt there was little variation in Cl content. After 29 days of exposure to leaching by rains, 264 A soil had an abundance of excess Cl from the surface down to the 30 cm maximum depth monitored. There was no longer any visible trace of the rock salt at the soil surface and levels at site 264 A were about two orders of magnitude higher than at sites 264 B or C where there was no excess Cl detected at the depths sampled. After 35 days, following very heavy rains, there was no longer any excess Cl in the upper 15 cm of soil at 264 A. However, at the 15 - 30 cm level, there was still about one order of magnitude excess of Cl over quantities in the soils at 264 B and C. After 48 days there was still excess Cl at levels from 30 cm to 152 cm below the surface. By the next collection, taken 84 days after experiment initiation, there was no trace of excess Cl down to a depth of 61 cm at 264 A. Thus 44.7 cm of rainfall over the period 2 February 1975 to 27 April 1975 had removed all of the excess 2.7 kg of salt from the upper (61 cm) 2 ft of mineral soil in the maritime forest.

During the entire period that excess Cl was observed at 264 A, there was never any excess Cl at 264 B or C at the depths sampled. Lateral movement of Cl through the soils apparently was minimal. Studies with fertilizer leaching from sandy soils (Terry and McCants 1974) revealed that ions spread in a fan of about 30° from the vertical. If this type of pattern also occurs for salts in dune soils, then soils at 264 B and C

Table 7. Observations on soil at Station 264, where 2.3 kg of rock salt was placed on the surface of the mineral soil under the humus mat. All chloride values are in μg Cl·g soil^{-1}. "A" is the site of salt implacement, "B" is 0.61 m from "A" toward the ocean, and "C" is 0.61 m from both "A" and "B".

	--2 Feb 75---			---3 Mar 75---			---9 Mar 75---			22 Mar 75	27 Apr 75	29 May 75
Depth (cm)	A	B	C	A	B	C	A	B	C	A	A	A
Surface	20	22	30	1040	22	27	27	25	45		22	25
0-15				695	13	10	10	20	10			16
15-31	10		9	1177	10	11	118	15	10	258		
61-76										181	17	
91-107										60		
107-122										70		
137-152										147		

would not be affected by the excess 2.7 kg of salt except for depths far below the maximum sampled.

The objective of soil sampling carried out between 1 July 1975 and 2 July 1976 was to aid in the development of an input-output budget of soluble Cl, Ca, and Mg for the forest system. Intact cores 30 cm long were taken to allow evaluation of salt quantities stored or lost from the system by water percolation. Sampling of soil below 30 cm was discontinued but monitoring of standing water at Station 325 was continued over the final year of the study. Results of the soil sampling from Stations 124, 264, 396, and 680 are presented in the Appendix Tables I and J. In a later section the soil ion concentrations will be used along with dry weight data to calculate the quantities of Cl, Ca, and Mg stored in the soil.

In comparing rainfall and percent soil moisture (Fig. 6) a similarity in patterns over time is seen. Therefore the quantity of rainfall is probably important in controlling the amount of soil moisture. Surrounding air temperature and relative humidity will probably be important also. However, the difference in quantity of water in the soil between stations at any one time depends on edaphic factors such as quantity of organic matter and proximity to the water table.

Figure 7 shows that there is little fluctuation in the concentrations of the ions at any of the four stations over the study period. Table 8 presents the mean annual concentration of each element in the mineral soil for the four stations. There was negligible variation in the cation levels over the study year. For Cl there was only a 40% maximum variation

Fig. 6. Water soluble Cl, Ca, and Mg in the upper 30 cm of mineral soil.

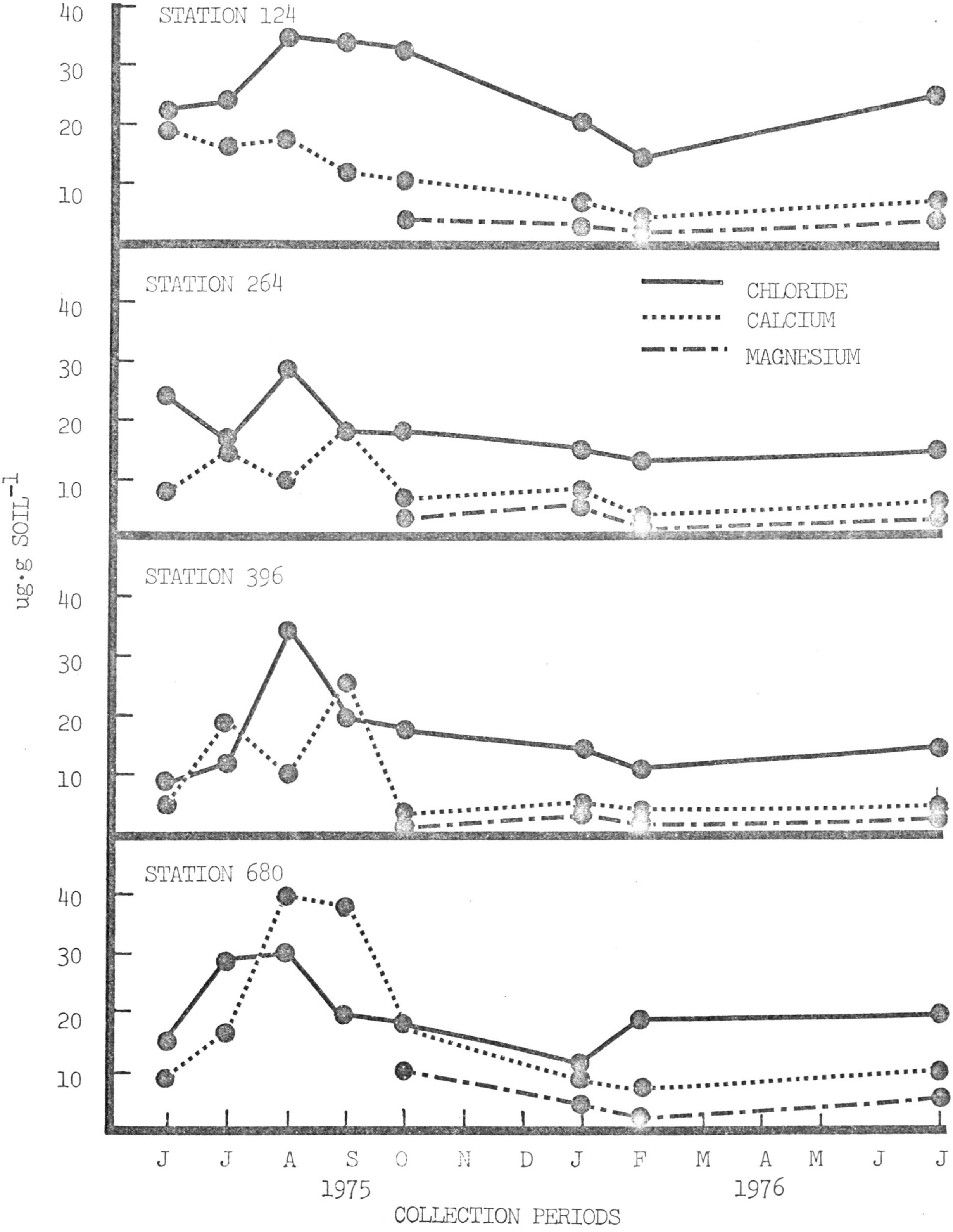

STATION 124
STATION 264
STATION 396
STATION 680
CHLORIDE
CALCIUM
MAGNESIUM
40
30
20
10
ug·g SOIL⁻¹
J
J
A
S
O
N
D
J
F
M
A
M
J
J
1975
1976
COLLECTION PERIODS

Fig. 7. Quantities of water in rainfall and throughfall for the forest over the second study year.

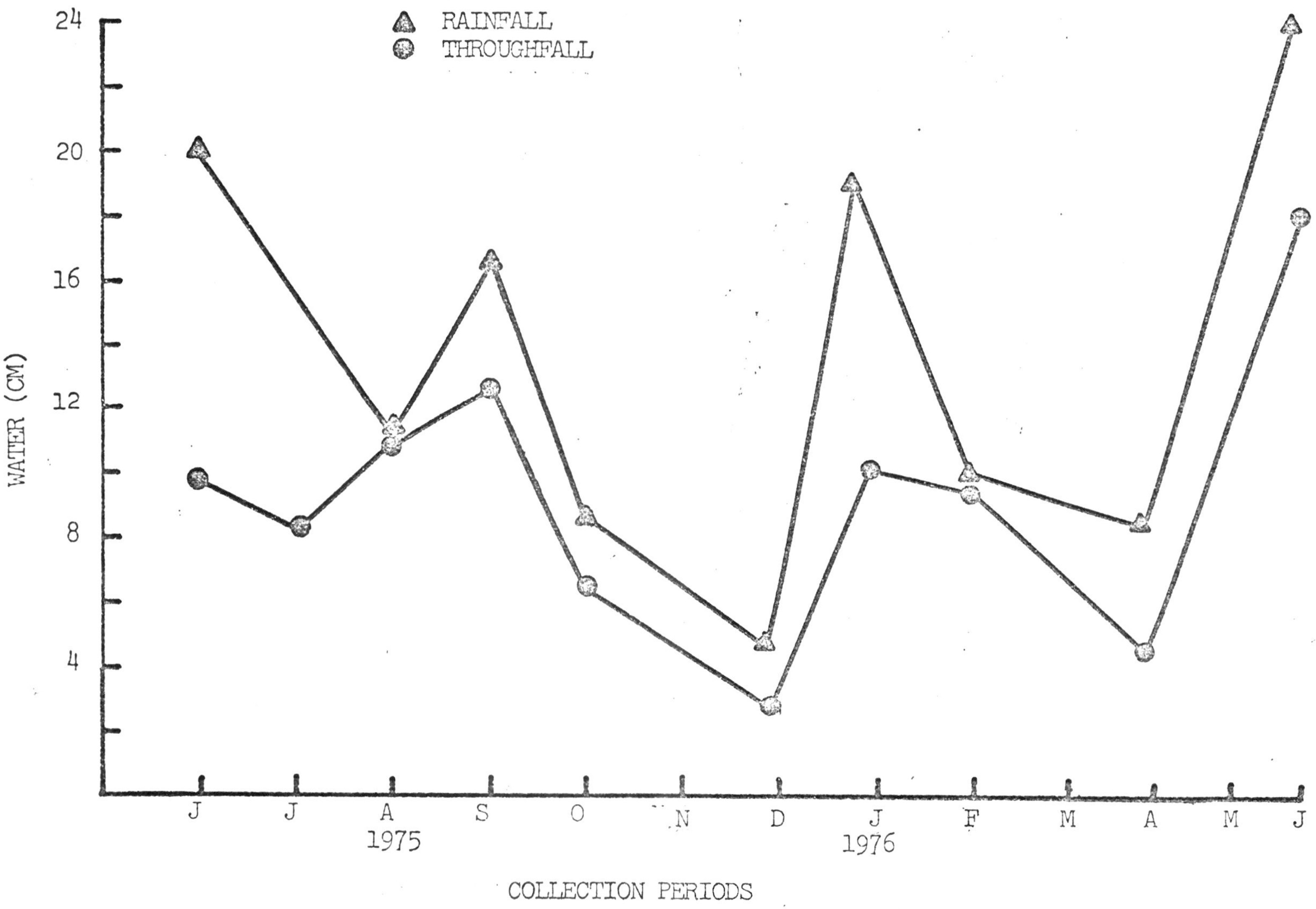

RAINFALL
THROUGHFALL
WATER (CM)
24
20
16
12
8
4
J
J
A
S
O
N
D
J
F
M
A
M
J
1975
1976
COLLECTION PERIODS

Table 8. Mean concentrations of Cl, Ca, and Mg in the soil collected over the period 26 June 1975 to 7 June 1976 are shown. Atmospheric inputs of each mineral over the period are also given for each station. Correlation coefficients for the changing quantities in the soil along the transect with the gradient of mineral inputs of the minerals along the transect are presented for each ion. Levels of minerals in the soils are in μg·g soil^{-1} and atmospheric inputs are in the form g·m^{-2}yr^{-1}. (A,B,C indicate triplicate samples.)

STATION		Cl		Ca		Mg	
		Soil Conc.	Atmos. Inputs	Soil Conc.	Atmos. Inputs	Soil Conc.	Atmos. Inputs
124	A	21.9	104.0	1.01	3.07	0.30	4.32
	B	34.2	104.0	1.65	3.07	0.38	4.32
	C	22.5	104.0	0.88	3.07	0.43	4.32
264	A	18.7	32.9	1.15	2.49	0.35	2.57
	B	16.5	32.9	0.78	2.49	0.89	2.57
	C	17.0	32.9	0.86	2.49	0.31	2.57
396	A	14.9	20.0	0.63	1.38	0.25	0.64
	B	15.4	20.0	0.74	1.38	0.26	0.64
	C	28.3	20.0	1.68	1.38	0.35	0.64
680	A	20.6	24.0	1.46	1.60	0.38	0.71
	B	21.4	24.0	1.92	1.60	0.65	0.71
	C	20.3	24.0	2.07	1.60	0.61	0.71

Cl:
r = 0.71
b = 4.988
m = -55.12
t = 3.185
P = 0.10

Ca:
r = -0.24
P = not signif.

