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The Correlation of Soil Algae, Airborne Algae, and Fern Spores with Meteorological Conditions on the Island of Hawaii[1]

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ABSTRACT: Correlations of the generic diversity of soil and airborne algae with altitude on the island of Hawaii are noted. Distribution of the soil algae was determined by culturing an aqueous soil extract from designated altitudes on agarized inorganic growth media. Distribution of airborne algae and fern spores was determined by investigations of viable particulate impactions on the surface of agarized inorganic growth media identical to that used in culturing the soil samples.

Little correlation occurs between the generic diversity of the airborne and soil algae at corresponding altitudes, which suggests a cosmopolitan mixing of airborne propagules that have been released from different altitudes. However, striking relationships were noted in the quantitative determinations of airborne green and blue-green algae and of fern spore impactions with the varying meteorological conditions of rain, fog-mist, and clear, sunny conditions accompanying the altitude change.

INTRODUCTION

THE HAWAIIAN ISLANDS of the Pacific Ocean are ideal natural sites for many scientific inquiries, particularly for studies of atmospheric dispersal both of microorganisms and higher plants (Brown 1965, 1971). The advantages of the islands for such investigations are twofold. First, the islands lie at least 2000 miles from any major land mass, and the prevalent northeast trade winds carry few viable disseminules over the many miles of ocean and into the islands. The ability of the marine environment to "scrub" particulates from the atmosphere has been observed and reported (Glynn 1933, Stepanov 1935, May 1958, Davies 1959, Brown 1971, and personal communication). Viable airborne microorganisms have been collected and cultured from air samples over the islands, suggesting that release and dispersal of these particulates is largely an activity of each individual island (Brown 1971). Secondly, weather conditions throughout the islands are highly uniform and predictable (Jones 1939, Leopold and Stidd 1949). Such conditions more readily permit analysis and modelling of dispersal mechanisms and patterns. The trade winds and the barriers provided by the topography of the islands constitute the principle variations in weather conditions (Doty and Mueller-Dombois 1966). These factors at times result in extreme variations of climate within very short distances. Humidity can vary from 0 to 100 percent within distances of several tens of miles, and temperatures can vary from 90° F at sea level to below zero at the summits of tall mountains (Carlquist 1970).

Studies of atmospheric dispersal of algae have received greater acknowledgment in recent years with concurrent findings that airborne algae and other airborne microbes are causal agents in inhalant allergies and other respiratory disorders (Hatch 1961; McElhenney et al. 1962; McGovern, McElhenney, and Brown 1965; Bernstein and Safferman 1966, 1970). Extensive studies of airborne fungal and bacterial particulates have been conducted (Pady and Gregory 1963, Pathak and Pady 1965, Pady and Kramer 1967). However, it has been shown that algae may be predominant members of the aerial flora and that algae are important colonizers of isolated land areas

