Microbial Dispersal in Relation to Weather Conditions and Micrometeorological Wind Flow

Abstract

The occurrence of atmospheric microbes has been investigated for many years. Such organisms may be of tremendous import in the study of disease transmission, the establishment of plant communities via 1° and 2° succession, and as indicator organissms in air pollution studies. These organisms have been collected and studied for many years; however, the vectors of their release, dispersal, and deposition have remained perplexing until the advent of sensitive micrometeorological monitoring instruments and the development of the concepts governing micrometeorological wind flow.

Certain areas of the tropics, particularly the Hawaiian Islands, have proved to be ideal sites for studies in atmospheric dispersal of microbes due to the consistent nature and high predictability of meteorological conditions. In these isolated and meteorologically simplified areas, marked correlations in generic diversity and population density with meteorological and geographic wind flow conditions have been noted.

Introduction

The Hawaiian Islands are a chain of small islands of volcanic origin in the mid-Pacific Ocean lying approximately 2000 miles from any major land mass. The climate is very equitable and highly predictable due to the prevailing northeast trade winds. Investigations have shown that the trade winds are, for all practical purposes, free of microbial life as they become incident upon the islands (Brown, 1969). However, air-borne microbes have been collected by air sampling over the islands which implies that these organisms arise locally throughout the islands and are dispersed on both an inter-island and intra-island basis. Thus, it is obvious that the islands provide a model system in which to study the roles of these air-borne microorganisms in the ecosystem as a function of their source, input into the atmosphere, dispersal, and inoculation into other areas.

In the volcano region on the "big island" of Hawaii are two volcanoes, Mauna Loa and Kilauea, which with their supporting rift zones, undergo eruptive activity from time to time. In 1959, the crater at Kilauea Iki was the site of a series of eruptions which resulted in the build-up of a massive cinder and ash cone over an extensive elliptical area by the directionally constant and prevailing trade winds. At the time of deposition, this substrate was completely sterile producing a "natural laboratory" for the study of atmospheric dispersal and succession both at the microbial and vascular plant level.

Figure 1

Postcard aerial photo of Kilauea Iki

The relatively recent development of ultrasensitive micrometeorological monitoring instruments has aided greatly in the elucidation of the mechanisms of micrometeorological wind flow. Thus it has been possible to investigate the dispersal mechanisms of atmospherically borne microorganisms in relation to the meteorology and wind flow over a given area.

The algae have proved to be excellent indicator organisms for these studies as algal cells (probably in encysted forms) occur in sufficient diversity and density in the air that they lend themselves readily to studies of dispersal over land areas of several square miles. With some modifications, the dispersal mechanisms of certain other entities such as seeds and spores may also be elucidated.

There are few publications dealing with the dispersal and establishment of microbial communities, particularly the algal flora, in relation to various meteorological and micrometeorological-geographic parameters. It appears that the Kilauea Iki area of HVNP provides a model system for attaining insight into microbial dispersal on a "semi-macro" basis in hope of eventual elucidation of the much more difficult problems of long-distance dispersal over large continental and sub-continental land areas.

This paper is the first of a series which will deal with the problems of dispersal, deposition, and succession of air-borne algae over sterile dated lava flows as well as in agricultural and urban-industrial areas in relation to various meteorological and micrometeorological-geographic parameters.

Materials and Methods

Sterile petri dishes of BBM were exposed to the northeast trade winds at six sites throughout the Kilauea Iki area under varying meteorological conditions during the summer months of 1971 and 1972. The plates were positioned vertically and horizontally to the trade winds at the soil surface at each site. Algal colonies appeared on the plates and were inspected for generic diversity and density 10-15 days after exposure.

Soil samples were also taken from each of the six sites and cultured in flasks of liquid BBM and then plated onto agarized BBM. These plates were also investigated for generic diversity and density..

Samples of rainwater were also collected in the Kilauea Iki area and inoculated onto agarized BBM. Generic diversity and density in these cultures was also inspected.

Results and Conclusions

The inoculation density of various algal genera over the Kilauea Iki ash fallout is a result of two related factors. First, the general meteorological conditions of the area determine to a great extent the diversity and density of microorganisms inoculation into this area. Under conditions of intense solar radiation and low humidity, the inoculation density of various fungi, mainly Deuteromycetes, exceeds that of the algae. However, an exact opposite relationship exists under overcast of foggy conditions, high humidity, and rain. In this situation, the inoculation density of algae greatly exceeds that of fungi.