Mg:
r = -0.18
P = not signif.

between stations having the greatest and lowest annual means. The mean Cl levels along the transect correlate (r = 0.71, P = 0.10) with the atmospheric inputs of Cl at the same sites. Since Cl is in excess as compared with Ca and Mg in these soils, is required by plants only in trace levels, and is very mobile in the soils, the Cl quantities in soils at various stations vary directly with atmospheric inputs of the ion. The amounts of Ca and Mg in the soils of the four stations, showed no significant correlation with their respective atmospheric inputs possibly since their storage and cycling in barrier island soils is determined largely by biological pathways (e.g. uptake and release by flora and fauna).

The low concentrations of total available Ca and Mg (exchangeable plus soluble, Appendix Table L) possibly result from the small amounts of organic matter in the soil, which would confirm the observations of Art (1971). With increasing distance from the salt spray sources, there is a general increase in total available Ca and Mg at the stations monitored.

Quantities of dissolved ions stored in the humus-litter layer are presented in Table 9. All three elements have low soluble ion levels relative to the quantities of these minerals reaching the forest from atmospheric sources.

Chloride, being readily soluble and in great excess over the low levels required by plants in the ecosystem, was expected to be rapidly leached from the humus and then from the soil. Without rapid leaching from the system, Cl would rapidly accumulate to toxic levels in the soils from excessive

Table 9. Quantities of soluble Cl, Ca, and Mg stored in the humus-litter layer 1 November 1975 to 7 June 1976. All values are in $g \cdot m^{-2}$.

Station and ion		1 Nov 75	11 Feb 76	6 Apr 76	7 Jun 76
124	Cl	3.11	3.43	3.01	1.96
	Ca	*	0.19	0.77	0.15
	Mg	*	0.08	0.26	0.07
264	Cl	1.43	1.44	1.55	1.08
	Ca	0.47	0.24	0.28	0.11
	Mg	0.34	0.16	0.15	0.07
396	Cl	1.10	1.24	3.10	1.02
	Ca	*	0.08	0.61	0.24
	Mg	*	0.04	0.15	0.05
680	Cl	1.02	1.75	2.96	1.25
	Ca	0.36	2.04	1.17	0.29
	Mg	0.24	0.70	0.39	0.11

*No data

atmospheric inputs of this ion from salt spray. This rapid leaching does occur as no significant increase in humus content or mineral soil content of Cl was recorded. This supports the work of Oosting and Billings (1942) who found low salinity in coastal soils.

The soluble Ca and Mg in the humus mats can follow several pathways. Cations in water are the form most readily available to plants being absorbed by roots. Leaching by percolation can occur resulting in loss from the system. Also the cations can adsorb to particulate matter often losing their ready solubility in water. These adsorbed ions are largely a function of the quantity of organic matter in the soil in the maritime forest (Art 1971) and therefore of the fermentation layer as most of the organic matter in relict dune soils occurs as humus and litter.

THROUGHFALL AND HUMUS LEACHATE OF WATER AND IONS

Materials and Methods

Throughfall collectors and humus leachate collectors (designed to catch water percolating through the humus mat) were installed at Stations 124, 264, 396, and 680 on 26 June 1975. These collectors were monitored for water volume and dissolved minerals over the second study year (26 June 1975 to 7 June 1976).

Throughfall was collected in three collectors at each of the four stations. The throughfall collectors were not moved over the study period because this would have also required moving the humus leachate collectors which had been buried immediately adjacent to the throughfall collectors. Throughfall collectors consisted of a 15 cm internal diameter funnel inserted into a 4 liter polyethylene bottle. The entire apparatus was supported on wooden stakes driven into the ground. The collectors were situated with the funnels approximately 36 cm above the forest floor. Fiber glass screening (1.5 mm mesh) was used to line the funnels in order to keep out litterfall.

Water and dissolved minerals leaching through the humus mat were collected in 800 ml plastic containers with 15 cm diameter funnels attached. Fiberglass screening (mesh 1.5 mm) was used to line the funnels of the humus leachate collectors to prevent particulate organic matter from the humus mat from entering the containers. A portion of the humus mat was cut away and removed intact. A hole was then dug in the mineral soil and the humus leachate collector placed inside. The humus mat was then replaced over the funnel and the apparatus adjusted until the humus mat fit relatively flush with the surrounding forest floor.

Volumes of throughfall and humus leachate were measured in the field and aliquots returned to the laboratory where analyses for dissolved Cl, Ca, and Mg were conducted following the procedures previously described in the section on atmospheric inputs.

Results and Discussion

From the beginning the humus leachate collectors were difficult to use effectively. If the humus mat was placed flat over the collectors, then water often failed to enter the containers. Possibly due to some effect of the humus-screen interface (Helvey and Patric 1965), water may have actually flowed around the collectors and into the soil. Better results were obtained when the humus mat was shaped to fit a slight depression made in the center of the screen over the funnel. Water striking the humus tended to flow to a center point and down into the collector. Even this technique modification did not produce satisfactory results as the greatest annual quantity of Cl found leaching from the humus mat was 41.3 $g \cdot m^{-2}$ for Station 124, although the annual throughfall input of Cl to the forest floor for this station was 86.0 $g \cdot m^{-2}$ (Appendix Table M). These data suggest that significant accumulation of Cl in the humus-litter layer occurred at this station; however, analysis of the humus mat (Table 9) showed no corresponding increase in Cl level. Also, this station was located on relatively flat terrain, therefore loss of Cl by above ground runoff can be discounted. Also the concentrations of Cl in the humus leachate was generally lower than those in the throughfall.

Humus leachate data was not useful in contributing toward hydrologic or mineral budgets because of the inconsistencies noted above. This method of estimating water percolation and associated leaching of dissolved minerals is not recommended for use by others because of the problems associated with this technique and the lack of reliable results. For coarse soils, such as exist on barrier islands, a lysimeter should give much better estimation of the leaching losses from the system (Bormann and Likens 1967).

Throughfall consists of rainwater which falls directly through the canopy or drips from foliage to the forest floor (Helvey and Patric 1965). Throughfall of water at four stations in the study area is presented in the Appendix Table M. Figure 7 shows the pattern of throughfall over the study year and its similarity to the rainfall pattern. Although the throughfall collectors were not moved after each collection as recommended by Rieley et al. (1969) in their modification of Wilm's method, the average percent deviation of the standard error from the mean when all twelve collectors were considered together was only 14.5. The collection was made on 24 July 1975 during eleven days of little rainfall. As a result the percent deviation of the standard error from the mean was high (51%). If data for this collection period is omitted, then an average percent deviation of the standard error from the mean of only 10.4 results when all twelve collectors are considered together. These percent deviations are comparable to the range given by Rieley et al. (1969) for other studies where collectors were not moved.

The annual mean throughfall for the forest was 86.0 cm or 69.4% of the annual rainfall (124 cm). Therefore 30.6% of the yearly rainfall was available for canopy interception loss and stemflow to the forest floor. Interception is defined as gross rainfall minus net rainfall, where net rainfall equals throughfall plus stemflow (Leyton et al. 1969). Thus interception is considered to include evaporation and absorption by foliage.

As a result of his work in a maritime forest on Fire Island, New York, Art (1971) found that throughfall amounted to 84% of the gross rainfall while stemflow amounted to 16% of the gross. Stemflow was not measured in this study; however, if the value given by Art (1971) of 16% is coupled with the 69.4% mean throughfall value recorded in the present study, a net rainfall of 106 cm (85.9% of the gross rainfall) could be expected to reach the forest floor. The estimation of interception for this study is then 14.6% of the gross rainfall, which agrees with the range of canopy interception for southern forests of 10 - 30% of the gross rainfall (Moehring 1969). This is admittedly a rough estimate of canopy interception since it is based on only a tenuous assumption of similar stemflow in maritime forests of widely different latitudes.

The concentrations of Cl, Ca, and Mg in throughfall are given in Appendix Table L and the quantities reaching the forest floor are presented in Appendix Table M. The annual mean concentrations of Cl and Ca in throughfall at Stations 124 and 264 were greater than concentrations in bulk precipitation at these stations (Appendix Table A). The mean concentrations of Cl, Ca and Mg at Stations 396 and 680 were greater in throughfall than in bulk precipitation.

Elevated concentrations in throughfall were probably caused by leaching of soluble Cl, Ca, and Mg out of the foliage and the washing of dust and impacted aerosols off the canopy leaves and twigs (Carlisle et al. 1966 and Art 1971). Both sources probably contribute significant amounts of Ca and Mg to throughfall. However, most of the Cl enrichment in throughfall was a result of prior accumulation by aerosol impaction because of the large quantities of this ion in salt spray and the low concentration of Cl in plant tissues relative to the concentrations of the macronutrients Ca and Mg. The smooth funnels of the bulk precipitation collectors do not provide as effective a collection surface for salt spray aerosols as do leaves and twigs (Boyce 1954 and Clayton 1972). Therefore somewhat lower levels of impacted Cl result in bulk precipitation collectors than is actually entering the forest. The values of Ca, Mg, and especially Cl reported here in bulk precipitation inputs are actually minimum values. This agrees with the work of Van der Valk (1974a) and Art (1971) both of whom believed their bulk precipitation collectors contained minimum quantities of dissolved minerals relative to total atmospheric inputs actually entering the system.

VEGETATION ANALYSIS

Materials and Methods

During the summer of 1975 analysis of vegetation comprising the canopy was conducted for all stations dominated by woody species. At each site 100 m transects were established parallel to the shore line. Every 10 m along the transects, species comprising the canopy were determined using the point-quarter technique (Cox 1972). Only woody species having a diameter at breast height greater than 2.4 cm were enumerated. Each individual was identified to species and its distance from a center point measured. All taxonomy follows the Manual of the Vascular Flora of the Carolinas (Radford et al. 1968).

Results and Discussion

Mean canopy height, species composition, species importance values, Shannon-Weiner indices of diversity, and eveness of distribution indices (Odum 1971) are presented for each station in Table 10. The Shannon-Weiner indices of diversity (H) were calculated using $\log_2$. The eveness of distribution component was computed by $E = H/H_{max}$, where $H_{max} = \log_2$ (number of species). The importance value for each species was determined by summation of relative density, relative dominance, and relative frequency of a species at each station. All forested dune ridge stations, except for Stations 214 and 396, were found to have a canopy dominated by *Quercus laurifolia*. Station 214 is in an interdune swale where the water table is

Table 10. Vegetation analysis of canopy species at various stations along the study transect - using the point-quarter technique (Cox 1972). The mean canopy height and standard deviation are in meters.

Station	Canopy Species	Importance Value	Mean canopy height	H	E
57*	*Quercus laurifolia* Michaux	126.49	3.51 (0.91)	1.9078	0.5242
	Juniperus virginiana L.	99.27			
	Ilex vomitoria Aiton	40.94			
	Quercus virginiana Miller	17.72			
	Persea borbonia L.	15.60			
168	*Q. laurifolia* Michaux	65.75	4.01 (1.69)	2.9176	0.3427
	Q. virginiana L.	47.36			
	Ilex opaca Aiton	61.39			
	J. virginiana L.	41.23			
	P. borbonia L.	30.17			
	Osmanthus americana (L.) Gray	23.73			
	I. vomitoria Aiton	10.35			
	Vaccinium aboreum Marshall	7.76			

	Pinus _taeda_ L.	6.51			
	Carpinus _caroliniana_ Walter	5.76			
214	_Pinus_ _taeda_ L.	85.86	8.45 (0.49)	2.8226	0.8496
	Nyssa _sylvatica_ Marshall	63.28			
	_Q._ _virginiana_ Miller	36.61			
	_P._ _borbonia_ L.	35.90			
	_Q._ _laurifolia_ Michaux	28.75			
	_I._ _opaca_ Aiton	22.69			
	_C._ _caroliniana_ L.	8.59			
	_V._ _arboreum_ Marshall	6.39			
	Magnolia _virginiana_ L.	6.12			
	Lyonia _lucida_ (Lam.) Koch	5.80			
264	_Q._ _laurifolia_ Michaux	177.77	4.88 (0.51)	2.0327	0.6776
	_I._ _opaca_ Aiton	33.15			
	_O._ _americana_ (L.) Gray	26.84			
	_I._ _vomitoria_ Aiton	21.45			
	_J._ _virginiana_ L.	15.81			
	_C._ _caroliniana_ L.	11.23			
	_P._ _taeda_ L.	7.59			
	_P._ _borbonia_ L.	6.15			

Table 10 continued

Station	Canopy Species	Importance Value	Mean Canopy height	H	E
325	*Fraxinus tomentosa* Michaux	160.46	8.78 (1.94)	1.9709	0.5074
	Myrica cerifera L.	67.05			
	P. borbonia L.	28.25			
	Acer rubrum L.	17.93			
	C. caroliniana L.	12.52			
	J. virginiana L.	7.21			
	O. americana (L.) Gray	6.60			
396	*P. borbonia* L.	54.01	9.61 (1.91)	2.8754	0.9585
	J. virginiana L.	49.30			
	P. taeda L.	48.86			
	C. caroliniana L.	46.15			
	I. opaca Aiton	33.22			
	Q. laurifolia Michaux	33.16			
	O. americana (L.) Gray	26.77			
	M. cerifera L.	8.51			
488	*F. tomentosa* Michaux	152.46	10.33 (1.45)	2.1433	0.7144