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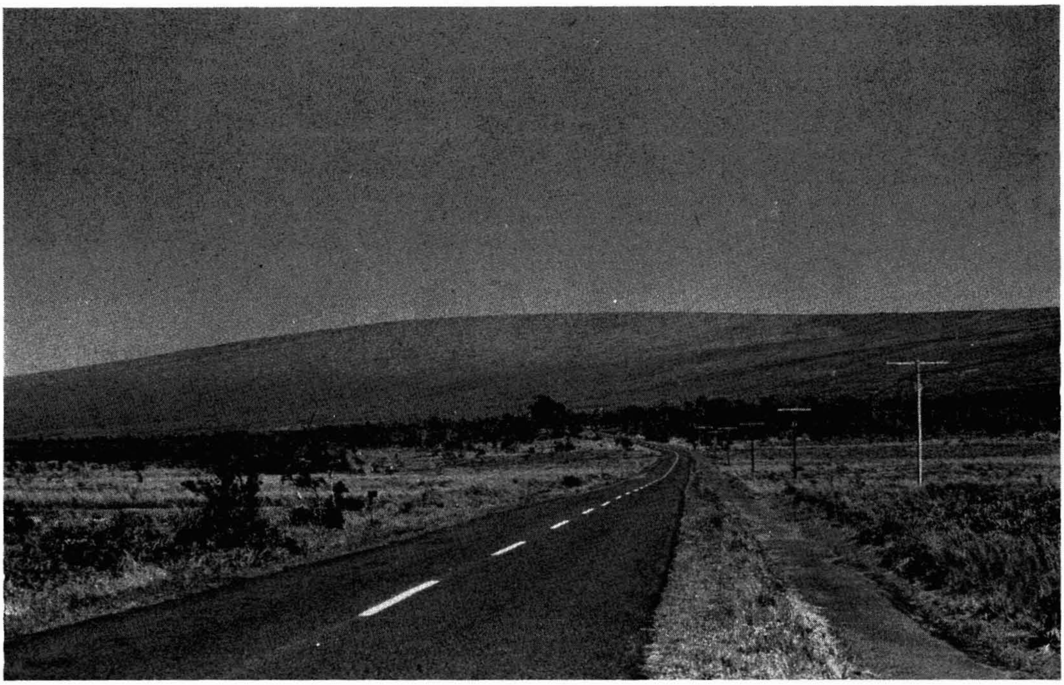

FIGURE 1. View of Mauna Loa and a portion of the Mauna Loa transect looking northwest at approximately 4000 feet above sea level.

(Brown 1965) and bodies of water (Maguire 1963).

Schlichting's studies (1961, 1964, 1969, 1971) include the collection of viable airborne algae and protozoa and the correlation of meteorological conditions with their dispersal. He noted the relationship of the aerial biota with the movement of air masses, but emphasized a greater correlation of the aerial flora with the micrometeorological conditions within the air mass.

Hawaii, the "Big Island," is an excellent site to investigate the variations among airborne algae with altitude and changing meteorological conditions within short geographical distances. Within a distance of 50 miles is an altitudinal gradient from sea level to 6500 feet as well as meteorological conditions that may vary from extensive rain downpours at the lower elevations to dry, sunny conditions at the higher altitudes. This is due to several features of the meteorological regime of the island. First, Hawaii, like the other islands of the chain, is influenced by orographic rainfall. This is particularly evident along the northeastern Hamakua Coast of the island. Secondly, high mountain masses like Mauna Loa (Figures 1 and 2), being very broad and wide, absorb great quantities of heat during the day, forming updrafts toward the summit. During the afternoon, air surrounding the mountains is rapidly drawn upward and the moisture it contains can be condensed rapidly. This can result in extensive rainfall on the lower slopes, tapering off to light showers higher up, and clear sunny conditions at higher altitudes (Carlquist 1970). Finally, the two preceding features may be influenced further by the inversion layer, which generally occurs from 5000 to 7000 feet. Such conditions result in a predictable variation of the soil algal flora. This, in turn, mediates the dispersal of biologically significant materials with potential reproductive capacity.

It is important that inquiries be made into the nature of dispersal in various geographical distances under predictable and consistent meteorological conditions. The transect described here is on the order to 50 miles through