Figure 2

Pictures of cultures taken under rainy and sunny conditions

Secondly, the variations in inoculation density at the six sites are due to the micrometeorological wind flow pattern over the cinder cone. Each of the six sites of investigation lie within one of four distinct zones of variation in inoculation density which come as a direct result of the variation in the micrometeorological parameters of surface shearing stress (friction), turbulence, and laminar wind flow. These four areas of the Kilauea Iki cinder cone may be described as follows: (1) a region relatively unaffected by the volcanic activity of 1959 consisting largely of the climax rain forest of <u>Metrosideros</u>, <u>Cibotium</u>, and <u>Sadleria</u> typical of this region. Inoculation of air borne microbes into this area may remain relatively inconspicuous until a period of rain which has the effect of washing the organisms from leaf surfaces to the ground where they were collected. (Note leaves in cultures of Figure 2). Climax microbial population occur in this area and rainy conditions bring microbial dispersal via a "splash factor"; that is, rain drops and drops of water falling from the trees strike the ground splashing soil particles which contain these microbes for distances of up to several cm.

Figure 3

Splash dispersal picture

This form of dispersal is of great importance in the climax forest-ash fallout boundary. Site III is representative of this zone. (2)An interface area in which all plant life was destroyed by the eruption of 1959, but which left a number of dead <u>Metrosideros</u> trees both standing and scattered over the ground. Pioneer vascular plant species are present and there is some organic litter over the ash and cinder base. Inoculation of atmospherically borne algae into this area is generally greater due to the fact that the low pioneer vegetation and dead trees have increased the surface shearing stress and interrupted the laminar wind flow resulting in a deposition of organisms being carried in the wind. Sites II and IV are representative of this zone.

(3)The area around the top of the cinder cone where the laminar trade wind flow hits the cinder cone resulting in extensive turbulence and fallout of many microorganisms as well as various seeds and fern spores. Site V is representative of this zone. (4)An extensive, fairly flat area of cinders and ash behind the cinder cone itself. In this area, the wind flow achieves once again its laminar flow and the profile is reinstated. In this zone, very few microbes are inoculated as the wind flow, having reattained its originally laminar nature, does not allow them to be deposited. The distance required to rinstate this laminar flow varies depending upon the wind speed.

Figure 4

Aerial profile of Kilauea Iki

A fortuitous xxxxxxx air sample of June 18, 1972 under conditions of both rain and sunshine in the same 24 hour period gave results representative of other air samples taken throughout the summer. Note the variation in inoculation density at each site as a result of both meteorological conditions and the micrometeorological wind flow pattern over the area

Figure 5

12 hr. samples

Total macroscopic colonies

	CLEAR AND SUNNY					
Site	I	II	III	IV	V	VI
	6	19	48	147	62	3
	Rain					
	71	21	∞	124	159	3

Figure 6

Vertical profile and model of microbial dispersal over Kilauea Iki

It appears clear that the primary mode of inoculation of microbial autotrophs (i.e. algae) into the Kilauea Iki area is by atmospheric means. Thus the above model of dispersal has been substantiated by making collections and cultures of the soil algae in these four zones. Chlorophyll concentration and generic diversity of these soil cultures showed a direct correlation to the density of air-borne algae collected in air sampling experiments.

The algal genera collected from air samples were confined largely to unicellular green algae such as Protococcus, Stichococcus, Chlorococcum, and Chlorella with Chlorella being the predominant inoculum. Rainwater samples from the area were cultured on agarized BBM. After a period of incubation, numerous colonies of unicellular algae appeared. In nearly every case the inoculation density was on the order of 1000 cells/ml. The predominant genus was Chlorella and there was a marked absence of Deuteromycetes. Hormidium, a filamentous green alga, was collected at sites II, IV, and III; however , it seems likely that the dispersal dissemules of this alga are moved about by splashing of soil by precipitation droplets (i.e. splash factor) rather than by actually becoming air-borne. Hormidium occurred extensively in soil cultures from the above 3 sites and its role in microbial succession as well as that of the Cyanophyceae deserves investigation.

Finally, the dispersal mechanism established for the Kilauea Iki area closely parallels that established by Brown (1969) for the Kailua-Honolulu area on the island of Oahu. This implies that similar dispersal mechanisms are at work in both places and that these concepts of dispersal may be applied in other areas of several square miles. As our knowledge of dispersal, meteorology, and micrometeorology expands, it may be possible to establish dispersal mechanisms over continental and sub-continental areas.