	_M._ _cerifera_ L.	65.08			
	_P._ _borbonia_ L.	27.11			
	Cornus _stricta_ Lam	16.75			
	_C._ _caroliniana_ L.	15.39			
	_P._ _taeda_ L.	10.58			
	Aralia _spinosa_ L.	6.36			
	_J._ _virginiana_ L.	6.24			
564	_Q._ _laurifolia_ Michaux	60.91	8.85 (3.88)	2.7695	0.9232
	_C._ _caroliniana_ L.	58.84	**		
	_O._ _americana_ (L.) Gray	54.41			
	_J._ _virginiana_ L.	46.68			
	_P._ _taeda_ L.	34.35			
	_P._ _borbonia_ L.	25.54			
	_F._ _tomentosa_ Michaux	11.74			
	_M._ _cerifera_ L.	7.49			
625	_F._ _tomentosa_ Michaux	136.94	6.1 (0.43)	1.9473	0.5135
	_M._ _cerifera_ L.	83.15	**		
	_J._ _virginiana_ L.	43.36			
	_P._ _borbonia_ L.	30.22			
	_P._ _taeda_ L.	6.33			

Table 10 continued

Station	Canopy Species	Importance Value	Mean canopy height	H	E
680	*Q. laurifolia* Michaux	87.06	9.61 (1.50)	2.6848	0.3725
	J. virginiana L.	79.17			
	O. americana (L.) Gray	35.88			
	P. borbonia L.	29.78			
	C. caroliniana L.	23.90			
	Q. virginiana L.	20.22			
	Cornus florida (L.)	12.58			
	I. opaca Aiton	5.88			
	Corylus americana Walter	5.59			
879	*Q. laurifolia* Michaux	145.78	7.81 (3.18)	1.7978	0.8989
	Q. virginiana L.	79.65			
	I. opaca Aiton	43.21			
	P. taeda L.	31.36			

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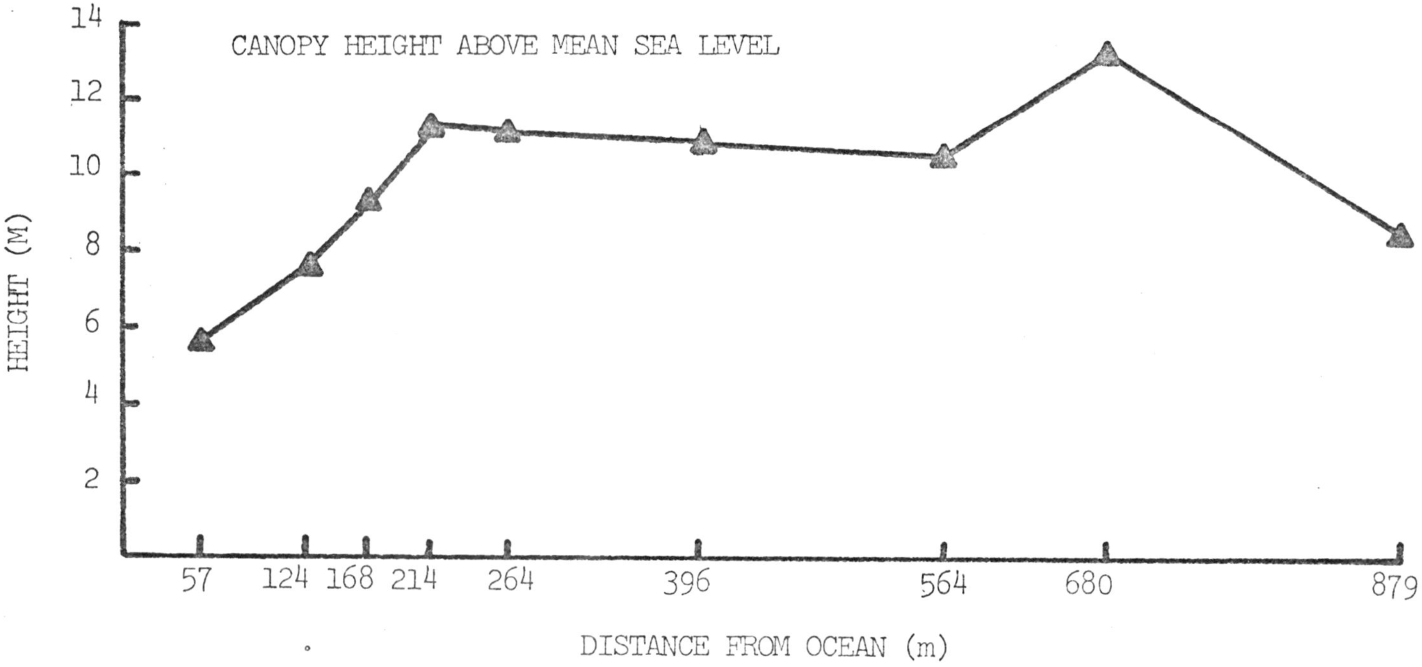
* Station number is distance from the ocean in meters

** Only two measurements of tree height taken at Stations 564, 625, and 680 usually less than 30 cm below the surface. The high water table together with the relative protection from salt spray afforded by the adjacent dune, probably accounts for this station's canopy being dominated by such salt intolerant species as Pinus taeda and Nyssa sylvatica. Station 396 is on a relict dune ridge but because of its great distance from the ocean, there is minimal toxic effect from salt spray. Salt intolerant species can more successfully compete with salt tolerant Q. laurifolia and Q. virginiana thus explaining the low importance value of Q. laurifolia at this site and the co-dominance of Persea borbonia, Juniperus virginiana, and P. taeda. The canopy of the inundated swale Stations 324, 488, and 625 were dominated by Fraxinus tomentosa with a Myrica cerifera understory.

The Shannon-Wiener index of diversity is lower near the salt spray sources of the Atlantic Ocean and Bogue Sound (Stations 57 and 879) than at stations further from the stress of wind-born salt aerosols. In addition, the eveness of distribution is lower for stations in the zones of maximum salt spray(Stations 57, 168, 264, 680, and 879) than for stations which receive less toxic Cl inputs (Stations 396 and 214). In other words, the number of important species comprising the canopy decreases in the zones of maximum salt spray and is especially noticeable at Stations 57 and 879.

Figure 8 is a graph of canopy height above mean sea level for all the forested dune ridge stations along the transect. Canopy height above mean sea level (defined as height above ground plus elevation at that station) increased with increasing distance from the salt spray sources. If this graph is compared with that of annual atmospheric inputs of Cl (Fig. 2),

Fig. 8 . Maritime Forest Canopy height above mean sea level (mean canopy height above ground + station elevation above mean sea level).


CANOPY HEIGHT ABOVE MEAN SEA LEVEL
HEIGHT (M)
14
12
10
8
6
4
2
57
124
168
214
264
396
564
680
879
DISTANCE FROM OCEAN (m)

it is clear that the patterns are similar but inverted. At Stations 57, 214, 168, 264, 680, and 879 where both canopy height above mean sea level and atmospheric inputs were directly measured, a correlation coefficient of -0.87 ($P = 0.05$) was found between the two parameters.

This agrees with the findings of Wells and Shunk (1942), Oosting and Billings (1942), Boyce (1954), and Martin (1959), all of whom relate tree height to salt spray deposition. In agreement with the observations of Wells and Shunk (1942), no significant correlation coefficient was found between canopy height and soil moisture or soil salinity.

Species composition and diversity in vegetational communities of the maritime strand vary directly with atmospheric inputs of oceanic salts. Also the general morphology of the maritime strand canopy is determined by the toxic effect of salt spray. However, even though the stress by wind-born Cl is the most readily observable feature of the maritime strand, without the associated nutrient inputs in salt spray, these vegetational communities could not develop.

CONTRIBUTIONS TOWARD A BARRIER ISLAND MINERAL BUDGET

Table 11 presents the annual atmospheric inputs and annual mean quantities in throughfall of Cl, Ca, and Mg determined in this study for Stations 124, 264, 396, and 680 and the results of similar studies by workers concerned with other ecosystems. Station 124 had Ca and Mg inputs comparing best to those of Van der Valk (1974a), in his cation budget of a foredune grass community. Stations 396 and 680 had bulk precipitation and throughfall values for Ca and Mg that agreed well with those reported by Art et al. (1974) for a maritime forest on Fire Island, New York.

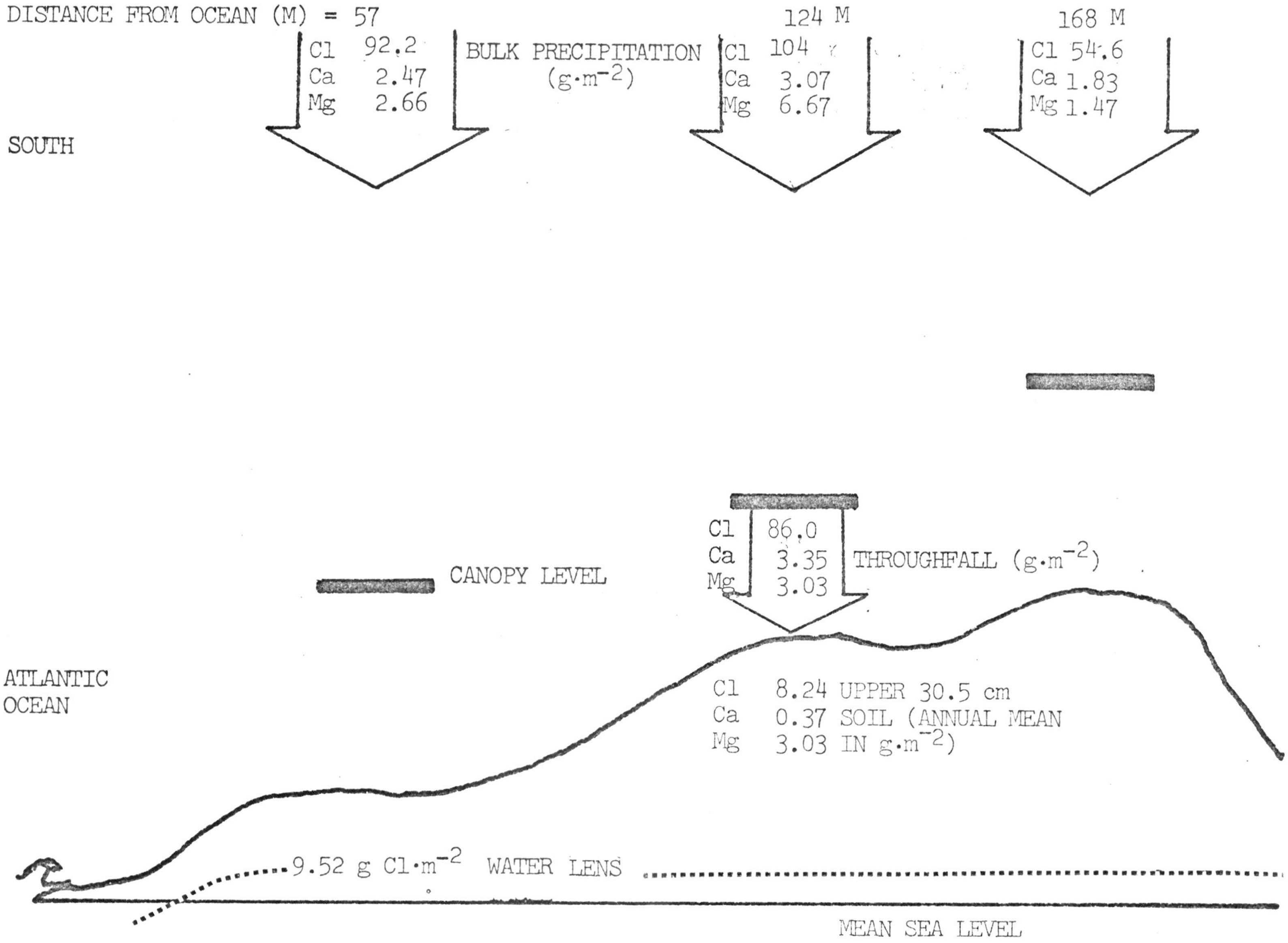
The low amounts of atmospheric nutrient inputs into inland ecosystems are usually only a small but important suppliment to the major source of nutrient inputs, weathering of bedrock (Bormann and Likens 1967). Weathering is a minimal source of nutrient cations in systems with sandy soils and no underlying bedrock such as barrier islands (Art 1971). Therefore atmospheric inputs of cations must be great enough to compensate for the lack of weathering for plant communities to maintain a constant amount of biomass (Art et al. 1974). As noted by Art et al. (1974) and confirmed here, atmospheric inputs of cation nutrients puts forested maritime ecosystems in the same range of cation inputs that inland forests have from both atmospheric inputs and geologic weathering.