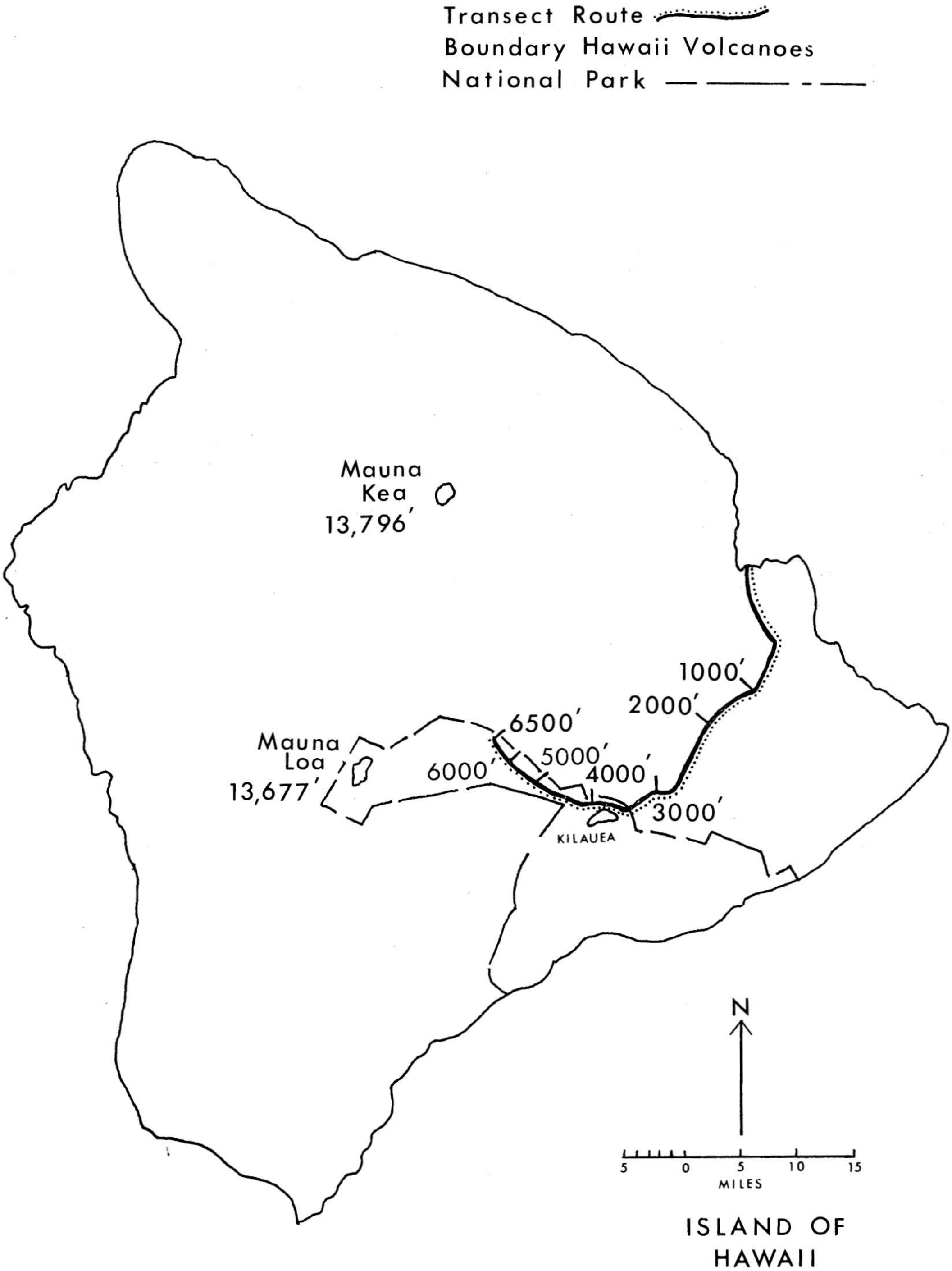

FIGURE 2. Map of the island of Hawaii showing the transect route.

areas of pronounced meteorological changes (Figure 2). A similar scheme has been described by Brown (1963), which was on the order of 15 miles and which also ranged through zones of marked meteorological changes.

MATERIALS AND METHODS

During the summer of 1971, a transect was set up on the island of Hawaii from the coastal city of Hilo up to 6500 ft on the slopes of Mauna Loa. Soil samples were collected aseptically in sterile plastic bags from the top 1.0 inch of the substrate at 1000-ft-altitude intervals and packaged and sent by air to our laboratory at the University of North Carolina. There, 5 g of each soil sample were suspended in 30 ml of Bold's Basal Media (BBM) (Brown and Bold 1964), sonicated mildly, and 0.5 ml of the suspension was cultured on each of three Petri dishes of agarized BBM. The cultures were inspected for algal generic diversity after being incubated for 1 month on a continuous light cycle of approximately 7000 lux and 19° C. During the autumn of 1973, the same transect was made; sterile Petri dishes of agarized BBM were exposed at 500-ft-altitude intervals for 1 minute each from an automobile traveling at 35 miles per hour from Hilo to 6500 ft on Mauna Loa. The air-sampling transect was made two times at different hours of the day under similar meteorological conditions. These plates were incubated for 1 month on a continuous light cycle of approximately 3500 lux and 19° C. Determinations of algal generic diversity were made as well as quantitative colony counts of the different taxa of airborne algae and fern spore impactions as a function of viable fern gametophytes observed. Results are a total of the two exposures made at each designated altitude.

The collection sites can be described briefly by altitude as follows: 0–2000 feet, urban-agricultural (sugarcane); 2000–4000 feet, wet upland forest (*Metrosideros-Cibotium*); 4000–6500 feet, dry upland forest (*Metrosideros-Acacia*).

RESULTS AND DISCUSSION

Cultures made from soil samples indicated that the greatest generic diversity of the soil algae occurs at an altitude of 4000 ft (Figure 3). Concurrently with these data, Figure 4 indicates that the generic diversity of airborne algae is also quite high at these altitudes. This area may be considered wet upland forest, and rainfall is sufficient to support a lush growth of many plants (Carlquist 1970). The persistence of the orographic cloud cover at this altitude further enhances the effect of the rain, as little evaporation occurs.

Relatively little correlation is apparent between the generic diversity of the soil algae and the airborne algae at the same altitude. The greatest coincidence of generic similarity of soil and airborne algae occurs at the 3000-ft level, an area permeated by fog-mist conditions, which may assist in the redeposition of viable particulates on a small scale. It seems apparent, however, that dispersal at other altitudes is little related to the soil flora at that altitude and, in fact, that some generic exchange of the air spora between altitudes may occur. Such an interaltitude exchange of particulates may be derived from daytime updrafts and convection. The released airborne particles may then be washed out or deposited by other mechanisms such as gravitation or turbulent deposition.

An extensive downpour occurred at the lower altitudes (1000–2000 ft) at the time of the air-sampling experiments. However, at altitudes of 2500–3000 ft, weather conditions were those of the fog-mist characteristic of this area. At those sampling stations 4000–6500 ft in altitude, conditions ranged from partly cloudy with intermittent sunshine to an almost perfectly clear atmosphere with visibility up to 20 miles.

Quantitative counts of the colonies of the Chlorophyceae, Cyanophyceae, and of viable fern spore impactions showed sharp contrast with changing meteorological conditions moving up the gradient. Data from the air samples (Figure 5) taken at the lower altitudes (1000–2000 ft) suggest that a fairly quantitative washout of viable airborne algae and fern spores occurs due to the extensive rainfall. This

Algal Genera Isolated from the Soil

Altitude (ft.) →	1000	2000	3000	4000	5000	6000
Characium sp.				▒		
Chlorella sp.	▒	▒	▒	▒	▒	▒
Chlorococcum sp.		▒	▒		▒	▒
Gloeocystis sp.				▒	▒	
Hormidium sp.	▒	▒	▒	▒	▒	▒
Nannochloris sp.				▒		
Phacotus sp.				▒		
Protococcus sp.		▒	▒		▒	▒
Stichococcus sp.		▒		▒		
Trebouxia sp.				▒		
Anabaena sp.					▒	
Hydrocoleum sp.						▒
Lyngbya sp.	▒	▒	▒	▒		
Nostoc sp.		▒			▒	▒
Phormidium sp.	▒		▒	▒	▒	▒
Plectonema sp.				▒		
Polycystis sp.				▒	▒	▒
Rivularia sp.				▒		
Scytonema sp.				▒		
Tolypothrix sp.				▒		
Botrydiopsis sp.				▒		
Monallantus sp.	▒	▒	▒	▒	▒	
Navicula sp.				▒		
Total Number Genera of Chlorophyceae	2	5	4	8	5	4
Total Number Genera of Cyanophyceae	2	2	2	7	4	4
Total Number Genera of Xanthophyceae	1	1	1	2	1	0
Total Number Genera of Bacillariophyceae	0	0	0	1	0	0