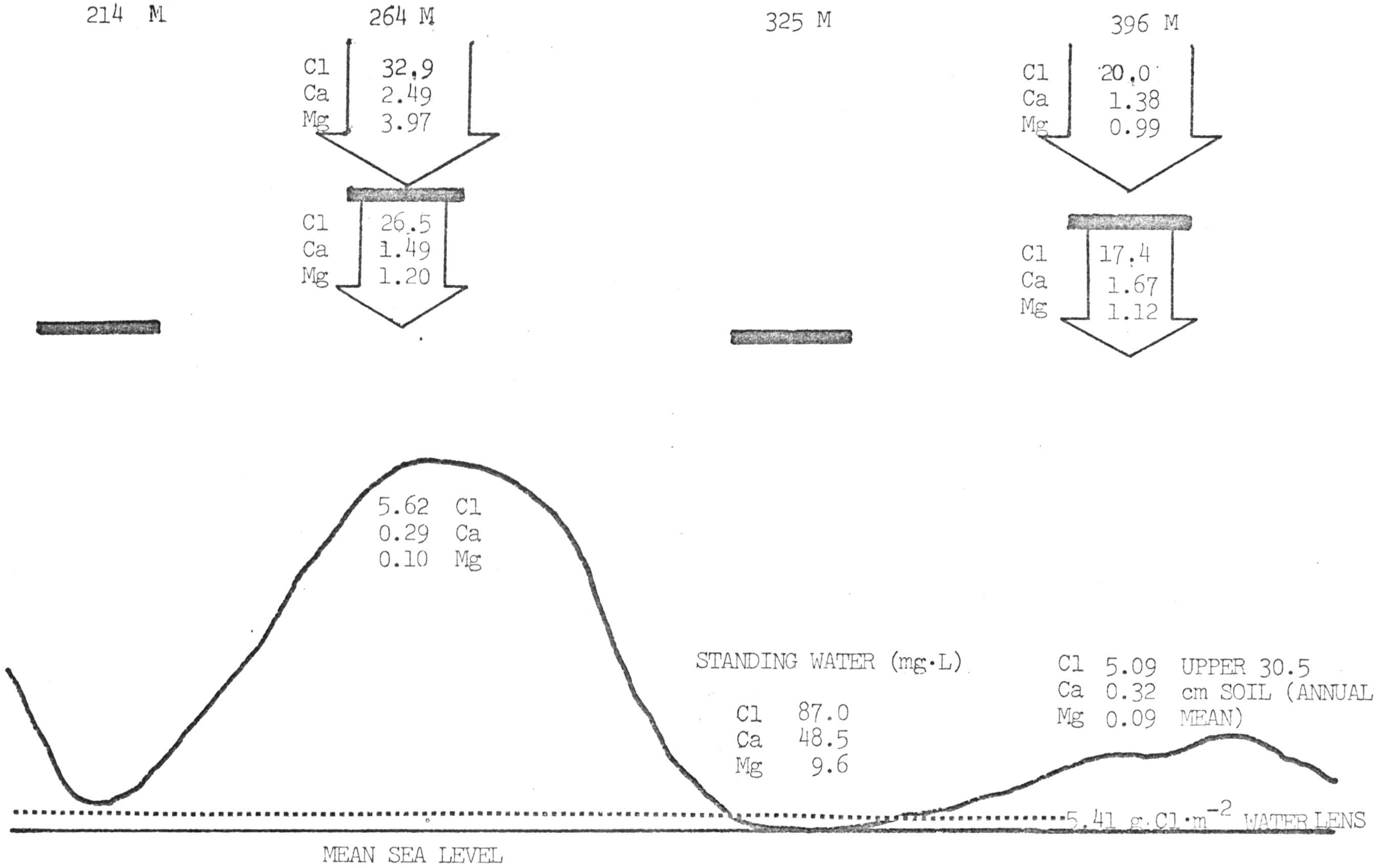
Figure 9 provides an overview of the work accomplished in this study. Results from studies on the various ecological parameters monitored are presented on a profile of the transect, drawn to scale using data from Table 1.

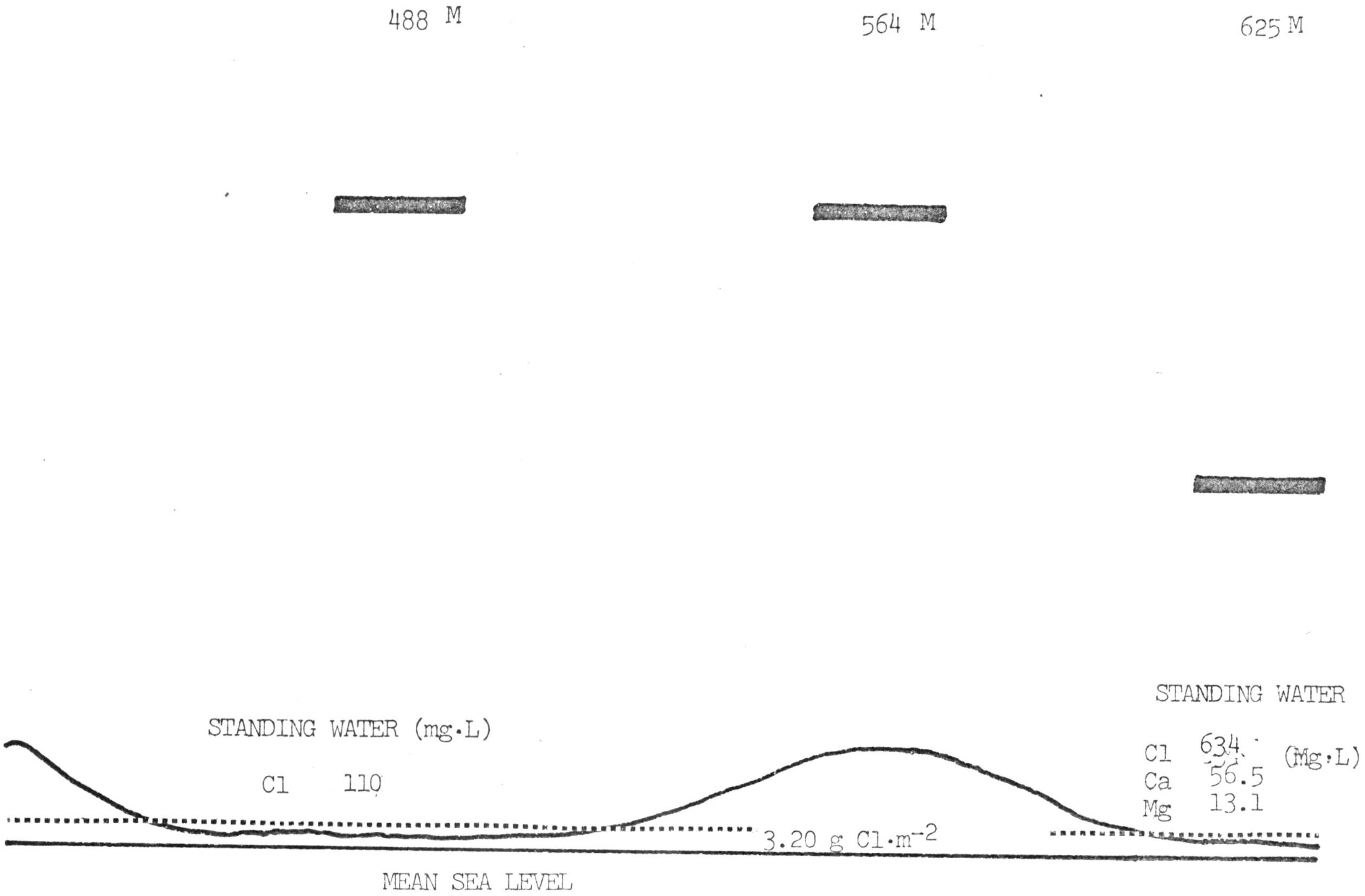
Table 11. Annual atmospheric inputs and throughfall in the present study and comparison with other studies. All values are in g·m^{-2}. Gross leaching indicates throughfall + stemflow.

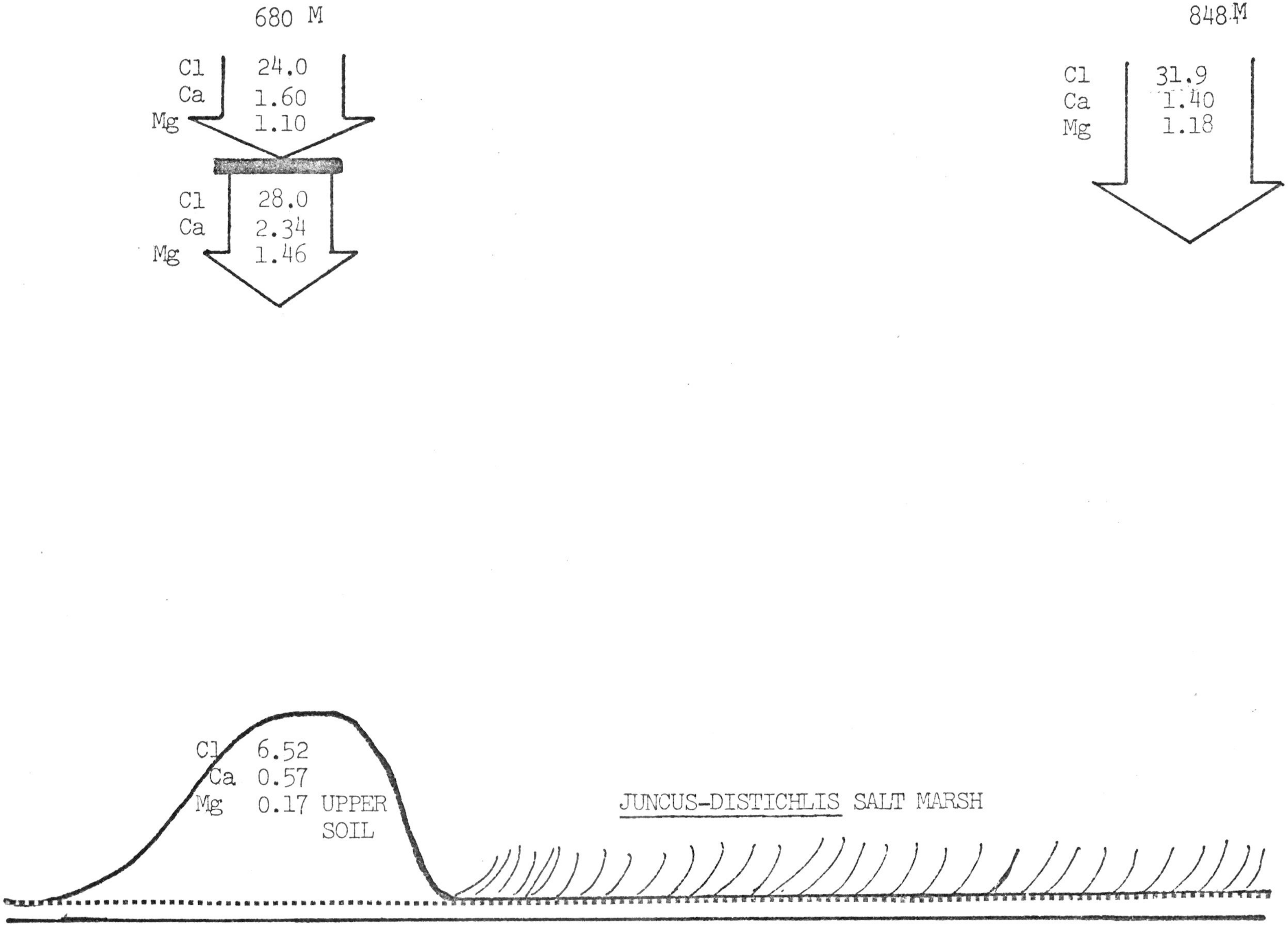
LOCATION		BULK PRECIPITATION			THROUGHFALL			REFERENCE
	STATION	Cl	Ca	Mg	Cl	Ca	Mg	
Roosevelt Natural Area								
Bogue Bank, N.C.	124	104.0	3.07	6.67	86.0	3.35	3.03	Present Study
	264	32.9	2.49	3.97	26.5	1.49	1.20	
	396	20.0	1.38	0.99	17.4	1.67	1.12	
	680	24.0	1.60	1.10	28.0	2.34	1.46	
Sunken Forest, Fire Island, New York			0.98	1.91		2.11	2.08	Art et al. 1974
						(Gross Leaching)		
Foredune Grassland								
Bodie Island, N.C.			5.80	10.7				Van der Valk 1974a
Ocracoke Island, N.C.			8.60	7.70				
Lanchasire, England								
Quercus petraea Forest			0.67	0.61		2.10	1.32	Carlisle et al. 1967
			(Rainfall)					
Quercus petraea Forest			0.73	0.46		1.72	0.94	Carlisle et al. 1966
Cedar Creek Natural History Area, Minnesota								
Oak Forest						0.76	0.31	Reiners 1972
Cedar Swamp						1.07	0.37	