FIGURE 3. Variation of generic diversity of soil algae by altitude.

washout has also been demonstrated by a rainwater culture on BBM, where quantitative colony counts of the Chlorophyceae sometimes reached 2000 per ml of cultured rainwater (Carson, unpublished data).

At altitudes of 2500–3000 ft, viable impactions were, in some cases, quite extensive. It is at this altitude that the orographic fog-mist is so prevalent. Nonlocal viable airborne disseminules may be trapped in this fog-mist either by collision or electrostatic attraction to the water droplets and subsequently deposited. Local release of particles is also likely to be due to splash dispersal from both precipitation and rainwater dripping from vegetation. At this altitude, it is also likely that fern spores could be deposited easily due to combined washing out and gravitation; but algal disseminules under such conditions are more likely to be released, dispersed, and then redeposited. These findings coincide with those of May (1958), who found that smaller and more variable droplets of frontal rain removed particulates more readily than had been previously thought.

At higher elevations (4500–6500 ft), however, Algal Genera Collected from the Atmosphere

Altitude (ft.) →	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500
Chlorella sp.	■		■	■	■	■	■	■	■			
Chlorococcum sp.	■			■	■	■	■					
Oocystis sp.	■							■				
Protococcus sp.	■						■					
Hormidium sp.					■							
Calothrix sp.	■			■	■	■						
Oscillatoria sp.			■	■	■	■						
Symploca sp.					■	■		■				
Lyngbya sp.			■			■						
Entophysalis sp.			■									
Synechocystis sp.					■							
Monallantus sp.							■					
Monocilia sp.							■					
Total Number Genera of Chlorophyceae	4	0	1	2	3	2	3	2	1	0	0	0
Total Number Genera of Cyanophyceae	1	0	3	2	4	4	0	1	0	0	0	0
Total Number Genera of Xanthophyceae	0	0	0	0	0	0	2	0	0	0	0	0

FIGURE 4. Variation of generic diversity of airborne algae by altitude.

the potential for release of algal disseminules decreases with the decreasing moisture factor. Furthermore, viable algal impactions are correspondingly lower. However, it is at this altitude that the greatest numbers of fern spore impactions occur. Furthermore, the fern spore impactions in many cases took the form of "clumps," suggesting that sufficient moisture was present after release to cause some cohesion among the spores and that their release had been recent and local. Thus, the potential for fern spore release increases at these altitudes due to the drying of the sporangial wall of ferns from the more intense longwave radiation regime and the resulting warmer temperatures.

In summary, it is clear that distinct systems of aerial dispersal operate in this locality. Two release mechanisms function, one which is basically passive and one which is active. The release of algae, some fungi, and other microorganisms to the air from the surface of the soil or vegetation is generally passive, with particles becoming airborne when the wind blowing across the substrate causes desiccation and subsequent release of substrate particles carrying viable particulates. The splashing by precipitation droplets of microbial-laden soil particles is also basically a passive form of dispersal. An active release of the biota is manifested by the ferns and possibly other cryptogams such as the Bryophyta, whose spore

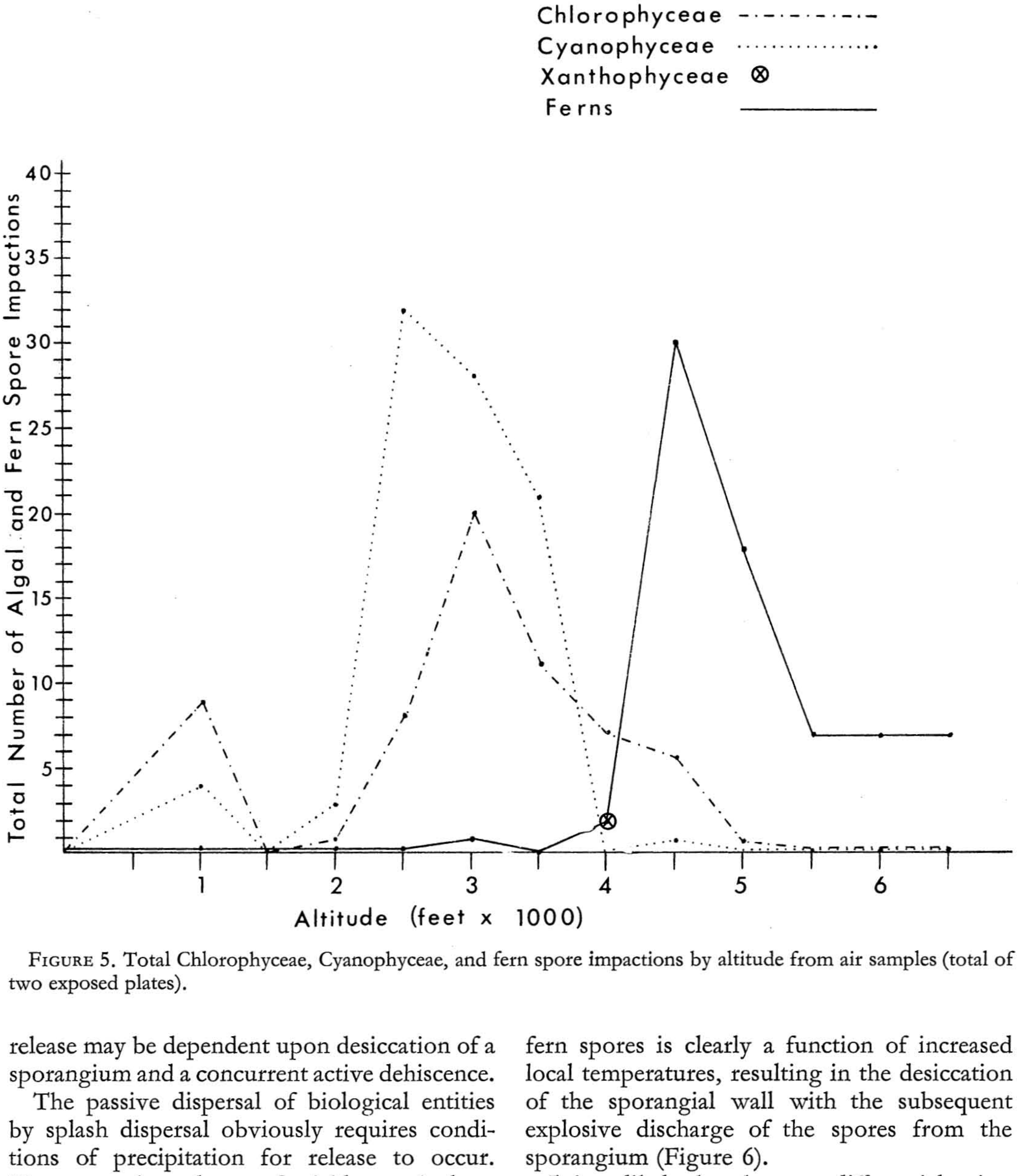

FIGURE 5. Total Chlorophyceae, Cyanophyceae, and fern spore impactions by altitude from air samples (total of two exposed plates).

release may be dependent upon desiccation of a sporangium and a concurrent active dehiscence.