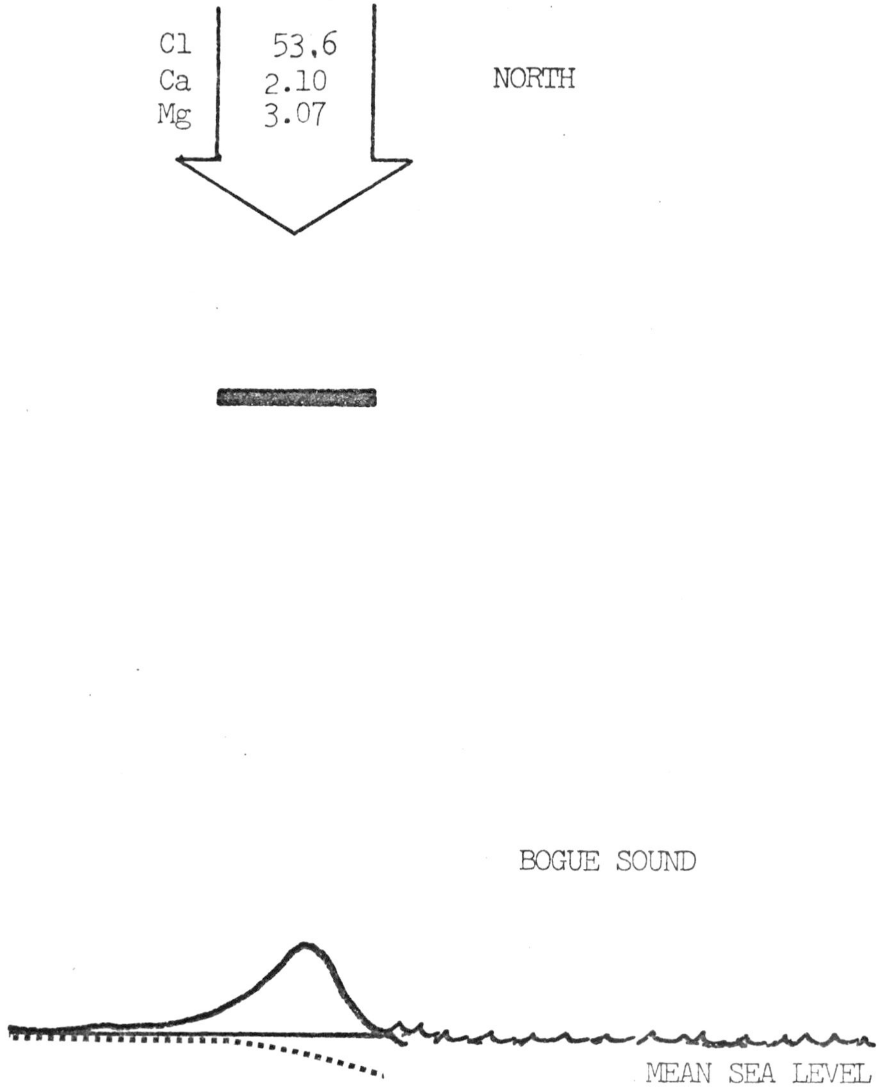
Fig. 9. Diagram of the island profile where the transect was established. Atmospheric inputs, throughfall, soil storage, standing water concentrations, and canopy height for stations monitored. (Vertical scale exaggerated ten times)


DISTANCE FROM OCEAN (M) = 57
124 M
168 M
Cl 92.2
Ca 2.47
Mg 2.66
BULK PRECIPITATION
(g·m-2)
Cl 104
Ca 3.07
Mg 6.67
Cl 54.6
Ca 1.83
Mg 1.47
SOUTH
CANOPY LEVEL
Cl 86.0
Ca 3.35
Mg 3.03
THROUGHFALL (g·m-2)
ATLANTIC
OCEAN
Cl 8.24 UPPER 30.5 cm
Ca 0.37 SOIL (ANNUAL MEAN
Mg 3.03 IN g·m-2)
9.52 g Cl·m-2 WATER LENS
MEAN SEA LEVEL


214 M
264 M
325 M
396 M
Cl 32.9
Ca 2.49
Mg 3.97
Cl 26.5
Ca 1.49
Mg 1.20
Cl 20.0
Ca 1.38
Mg 0.99
Cl 17.4
Ca 1.67
Mg 1.12
5.62 Cl
0.29 Ca
0.10 Mg
STANDING WATER (mg·L)
Cl 87.0
Ca 48.5
Mg 9.6
Cl 5.09 UPPER 30.5
Ca 0.32 cm SOIL (ANNUAL
Mg 0.09 MEAN)
5.41 g·Cl·m-2 WATER LENS
MEAN SEA LEVEL


488 M
564 M
625 M
STANDING WATER (mg·L)
Cl 110
STANDING WATER
Cl 634 (Mg·L)
Ca 56.5
Mg 13.1
3.20 g Cl·m^{-2}
MEAN SEA LEVEL


680 M
Cl 24.0
Ca 1.60
Mg 1.10
Cl 28.0
Ca 2.34
Mg 1.46
848 M
Cl 31.9
Ca 1.40
Mg 1.18
Cl 6.52
Ca 0.57
Mg 0.17
UPPER SOIL
JUNCUS-DISTICHLIS SALT MARSH



1. THE LEVEL OF THE FRESH WATER LENS IS ARBITRARILY PLACED IN THE FIGURE
2. THE HORIZONTAL SCALE IS 1 CM = 9.5 M
3. THE VERTICAL SCALE IS 1 CM = 0.95 M.
4. ALL VALUES WERE QUANTITIVELY DETERMINED EXCEPT THOSE OF THE FRESH WATER LENS

The annual means of the "soluble" and "total available" data for the cores of the upper 35 cm of mineral soil (Appendix Table I) and means of all values recorded for soluble Cl in the soil at the fresh water table (Table 4) were converted to g·m^{-2} by multiplying the ionic content in μg·gram soil^{-1} by the bulk density of the mineral soil in g·m^{-3}. The ionic concentrations of ions in the standing water of the swale stations is in mg·l^{-1} (from Table 6). Soil contents of Cl at the fresh water table was not measured over the same period of time or as frequently. Therefore these data may not be directly comparable to other parameters monitored regularly over a long time period.

Values for standing water in the swales are the means of all data listed in Table 6 for a particular ion at a station. Most measurements of Cl at Stations 488 and 625 were taken over the period 3 November 1974 to 3 June 1975 and Ca and Mg were analyzed for in these two swales only intermittantly. The values for these two stations may not be directly comparable of those of swale Station 325 monitored over the entire study period for Cl and for Ca and Mg over the second study year. Additionally, the mean Cl content of fresh water table soils, observed over the period 3 November 1974 to 25 October 1975, are based on only one to five soil samples (depending on the station) and so may not truly reflect annual mean concentrations. However, these data may approximate yearly means since the salt content at the fresh water table is not expected to vary greatly.

Due to the phenomenon of wind blown salt spray, coastal atmospheric inputs (for ions having salt spray as a major input factor) vary with topography (Oosting 1954 and Martin 1959). It has been shown (Appendix Tables C to D) that for ions occurring in sufficient quantities in salt spray, annual inputs can be estimated for an entire transect from ocean to sound using linear regression between the inputs at points monitored along the transect and calculated topographic indices at the points where atmospheric inputs were measured. The topographic index calculations require knowledge of only the distances from the ocean and the sound and the elevation of a station above mean sea level. Atmospheric inputs can be computed from the resulting regression equation for any point along the transect for which the appropriate distances and elevation are known.

A significant correlation also exists between the topographic indices and throughfall of Cl ($r = 0.76$, $P = 0.01$, $N = 12$) at the four stations where throughfall was monitored. No significant correlation between the topographic index and Ca or Mg in throughfall was found, probably due to excesses from leaching and inputs from other sources.

Significance of these analyses is that future studies on mineral cycling and budgets of Cl, Ca, and Mg in barrier island maritime forests and some mainland maritime forests can estimate patterns of atmospheric inputs in bulk precipitation while having to monitor only a few sites (at least 5 for regression analysis) for actual inputs. Any working model of nutrient cycling in barrier island forests must consider the entire gradient of atmospheric inputs into this system, since it is this gradient that largely determines the functional dynamics within the barrier island plant communities.

The following research will be necessary to produce mineral budgets for Cl and cations for barrier island maritime forests: (1) lysimeter studies to determine percolation losses of dissolved ions, (2) extensive measurements of biomass and productivity for various stations along a transect from ocean to sound, (3) intrasystem mineral cycling studies involving decomposition studies and perhaps tracer work, and (4) extensive measurements of stemflow and throughfall at enough stations along the transect to provide sufficient data for statistical comparison with calculated topographic indices.

Budgets for these minerals are not enough by themselves, models must also be constructed for phosphorus, nitrogen, and sulfur before we can really begin to understand the energetics of barrier island maritime forests and their functional ties to the sea.

SUMMARY

This work has quantified atmospheric inputs of Cl, Ca, and Mg at eight stations along a transect from ocean to sound and annual amounts in throughfall at four of these stations over the period 26 June 1975 to 7 June 1976. Rainfall and throughfall hydrology parameters have also been determined over this period. There is good agreement of all values reported with those in the literature.

A simple method for predicting the atmospheric inputs of Cl, Ca, and Mg along a transect from ocean to sound was presented. The technique involves computation of a topographic index (TI) for each point along the transect for which atmospheric inputs are to be monitored or calculated. Calculation of the TI for a station requires knowledge of the distances to the ocean and sound and the elevation above mean sea level. Linear regression analyses between the independent variable (X) the TI and the dependent variables (Y) of the annual inputs of Cl, Ca, and Mg produced the following results: (1) Cl, $r = 0.93$, $N = 8$, $P = 0.01$ with resulting equation of $Y = 24.42\ X - 14.53$, (2) Ca, $r = 0.88$, $N = 8$, $P = 0.05$ with the resulting equation $Y = 0.40\ X + 0.98$, and (3) Mg, $r = 0.83$, $N = 8$, $P = 0.05$ defined by the equation $Y = 1.11\ X - 0.26$. Similar analysis conducted on data reported by Martin (1959) confirmed the mathematical relationship between TI and atmospheric salt inputs. The topographic index may be useful to workers needing to quantify the atmospheric input gradients of oceanically derived salts across barrier islands but wishing to devote more time to determinations of other parameters. Possibly other constituents of sea

water such as sodium, potassium, and sulfate show a similar relationship between patterns of deposition and topography.

Estimation of Cl, Ca, and Mg in throughfall along the transect should be possible by the same general procedure outlined above for atmospheric inputs if quantities of the ions leaching out of the canopy foliage do not vary greatly over the transect. However in this study linear regression of ions in throughfall with the topographic indices showed no significant correlation (at $P = 0.05$) possibly due to the small number (four) of sampling stations.

Analyses of 30 cm deep soil cores over the second study year revealed low levels of soluble Cl, Ca, and Mg and little variation over the year at four stations.

Observations on the Cl content of soils collected every 15 cm in the soil column down to depths as great as 152 cm indicated relatively uniform Cl levels for a particular station at any given time. Also only small quantities of Cl were found in the soils taken from the fresh water table.

Ionic concentrations in standing water at swale Station 325 were found to range as follows: (1) Cl, 120 to 48.5, (2) Ca, 66.4 to 7.30, and (3) Mg, 10.5 to 8.1 $mg \cdot l^{-1}$. In swale Station 488 Cl concentration was found to remain relatively constant ranging from 94.4 to 113 $mg \cdot l^{-1}$. However, swale Station 625 is connected to Bogue Sound and the Cl content was found to be high and of considerable range (278 to 1456 $mg \cdot l^{-1}$). The Ca and Mg concentrations in swale Station 625 were in close agreement with those reported for swale Station 325.

Most non-flooded stations in the forest have a canopy dominated by *Quercus laurifolia* and/or *Q. virginiana*; while *Fraxinus tomentosa* dominated the canopy of all three swale stations. An inverse relationship (correlation coefficient of -0.87, P = 0.05) was found to exist between inputs of Cl and mean canopy height across the transect. Diversity of canopy species tended to increase away from the salt spray sources of the Atlantic Ocean and Bogue Sound.

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APPENDIX

Table A. Concentrations ($mg \cdot l^{-1}$) of Cl, Ca, and Mg in bulk precipitation over the entire study period, 8 December 1974 to 7 June 1976.