The passive dispersal of biological entities by splash dispersal obviously requires conditions of precipitation for release to occur. However, the release of viable particulates from the surface of soil and vegetation by desiccation requires the coordinate events of substrate desiccation and pickup by wind currents. These events clearly occur under clear atmospheric conditions but may also occur under overcast conditions, provided no precipitation occurs, in which case splash dispersal is operative. The active dispersal of fern spores is clearly a function of increased local temperatures, resulting in the desiccation of the sporangial wall with the subsequent explosive discharge of the spores from the sporangium (Figure 6).

It is unlikely that there are differential point, area, or line sources of airborne algae and other passively released biological particles to any significant degree up to 6000 ft. There is, however, a likelihood of source differentiation in terms of the fern flora, as the lower altitudes are dominated by agriculture. One only begins to note a significant fern flora at approximately 2500 ft. The ferns are conspicuous members of

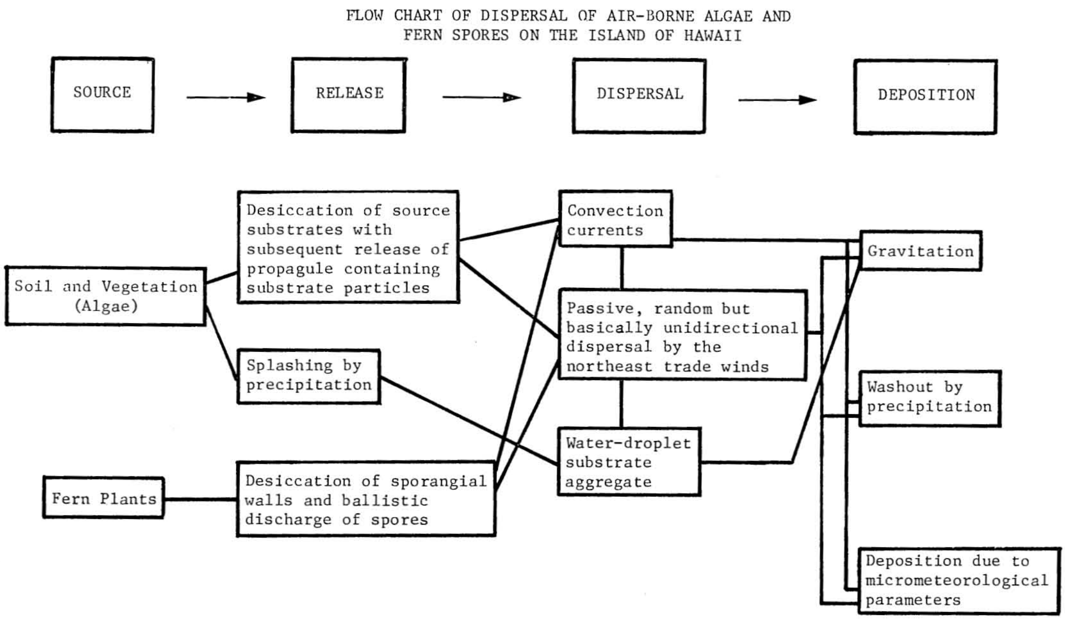

FIGURE 6. Flow chart of the dispersal of airborne algae and fern spores on the Mauna Loa transect.

the flora on the upper reaches of the transect, although this may not be true for the island as a whole.

The consistent local meteorological conditions of the tropics make models such as this predictable with reproducible results as indicated in studies by Brown (personal communication) on Haleakala, Maui, and by Carson (unpublished data) on the Nuuanu Pali, Oahu. The transect of this study is dominated throughout the year by the meteorological scheme previously outlined except during some periods of frontal weather, which generally occur during the winter months (Daingerfield 1921). It should be noted that the data presented here do not constitute an absolute qualitative or quantitative value but rather provide a representation from both soil and air samples which indirectly reflects the biota in the soil, the airborne flora, and the mechanisms by which dispersal may occur.

It is the goal of aerobiological studies such as these to design both conceptual and mathematical models which illustrate the entire scope of dispersal and colonization of biologically significant materials in a given area. Figure 6 is given as such a conceptual model of the aerobiological features on this particular transect.

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