Collection date	Station 57 Cl	Station 57 Ca	Station 57 Mg	Station 124 Cl	Station 124 Ca	Station 124 Mg
28 Dec 74	51.2					
2 Feb 75	57.2					
2 Mar 75	55.2					
23 Mar 75	85.0			93.0		
27 Apr 75	92.4			73.0		
3 Jun 75	45.0			33.0		
26 Jun 75	79.5			28.8		
13 Jul 75	115.0	3.41		45.2	1.70	
1 Sep 75	49.7	2.00		48.5	2.00	
28 Sep 75	30.0	1.02		30.0	1.02	
25 Oct 75	32.0	1.07	1.22	38.0	1.43	1.43
6 Dec 75	48.2	2.04	2.24	38.3	2.03	1.84
21 Jan 76	78.0	1.29	1.33	32.3	1.28	1.33
11 Feb 76	36.8	1.28	1.28	20.9	0.72	0.61
2 Apr 76	70.0	2.81	4.38	148.0	12.80	25.20
7 Jun 76	87.2	1.63	2.42	287.0	3.23	7.32
Mean	62.7	1.84	2.15	70.5	2.91	6.29
Standard error	5.9	0.27	0.50	20.5	1.26	3.91

Appendix Table A. continued

Collection date	Station 168			Station 214		
	Cl	Ca	Mg	Cl	Ca	Mg
28 Dec 74	32.8			24.9		
2 Feb 75	24.6			21.9		
2 Mar 75	23.4			24.9		
23 Mar 75	47.0			41.0		
27 Apr 75	22.4			30.0		
3 Jun 75	15.0			18.0		
26 Jun 75	20.0			20.4		
13 Jul 75	29.8	1.34		37.3	1.87	
1 Sep 75	22.4	1.53				
28 Sep 75						
25 Oct 75	27.0	1.33	0.92	31.0	2.04	
6 Dec 75	25.3	1.95	1.22	24.9	2.21	
21 Jan 76	21.9	0.94	0.82			
11 Feb 76	19.9	0.77	0.61			
6 Apr 76	40.8	2.12	2.30			
7 Jun 76	93.9	4.85	4.34			
Mean	29.8	1.85	1.70	27.4	2.04	
Standard error	5.0	0.46	0.58	2.3	0.10	

Appendix Table A continued

Collection date	Station 264 Cl	Ca	Mg	Station 325 Cl	Ca	Mg
28 Dec 74				17.4		
2 Feb 75				13.4		
2 Mar 75	22.9			10.4		
23 Mar 75	70.0			29.0		
27 Apr 75	45.0			14.9		
3 Jun 75	24.0			9.9		
26 Jun 75	19.9			14.4		
13 Jul 75	29.8	0.85		13.4	0.51	
1 Sep 75	24.9	1.19		13.9	0.85	
28 Sep 75	17.0	0.85		12.0	0.85	
25 Oct 75	20.0	0.92	0.82	25.0	3.03	0.77
6 Dec 75	19.9	0.77	0.71	22.4	1.02	0.61
21 Jan 76	21.9	0.77	0.71			
11 Feb 76	28.8	0.85	1.12			
6 Apr 76	51.2	1.61	2.68			
7 Jun 76	34.2	6.43	8.28			
Mean	30.7	1.67	2.47	16.3	1.25	0.69
Standard error	4.0	0.60	1.20	1.7	0.45	0.08

Appendix Table A continued

Collection date	Station 396 Cl	Ca	Mg	Station 680 Cl	Ca	Mg
28 Dec 74				12.4		
2 Feb 75				14.9		
2 Mar 75				17.4		
23 Mar 75				26.0		
27 Apr 75				14.9		
3 Jun 75				9.9		
26 Jun 75				10.9		
13 Jul 75				11.9	0.34	
1 Sep 75	14.9	2.55		13.9	1.71	
28 Sep 75	14.0	2.50				
25 Oct 75	16.0	2.45	0.82	22.0	2.90	1.17
6 Dec 75	16.4	0.81	0.97	15.9	2.34	0.82
21 Jan 76	15.4	0.94	0.51	20.9	0.94	0.82
11 Feb 76						
6 Apr 76	29.8	1.95	1.36	28.8	1.61	1.28
7 Jun 76	25.8	1.07	1.07	17.4	0.71	0.66
Mean	18.9	1.75	0.95	16.9	1.51	0.95
Standard error	2.3	0.30	0.14	1.5	0.35	0.12

Appendix Table A continued

Collection date	Station 848 Cl	Ca	Mg	Station 879 Cl	Ca	Mg
28 Dec 74	14.9			10.9		
3 Feb 75	15.4			16.4		
2 Mar 75	10.4			29.8		
23 Mar 75	29.0			27.0		
27 Apr 75	19.9			15.0		
3 Jun 75				25.0		
26 Jun 75	14.9			14.9		
13 Jul 75	16.4	0.68		22.4	0.66	
1 Sep 75	29.3	1.19		52.2	2.21	
28 Sep 75	30.0	1.19		34.0	1.36	
25 Oct 75	24.0	1.53	0.92	209.0	4.94	6.12
6 Dec 75	16.9	1.53	0.71	28.0	1.79	1.43
21 Jan 76	11.4	0.59	0.31	14.4	0.59	0.51
11 Feb 76	17.4	0.64	0.41	17.4	0.59	0.36
6 Apr 76	25.3	1.19	1.23	71.6	2.12	4.16
7 Jun 76	24.4	0.82	0.95	24.4	0.97	2.04
Mean	20.0	1.04	0.76	38.3	1.69	2.44
Standard error	1.7	0.12	0.14	12.0	0.46	0.93

Table B. Total meterologic inputs ($g \cdot m^{-2}\ yr^{-1}$) of Cl, over the year 8 December 1974 to 6 December 1975, and of Cl, Ca, and Mg over the year 26 June 1975 to 7 June 1976. (Separation of inputs between rainfall and dry fallout were made using rainfall inputs calculated from Gambell and Fisher (1966).)

Station and ion		8 December 1974 to 6 December 1975			26 June 1975 to 7 June 1976		
		Total $g \cdot m^{-2} yr^{-1}$	% due to rainfall	% from dryfall	Total $g \cdot m^{-2} yr^{-1}$	% due to rainfall	% from dryfall
57*	Cl	107.0	9.7	90.3	92.2	10.1	89.9
	Ca				2.47	37.6	62.4
	Mg				2.66	35.4	64.6
124	Cl				104.0	8.9	91.1
	Ca				3.07	30.3	69.7
	Mg				6.67	14.1	85.9
168	Cl	35.4	29.3	70.7	54.6	17.0	83.0
	Ca				1.83	50.7	49.2
	Mg				1.47	64.1	35.9
214	Cl	31.7	32.7	67.3			
264	Cl				32.9	28.2	71.9
	Ca				2.49	37.3	62.7
	Mg				3.97	23.7	76.3
325	Cl	16.5	62.7	37.3			
396	Cl				20.0	46.3	53.7
	Ca				1.38	67.3	32.7
	Mg				0.99	95.2	4.8

680	Cl	20.9	49.5	50.5	24.0	38.7	61.3
	Ca				1.60	58.1	41.9
	Mg				1.10	85.7	14.3
848	Cl	33.3	31.2	68.8	31.9	29.1	70.9
	Ca				1.40	66.4	33.6
	Mg				1.18	79.8	20.2
879	Cl	52.7	19.7	80.3	53.6	17.3	82.7
	Ca				2.10	44.2	55.7
	Mg				3.07	30.7	69.3

*Station numbers are distances from the ocean in meters.

Table C. The topography indices (TI), calculated from the distance of a station in meters from the ocean (A), the distance from the sound in meters (D), and the elevation of a station above mean sea level (B, scale expanded to m X 100) are presented. Regression analysis between the TI's and atmospheric inputs of Cl ($g \cdot m^{-2} yr^{-1}$) over the second study year are also presented below. Y is atmospheric inputs and X is the TI.

DIST OC A	ELEVATION B	HYPOTENUSE C	C/A	DIST SND D	HYPOTENUSE E	E/D	TI	ATMOS INPUTS
57	213	220.5	3.8683	824	852.1	1.0328	3.9489	92.2
124	458	542.4	4.3740	758	885.6	1.1684	4.4651	104.0
168	528	554.1	3.2981	714	888.0	1.2437	3.3951	54.6
264	630	683.1	2.5874	618	882.5	1.4280	2.6988	32.9
396	135	418.4	1.0565	486	504.4	1.0379	1.1375	20.0
680	365	771.8	1.1350	202	417.2	2.0652	1.2961	24.0
848	14	848.1	1.0001	34	36.8	1.0814	1.0848	31.9
879	71	881.9	1.0033	3	71.1	23.6880	2.8509	53.6

$r = 0.91$, $P = 0.05$, $Y = 21.91\,X - 5.48$, where Y = ATMOS INPUTS and X = TI

Table D. Regression analysis between the calculated topographical indices (TI) and atmospheric inputs of Cl ($g \cdot m^{-2}$) over the first study year, 8 December 1974 to 6 December 1975.

Station	TF (x)	Meterologic inputs (y)
57	3.9489	107.0
168	3.3951	35.4
214	1.6152	31.7
325	1.0861	16.5
680	1.2961	20.9
848	1.0848	33.3
879	2.8509	52.7

$r = 0.80$ ($p = 0.05$) $b = 20.63$ $m = -2.4761$

$Y = 20.63\ X - 2.48$

*b = slope, m = y-intercept

Table E. Linear regression of calculated TI and atmospheric inputs of Ca in g·m^{-2}yr^{-1}.

Station	TI (x)	atmospheric inputs (y)
57	3.9489	2.47
124	4.4651	3.07
168	3.3951	1.83
264	2.6988	2.49
396	1.1375	1.38
680	1.2961	1.60
848	1.0848	1.40
879	2.8509	2.10

$r = 0.88$ $(p = 0.05)$ $b = 0.40$ $m = 0.98$

$Y = 0.40\ X + 0.98$

Table F. Linear regression of calculated TI and atmospheric inputs of Mg in g·m^{-2}yr^{-1}.

Station	TI (x)	atmospheric inputs (y)
57	3.9489	2.66
124	4.4651	6.67
168	3.3951	1.47
264	2.6988	3.97
396	1.1375	0.99
680	1.2961	1.10
848	1.0848	1.18
879	2.8509	3.07

$r = 0.75$ $P = 0.05$ $Y = 1.11\ X - 0.26$

Table G. Regression analysis between topography index and atmospheric salt inputs reported by Martin (1959). Salt was collected over short time periods and only when winds were onshore (therefore the topography index (TI) is defined by C/A only). Salt inputs are given here in $g \cdot m^{-2}$ and distance from the ocean in meters. Elevation is in m X 100. Transects I, II, IV, and VI were in forested areas and inputs were collected at canopy level. Transects III and V were in non-forested areas (salt collections were made at one foot and three feet above ground surface). Regression analyses was conducted using the total salt inputs (at both the one foot and three feet levels) of six "runs" for transects III and V.

TRANSECT I

STATION	DISTANCE OCEAN A	ELEVATION B	HYPOTENUSE (C) $C^2 = A^2 + B^2$	TOPOGRAPHY INDEX (C/A)	ATMOSPHERIC SALT INPUTS
1	40	183	187.3	4.6830	4.8
2	70	458	463.3	6.6188	4.5
3	100	458	468.8	4.6879	3.3
4	135	458	477.5	3.5369	2.9
5	180	305	354.2	1.9678	2.8
6	205	580	615.2	3.0008	2.6
7	240	275	365.0	1.5208	1.4
8	290	366	467.0	1.6102	1.6
9	275	488	560.2	2.0369	1.5
10	390	671	776.1	1.9900	2.0
11	459	458	648.4	1.4127	1.1
12	520	732	897.9	1.7267	0.9
13	610	732	952.9	1.5620	0.9
14	710	671	976.9	1.3759	0.7
15	780	336	849.3	1.0888	0.1

r = 0.90, P = 0.01, Y = 0.78 X + 0.06, (Y = ATMOSPHERIC INPUTS, X = TOPOGRAPHY INDEX)

TRANSECT II.

STATION	DISTANCE OCEAN A	ELEVATION B	HYPOTENUSE (C) $C^2 = A^2 + B^2$	TOPOGRAPHY INDEX (C/A)	ATMOSPHERIC SALT INPUTS
1	35	366	367.7	10.5048	4.7
2	75	1067	1070.1	14.2680	3.1
3	110	366	382.2	3.4734	2.3
4	200	366	417.1	2.0854	2.4
5	300	427	521.9	1.7395	2.0
6	350	854	922.9	2.6396	1.1
7	450	946	946.8	2.1040	0.7
8	600	946	1119.8	1.8663	0.7
9	600	153	619.2	1.0320	0.1

$r = 0.75$, $P = 0.05$, $Y = 0.23\ X + 0.09$

TRANSECT IV

1	50	549	551.3	11.0254	5.0
2	65	976	978.2	15.0486	4.7
3	95	671	677.7	7.1336	2.3
4	160	549	571.8	3.5740	1.9
5	210	366	422.0	2.0094	1.3
6	260	366	448.9	1.7267	1.5
7	370	610	713.4	1.9282	1.2
8	470	366	595.7	1.2672	0.6
9	510	153	532.3	1.0437	0.3

$r = 0.95$, $P = 0.01$, $Y = 0.32\ X + 0.51$

TRANSECT VI.

STATION	DISTANCE OCEAN A	ELEVATION B	HYPOTENUSE (C) $C^2 = A^2 + B^2$	TOPOGRAPHY INDEX (C/A)	ATMOSPHERIC SALT INPUTS
1	60	366	370.9	6.1814	5.1
2	80	488	494.5	6.1814	3.0
3	130	366	388.4	2.9877	2.2
4	180	580	606.8	3.3713	2.4
5	210	763	790.9	3.7661	2.2
6	330	397	515.9	1.5632	0.4
7	330	793	858.9	2.6028	2.2
8	450	397	599.8	1.3328	0.9
9	550	397	678.0	1.2328	0.8
10	630	305	699.9	1.1110	0.5
11	730	183	752.6	1.0309	0.6
12	830	183	849.9	1.0240	0.7
13	930	183	947.8	1.0192	0.5
14	1030	183	1046.1	1.0157	0.5
15	1030	305	1074	1.0429	0.6

$r = 0.94$, $P = 0.01$, $Y = 0.69 X - 0.12$

Table G continued. Collectors situated one foot and three feet above ground. No trees along transect. Distance from ocean is in meters and elevation in m X 100.

TRANSECT III.

STATION	DISTANCE OCEAN A	ELEVATION B	HYPOTENUSE (C) $C^2 = A^2 + B^2$	TOPOGRAPHY INDEX (C/A)	ATMOS SALT INPUT ONE FOOT	ATMOS SALT INPUT THREE FEET
1	50	366	369.4	7.3880	69.5	96.0
2	80	702	706.5	8.8318	58.2	67.5
3	90	1037	1040.9	11.5700	15.6	44.7
4	120	427	443.5	3.6962	12.8	22.5
5	165	610	631.9	3.8298	31.3	36.5
6	215	214	303.4	1.4109	8.4	15.1
7	285	397	488.7	1.7148	13.2	20.0
8	325	183	373.0	1.1476	4.9	10.3
9	385	122	403.9	1.0490	0.5	1.4

ONE FOOT: $r = 0.60$, $P = 0.10$, $Y = 3.77\,X + 6.78$ (Y = ATMOS INPUTS, X = TOPOG INDEX)
THREE FEET: $r = 0.74$, $P = 0.05$, $Y = 5.87\,X + 8.37$

TRANSECT V. No trees along transect.

STATION	DISTANCE OCEAN A	ELEVATION B	HYPOTENUSE (C) $C^2 = A^2 + B^2$	TOPOGRAPHY INDEX (C/A)	ATMOS SALT INPUT ONE FOOT	ATMOS SALT INPUT THREE FEET
1	30	366	367.2	12.2410	64.7	90.4
2	60	702	704.6	11.7427	35.7	47.2
3	110	1098	1103.5	10.0318	18.7	24.4
4	170	366	403.6	2.3738	4.9	13.2
5	250	702	745.2	2.9807	10.8	16.7
6	270	488	557.7	2.0656	3.8	5.2
7	435	610	749.2	1.7223	1.7	4.8
8	485	702	853.2	1.7593	0.7	1.0
9	735	183	757.4	1.0305	0.7	1.3

Table H. The water soluble Cl, Ca, and Mg content of soils taken over the period 1 July 1975 to 2 July 1976. All values are in μg· g soil $^{-1}$. (A,B,C indicate triplicate samples.)

STATION AND MINERAL			1975					1976			
			1 Jul	24 Jul	1 Sep	28 Sep	25 Oct	21 Jan	11 Feb	2 Jul	Annual Mean
124	Cl	A	26.8	21.4	27.2	26.3	19.9		14.9	18.9	
		B	27.3	38.3	51.5	52.2	48.7		13.9	22.3	
		C	14.9	12.9	27.4	25.3	28.8	19.4	14.4	36.8	
	Mean		23.0	24.2	35.4	34.6	32.7	19.4	14.4	26.0	26.2
	SE*		3.3	6.1	6.6	7.2	7.0	19.4	0.2	5.5	
	Ca	A	2.04	0.94	1.36	1.22	0.71		0.51	0.69	
		B	2.35	2.89	2.77	1.33	1.82		0.42	1.03	
		C	1.33	0.94	1.19	1.15	0.65	0.62	0.51	0.68	
	Mean		1.91	1.59	1.77	1.23	1.06	0.62	0.48	0.80	1.18
	SE		0.25	0.53	0.41	0.05	0.31	0.62	0.03	0.12	
	Mg	A					0.41		0.20	0.20	
		B							0.23	0.42	
		C					0.50	0.40	0.23	0.58	
	Mean						0.46	0.40	0.22	0.40	0.37
	SE						0.05	0.40	0.01	0.11	
264	Cl	A	20.4	20.4	22.4	21.9	20.9	13.9	12.9	16.9	
		B	15.9	9.9	32.1	13.4	17.4		11.4	17.9	
		C	30.3		18.6		14.9		12.4	12.9	
	Mean		23.1	15.2	27.3	17.7	17.7	13.9	12.2	15.9	17.9
	SE		4.2	5.3	4.9	4.3	1.7	13.9	0.4	1.5	

STATION AND			1975					1976			
MINERAL			1 Jul	24 Jul	1 Sep	28 Sep	25 Oct	21 Jan	11 Feb	2 Jul	Annual Mean
264	Ca	A	0.68	2.38	1.36	2.09	0.99	0.83	0.38	0.51	
		B	0.71	0.59	0.85	1.75	0.51		0.42	0.55	
		C	0.74	1.28	1.02	1.63	0.53		0.33	0.51	
	Mean		0.71	1.42	1.08	1.82	0.68	0.83	0.38	0.52	0.93
	SE		0.02	0.52	0.15	0.14	0.16	0.83	0.03	0.01	
	Mg	A					0.52	0.53	0.15	0.18	
		B					0.17		0.19	0.20	
		C					0.27		0.23	0.22	
	Mean						0.32	0.53	0.19	0.20	0.31
	SE						0.10	0.53	0.03	0.01	
396	Cl	A	3.0	11.9	33.9	18.9	20.9	12.4	7.0	11.3	
		B	11.4			13.9	13.4		9.9	16.2	
		C	11.4			29.8	16.9		12.9	17.1	
	Mean		8.6	11.9	33.9	20.9	17.1	12.4	9.9	14.9	16.9
	SE		2.8	11.9	33.9	4.7	2.2	12.4	1.7	1.8	
	Ca	A	0.34	0.85	1.02	1.02	0.37	0.59	0.41	0.43	
		B	0.34			0.71	0.41		0.52	0.36	
		C	0.38	3.07		6.72	0.62		0.44	0.62	
	Mean		0.35	1.96	1.02	2.82	0.47	0.59	0.44	0.49	1.02
	SE		0.01	1.11	1.02	1.95	0.08	0.59	0.04	0.08	
	Mg	A					0.28	0.42	0.10	0.18	
		B					0.13		0.26	0.21	

STATION AND MINERAL			1975					1976			
			1 Jul	24 Jul	1 Sep	28 Sep	25 Oct	21 Jan	11 Feb	2 Jul	Annual Mean
396	Mg	C					0.43		0.23	0.30	
	Mean						0.28	0.42	0.20	0.23	0.28
	SE						0.09	0.42	0.05	0.04	
680	Cl	A	12.9	41.7	38.5	14.4	12.9	11.9	14.4	17.9	
		B	18.4		21.2	28.8	16.4		25.3	19.9	
		C	14.4	17.5	31.3	14.9	27.3		16.9	27.8	
	Mean		15.2	29.6	30.3	19.4	18.9	11.9	18.9	21.9	20.8
	SE		1.6	12.1	5.0	4.7	4.3	11.9	3.3	3.0	
	Ca	A	0.54	2.63	2.72	1.94	1.99	0.81	0.41	0.66	
		B	1.53		5.78	1.63	1.53		1.20	0.97	
		C	0.54	1.10	3.23	7.63	1.64		0.42	1.19	
	Mean		0.87	1.87	3.91	3.73	1.72	0.81	0.68	0.94	1.82
	SE		0.33	0.77	0.95	1.95	0.14	0.81	0.26	0.15	
	Mg	A					0,78	0.38	0.12	0.22	
		B					1.32			0.54	
		C					0.94		0.22	0.90	
	Mean						1.05	0.38	0.17	0.55	0.54
	SE						0.27	0.38	0.05	0.20	

*INDICATES ONE STANDARD ERROR

Table I. Soil moisture data, as percent dry weight of soil, for triplicate samples taken at each of four stations selected for mineral budget analysis is given.

		1975					1976			
Station		1 Jul	24 Jul	1 Sep	28 Sep	25 Oct	21 Jan	11 Feb	2 Jul	Annual $\bar{x}$
57	A	4.30	4.75	5.50	9.62	6.80	-	7.00	8.50	
	B	6.92	9.10	5.80	10.90	2.60	-	8.10	7.11	
	C	4.95	3.36	2.43	6.54	5.30	7.20	5.90	5.10	
Mean		5.39	5.74	4.58	9.02	4.90	7.20	7.00	6.90	6.38
SE*		0.79	1.73	1.08	1.29	1.23	7.20	0.64	0.99	0.50
264	A	6.86	6.34	-	1.85	5.40	7.10	6.70	9.70	
	B	6.20	5.62	5.20	28.82	6.40	-	6.80	11.01	
	C	7.03	9.95	1.12	7.16	6.40	-	6.50	8.30	
Mean		6.70	7.30	3.16	12.61	6.07	7.10	6.63	9.67	7.41
SE		0.25	1.34	2.23	8.25	0.33	7.10	0.07	0.78	0.97
396	A	8.42	8.53	2.68	14.78	4.70	-	8.70	9.10	
	B	7.84	-	-	8.01	5.90	10.40	12.00	10.71	
	C	13.43	17.22	-	33.20	6.10	-	8.00	9.30	
Mean		9.90	12.88	2.68	18.66	5.57	10.40	9.57	9.70	9.92
SE		1.77	9.11	2.68	7.53	0.44	10.40	1.24	0.51	1.67
680	A	4.66	5.29	3.95	12.26	4.90	8.10	6.60	10.10	
	B	5.14	-	-	5.92	5.40	-	5.20	5.71	
	C	5.56	3.65	3.75	5.86	1.40	-	5.40	4.90	
Mean		5.12	4.47	3.85	8.01	3.90	8.10	5.73	6.90	5.76
SE		0.26	3.16	2.72	2.12	1.26	8.10	0.44	1.62	0.61

*Indicates one standard error from the mean

Table J. The total available (soluble plus exchangeable), as determined by extraction with ammonium acetate (pH = 7.0), is given. Samples were taken over the period 1 July 1975 to 2 July 1976. All values are in μg· g soil $^{-1}$. (A,B,C indicate triplicate samples.)

Station	1975					1976		
and ion	1 Jul	24 Jul	1 Sep	28 Sep	25 Oct	21 Jan	11 Feb	2 Jul
124 Ca								
A	68.8	26.5	29.1	18.2	15.7		34.5	41.6
B	239.4	127.5	98.7	20.8	54.5		18.4	25.7
C	78.9	20.6	29.0	28.2	11.7	18.4	15.5	31.6
Mean	129.0	58.2	52.3	22.4	27.3	18.4	22.8	33.0
SE*	55.3	34.7	23.2	3.0	13.6	18.4	5.9	4.6
			Annual Mean = 45.4					
Mg								
A					9.4		7.9	19.1
B					9.5		8.9	12.3
C					24.1	9.0	5.6	17.1
Mean					14.3	9.0	7.5	16.2
SE					4.9	9.0	1.0	2.0
			Period Mean = 11.8					
264 Ca								
A	44.6	57.3	41.2	32.2	41.8	33.7	18.5	22.0
B	30.9	11.8	23.6	23.9	12.3		12.9	125.0
C	32.5	26.6	29.8	90.3	15.2		11.5	26.1
Mean	36.0	31.9	31.5	48.8	23.1	33.7	14.3	57.7
SE	4.3	13.4	5.2	20.9	9.4	33.7	2.2	33.7
			Annual Mean = 34.6					
Mg								
A					13.7	11.9	8.9	12.4
B					6.2		8.0	24.4
C					7.8		5.9	19.1
Mean					9.2	11.9	7.6	18.6
SE					2.3	11.9	0.9	3.5
			Period Mean = 11.8					

Table J continued

Station and ion	1975					1976		
	1 Jul	24 Jul	1 Sep	28 Sep	25 Oct	21 Jan	11 Feb	2 Jul
396 Ca								
A	40.3	38.7	23.6	38.5	8.5	20.6	14.4	16.3
B	39.5			28.1	9.3		50.1	
C		149.2		48.9	37.9		34.8	
Mean	39.9	94.0	23.6	38.5	18.6	20.6	33.1	16.3
SE	0.4	55.3	23.6	6.0	9.7	20.6	10.3	16.3
Annual Mean = 35.6								
Mg								
A					6.4	9.3	10.4	9.1
B					5.9		20.6	
C					18.3		14.5	
Mean					10.2	9.3	15.2	9.1
SE					4.1	9.3	3.0	9.1
Period Mean = 11.0								
680 Ca								
A	37.7	46.3	40.8	53.1	39.7	32.0	18.1	22.2
B	50.1		70.0	19.8	13.5		41.2	52.1
C	27.6	20.7	46.5	31.1	37.2		11.4	21.7
Mean	38.5	33.5	52.4	34.7	30.1	32.0	23.6	32.0
SE	6.5	12.8	8.9	9.8	8.3	32.0	9.0	10.1
Annual Mean = 34.6								
Mg								
A					8.9	8.8	6.5	10.5
B					8.7		12.6	19.7
C					10.1		5.8	11.5
Mean					9.2	8.8	8.3	13.9
SE					0.4	8.8	2.2	2.9
Period Mean = 10.1								

Appendix Table K. Quantities of water (in cm) in throughfall over the period 26 June 1975 to 7 June 1976. All twelve gages at the four stations are considered together. (A,B,C indicate triplicate samples.)

Station		COLLECTION PERIODS 1975						1976			
		13 Jul	24 Jul	1 Sep	28 Sep	25 Oct	6 Dec	21 Jan	11 Feb	6 Apr	7 Jun
124	A	7.71	2.82	8.05	14.41	6.38	3.22	13.84	10.79	4.35	18.33
	B	5.58	0.68	5.00	7.97		2.32	7.06	5.88	3.70	14.24
	C	11.11	8.53	22.60	19.77	15.59	2.77	16.78	22.60	2.06	16.95
264	A	11.58	0.64	9.18	13.79	6.27	3.45	11.30	13.25		23.73
	B	8.42	0.68	10.08	12.15		2.71		6.24		17.71
	C	8.76	0.65	6.36	12.77	6.38	3.33	10.34	9.27	5.14	19.42
396	A	12.85	1.00	9.04	13.56	6.44	3.45	12.34	8.59	5.17	
	B	9.81			13.64	5.14	2.82	10.03	5.82	3.67	18.14
	C	8.76				4.07	1.98	7.40	7.57	4.29	17.71
680	A	15.14	0.42	8.33		7.23	2.09	11.30	15.48	5.51	21.53
	B		0.27	6.03	7.06	2.99	1.81	5.65	5.37	2.97	11.86
	C	8.98	0.42	8.90	11.92	5.08	2.99	7.68	7.85	4.86	22.03
Mean		9.80	1.58	9.41	12.70	6.56	2.74	10.34	9.89	4.27	18.33
SE		0.78	0.81	1.56	1.11	1.08	0.17	0.99	1.46	0.34	1.02
% deviation		7.9	51.1	16.6	8.7	16.5	6.1	9.6	14.8	8.2	5.6

Table L. Concentrations of Cl, Ca, and Mg (in mg·l^{-1}) in throughfall collected over the period 26 June 1975 to 7 June 1976. (A, B, C indicate triplicate samples.)

Station and ion	1975						1976				Annual mean
	13 Jul	24 Jul	1 Sep	28 Sep	25 Oct	6 Dec	21 Jan	11 Feb	6 Apr	7 Jun	
124 Cl											
A	55.2	43.2	45.7	35.0	57.2	59.6	93.8	38.8	130.7	353.4	
B	56.7	58.6	50.2	43.0	42.7	57.2	50.2	39.3	97.9	45.2	
C	65.1	59.1	145.6	89.0	107.0	129.0	104.9	64.1	289.8	38.4	
Mean	59.0	53.6	80.5	68.1	68.4	71.8	83.0	47.4	172.8	145.7	85.0
SE	3.1	5.2	32.5	17.3	12.5	10.7	16.7	8.4	59.3	103.9	
Ca											
A	3.40	2.46	4.12	3.06	6.67	5.72	3.37	1.60	12.80	3.27	
B	3.06	3.06	4.08	3.06	3.26	4.04	2.55	1.79	9.14	2.42	
C	4.59	1.70	7.31	3.33	3.88	5.89	3.54	2.53	14.14		
Mean	3.68	2.41	5.17	3.15	4.60	5.22	3.15	1.97	12.03	2.85	4.28
SE	0.46	0.39	1.07	0.09	1.05	0.59	0.31	0.28	1.49	0.43	
Mg											
A					1.63	4.04	2.02	1.31	10.50	1.07	
B					3.37	5.20	3.52	2.14	7.07	2.68	
C					5.61	9.09	6.06	3.84	21.60		
Mean					3.54	6.11	3.87	2.43	13.06	1.88	5.15
SE					1.15	1.53	1.18	0.75	4.38	0.81	
264 Cl											
A	35.8	71.1		30.0	34.0	39.3	47.2	25.4		24.8	
B	36.3	33.3	18.4	17.0	38.0	30.3		30.3		24.8	
C	51.7	48.7		25.0	33.0	43.0	30.3	20.9	45.2	24.4	
Mean	41.3	51.0	18.4	24.0	35.0	37.5	38.8	25.5	45.2	24.7	34.1
SE	5.2	10.9	18.4	3.8	1.5	3.8	8.5	2.7	45.2	0.1	

Station and ion	1975 13 Jul	24 Jul	1 Sep	28 Sep	25 Oct	6 Dec	1976 21 Jan	11 Feb	6 Apr	7 Jun	Annual mean
264 Ca											
A	1.70	4.08		2.38	2.09	2.83	2.47	1.36		1.33	
B	1.36	1.87	1.36	1.02	4.23	1.57		1.36		1.02	
C	2.72	6.63		1.53	1.99	3.14	1.74	1.10	2.71	1.28	
Mean	1.93	4.19	1.36	1.64	2.77	2.51	2.11	1.27	2.71	1.21	2.17
SE	0.41	1.38	1.36	0.40	0.73	0.48	0.37	0.09	2.71	0.10	
Mg											
A					2.09	2.96	2.45	1.22		1.22	
B					2.45	1.53		1.53		0.96	
C					1.63	2.96	1.53	0.92	3.06	1.62	
Mean					2.06	2.48	1.99	1.22	3.06	1.27	2.01
SE					0.24	0.48	0.46	0.18	3.06	0.19	
396 Cl											
A		30.8	14.9	19.0	30.0	29.8	24.4	21.4	34.8		
B	23.4	26.3		20.0	23.0	27.3	21.4	13.9	36.3	15.4	
C	20.4	22.4	21.4		27.0	37.3	22.4	18.4	35.3	23.9	
Mean	21.9	26.5	18.2	19.5	26.7	31.5	22.7	17.9	35.3	19.7	24.0
SE	1.5	2.4	3.3	0.5	2.0	3.0	0.9	2.2	0.4	4.3	
Ca											
A		2.21	2.55	1.53	1.63	3.61	1.70	0.93	9.60		
B	1.19			1.19	1.38	3.14	1.66	1.02	3.91	1.73	
C	1.70	1.19	3.91		3.47	8.08	2.72	1.44	4.41	3.16	
Mean	1.45	1.70	3.23	1.36	2.16	4.94	2.03	1.13	5.97	2.45	2.64
SE	0.26	0.51	0.68	0.17	0.66	1.57	0.35	0.16	1.82	0.72	

Station and ion	13 Jul	24 Jul	1 Sep	28 Sep	25 Oct	6 Dec	21 Jan	11 Feb	6 Apr	7 Jun	Annual Mean
		1975					1976				
396 Mg											
A					1.17	2.81	2.02	0.82	6.48		
B					1.12	2.40	1.72	0.61	3.48	1.36	
C					2.55	6.87	2.32	0.92	4.21	1.82	
Mean					1.61	4.03	2.02	0.78	4.72	1.59	2.46
SE					0.47	1.43	0.17	0.09	0.90	0.23	
680 Cl											
A	36.7	100.4	37.3	29.0	44.0	48.2	34.8	24.8	79.0	39.3	
B	48.5	70.1	25.8	27.0		34.8	33.8	20.9	50.2	35.8	
C	35.8	48.7	36.8	27.0	35.0	33.3	37.3	23.9	54.2	33.3	
Mean	40.3	73.1	30.0	27.7	39.5	38.8	35.3	23.2	61.1	36.1	40.5
SE	4.2	15.0	3.7	0.7	4.5	4.7	1.0	1.2	9.0	1.7	
Ca											
A	2.72		4.93	3.06	5.25	5.64	3.62	1.19	9.60	3.21	
B	2.55	4.76	2.55	2.89		3.74	2.53	1.53	3.91	2.24	
C	1.87	3.74	2.72	1.53	2.60	3.48	3.11	1.28	4.41	1.84	
Mean	2.38	4.25	3.40	2.49	3.93	4.29	3.09	1.33	5.97	2.43	3.36
SE	0.26	0.51	0.77	0.48	1.33	0.68	0.31	0.10	1.82	0.41	
Mg											
A					1.33	4.04	2.02	1.12	1.83	2.14	
B					1.89	2.65	1.72	1.02	3.62	1.84	
C					1.63	2.35	2.32	1.02	4.37	1.79	
Mean					1.62	3.01	2.02	1.05	3.27	1.92	2.15
SE					0.16	0.52	0.17	0.03	0.75	0.11	

Table M. The Cl, Ca, and Mg content (in g·m^{-2}) of throughfall over the period 26 June 1975 to 7 June 1976. (A,B,C indicate triplicate samples.)

Station	1975						1976				Mean
and ion	13 Jul	24 Jul	1 Sep	28 Sep	25 Oct	6 Dec	21 Jan	11 Feb	6 Apr	7 Jun	Total
124 Cl											
A	4.26	1.23	2.63	5.08	3.65	1.93	5.50	4.21	5.69	64.78	
B	3.32	0.40	2.51	3.40		1.33	3.54	2.32	3.62	6.44	
C	7.25	5.06	32.80	17.69	16.66	3.60	17.60	14.57	5.98	6.50	
Mean	4.94	2.23	12.68	8.72	10.16	2.29	8.88	7.03	5.10	25.91	87.9
SE*	1.18	1.43	10.11	4.51	6.51	0.68	4.40	3.81	0.74	19.44	
Ca											
A	0.26	0.03	0.36	0.44	0.42	0.18	0.47	0.17	0.40	0.60	
B	0.18	0.01	0.20	0.24	0.08	0.09	0.18	0.11	0.20	0.35	
C	0.51	0.04	1.65	0.67	0.06	0.16	0.59	0.57	0.29		
Mean	0.32	0.03	0.74	0.45	0.18	0.15	0.41	0.29	0.30	0.47	3.35
SE	0.10	0.01	0.46	0.12	0.12	0.03	0.12	0.15	0.06	0.13	
Mg											
A					0.10	0.13	0.28	0.14	0.46	0.20	
B					0.08	0.12	0.25	0.13	0.26	0.38	
C					0.88	0.25	1.02	0.87	0.45		
Mean					0.35	0.17	0.52	0.38	0.39	0.29	2.10
SE					0.26	0.04	0.25	0.25	0.07	0.09	
264 Cl											
A	4.15	0.45		4.10	2.15	1.36	5.34	3.38	1.89	5.90	
B	3.06	0.22	1.86	2.12		0.83		1.90		4.42	
C	4.54	0.32		3.17	2.09	1.45	3.31	1.95	2.33	4.73	
Mean	3.92	0.33	1.86	3.13	2.12	1.21	4.32	2.41	2.11	5.02	26.4
SE	0.44	0.07	1.86	0.57	0.03	0.19	1.02	0.49	0.22	0.45	

Station and ion	1975						1976				Mean Total
	13 Jul	24 Jul	1 Sep	28 Sep	25 Oct	6 Dec	21 Jan	11 Feb	6 Apr	7 Jun	
264 Ca											
A	0.20	0.02		0.33	0.13	0.10	0.28	0.18	0.11	0.32	
B	0.11	0.01	0.14	0.12	0.13	0.04	0.23	0.09		0.18	
C	0.24	0.04		0.20	0.13	0.11	0.18	0.10	0.15	0.25	
Mean	0.18	0.03	0.14	0.22	0.13	0.08	0.23	0.12	0.13	0.25	1.51
SE	0.04	0.01	0.14	0.06	0.01	0.02	0.03	0.03	0.02	0.04	
Mg											
A					0.13	0.10	0.28	0.16	0.12	0.29	
B					0.07	0.04	0.16	0.10	0.07	0.17	
C					0.10	0.10	0.08	0.09	0.15	0.31	
Mean					0.10	0.08	0.17	0.12	0.11	0.26	0.84
SE					0.02	0.02	0.06	0.02	0.02	0.05	
396 Cl											
A		0.20	1.71	2.56	1.92	1.03	3.01	1.85	1.80	3.65	
B	2.30		0.82	2.78	1.20	0.78	2.14	0.81	1.33	2.79	
C	1.79				1.09	0.74	1.66	1.40	1.52	4.23	
Mean	2.05	0.20	1.66	2.67	1.40	0.85	2.27	1.35	1.55	3.56	17.6
SE	0.26	0.20	0.31	0.11	0.26	0.09	0.40	0.30	0.14	0.42	
Ca											
A		0.01	0.37	0.21	0.11	0.13	0.21	0.08	0.11	0.45	
B	0.12		0.15	0.16	0.07	0.09	0.15	0.06	0.07	0.31	
C	0.15				0.18	0.16	0.20	0.11	0.16	0.56	
Mean	0.13	0.01	0.26	0.19	0.12	0.13	0.19	0.08	0.11	0.44	1.65

Station and ion	13 Jul	24 Jul	1 Sep	28 Sep	25 Oct	6 Dec	21 Jan	11 Feb	6 Apr	7 Jun	Mean Total
396 Mg											
A					0.06	0.10	0.16	0.17	0.12		
B					0.06	0.07	0.13	0.04	0.07	0.25	
C					0.13	0.14	0.14	0.07	0.15	0.32	
Mean					0.08	0.10	0.14	0.06	0.11	0.05	0.55
SE					0.03	0.02	0.01	0.01	0.02	0.03	
680 Cl											
A	5.50	0.88	3.11		3.20	1.01	3.93	3.87	4.35	8.45	
B		0.19	1.56	1.94		0.63	1.91	0.13	1.49	4.24	
C	3.22	0.21	2.38	3.20	1.79	1.00	2.86	1.88	2.63	7.34	
Mean	4.36	0.43	2.35	2.57	2.50	0.88	2.90	2.29	2.82	6.68	27.8
SE	1.14	0.23	0.45	0.63	0.71	0.13	0.53	0.82	0.83	1.26	
Ca											
A	0.41		0.41		0.38	0.12	0.41	0.19	0.53	0.69	
B		0.01	0.15	0.20		0.07	0.14	0.08	0.12	0.27	
C	0.17	0.02	0.24	0.18	0.13	0.10	0.24	0.10	0.21	0.41	
Mean	0.29	0.02	0.27	0.19	0.26	0.10	0.26	0.12	0.29	0.45	2.25
SE	0.12	0.01	0.08	0.01	0.12	0.02	0.08	0.03	0.12	0.13	
Mg											
A					0.10	0.08	0.23	0.18	0.36	0.46	
B					0.12	0.05	0.10	0.06	0.10	0.22	
C					0.01	0.07	0.18	0.08	0.20	0.40	
Mean					0.11	0.07	0.17	0.10	0.22	0.36	1.02
SE					0.01	0.01	0.04	0.04	0.08	0.07	

*Indicates one standard error from the mean