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Aerial Dispersal of Biological Material from Australia to New Zealand

by

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ABSTRACT. — New Zealand lies 2000 km across the Tasman Sea, southeast of Australia, in the path of prevailing westerly winds and thus is well sited for studies of long distance dispersal. The aerial transfer of biological material across the Tasman Sea from Australia to New Zealand is not well documented and evidence for this is reviewed. Plant Pathogens: Regular surveys have identified the races of wheat stem rust present in both countries. In general the identification of a new race in Australia was quickly followed by its appearance in New Zealand. Similarly *Antirrhinum* rust and poplar leaf rusts were detected in New Zealand soon after their first appearance in Australia. Insects: Coccids, the grain aphid, and blue moon and other butterflies and moths appear to have been carried across the Tasman during appropriate meteorological conditions. Seeds and Pollen: There is evidence for a west to east movement of seeds, spores and pollen. The affinities of the orchid and fern floras between the two countries provides circumstantial evidence and it is generally accepted that *Casuarina* pollen found in peat and surface samples from various parts of New Zealand has its source in eastern Australia.

INTRODUCTION

The three main islands of New Zealand, North, South and Stewart, lie between latitudes 34°-47°S and longitudes 166°-179°W, 2,000 km south-east across the Tasman Sea from Australia, the nearest neighbour (Fig. 1). The landscape is rugged and important features of North and South Islands are south-west, north-east trending axial mountain ranges which have a mean height of 1,000-1,500 m. In the South Island some peaks rise to more than 3,500 m.

Climate is determined by the regular procession of anticyclones and low pressure troughs which move across the Tasman Sea from Australia to New Zealand. Since no place is more than 130 km from the sea oceanic influences prevail, but these may be modified by topographic factors and there are regions with a continental type climate. Thus, the axial ranges lie across the path of prevailing westerly air streams so that

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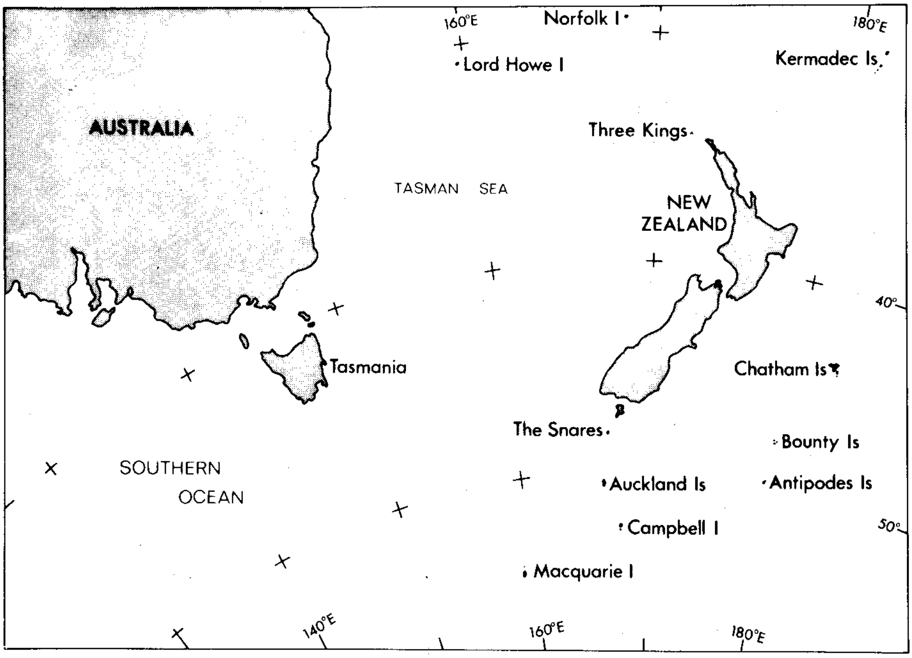

Fig. 1. Locality map showing the position of Australia relative to New Zealand, and of the other islands in the area.

there are marked differences in precipitation between western (up to 7,000 mm) and eastern (as low as 300 mm) sides of the islands. Mean annual temperatures range from 9°C in the south to 15°C in the north.

Because of the prevailing westerly air currents in the southern hemisphere, and because of its position south-east of Australia, New Zealand is well placed for studies of long range dispersal of organisms from one land to another. The possibilities were high-lighted by reports that a balloon, released in Christchurch as part of the GHOST project, circled the world 8 times in 102 days at an altitude of 12 km (Lally and Lichfield, 1969; Mason, 1971). Aerial transport of organic and inorganic particles is of course a well known phenomenon and is important in the field of plant geography (Gressitt, 1963; Raven, 1973), to those concerned with plant diseases (Gregory, 1973), and the dispersal of insects (Johnson, 1969). The interest of this work is emphasised by Glasby (1971) who reviewed the literature relating to long range dispersal of dust particles in the south-west Pacific.

In this review we discuss evidence for dispersal of biological material from Australia to New Zealand, i.e. trans-Tasman dispersal.

WEATHER CONDITIONS FOR DISPERSAL

Certain important conditions are necessary for aerial transport of particles across the Tasman Sea. The particles must become airborne, they must remain airborne until they cross the Tasman Sea and they must settle out on New Zealand.

NATURAL LIFTING MECHANISMS

There are five mechanisms by which particles become airborne (Tomlinson, 1973) and of these thermal lifting and frontal lifting are the most important for trans-Tasman dispersal.

Lifting by thermals occurs when there is differential heating of the land. On a hot sunny day the air over dark surfaces may become considerably hotter than that over adjacent lighter coloured areas. This effect could lift particles a kilometre or more above the ground to a level of westerly winds which would initiate dispersal. It is a fairly gentle process and is likely to coincide with insect flights and with fungal spore dispersal.

Frontal lifting is provided by the passage of a cold front. In the latitude of New Zealand and Australia the weather is dominated by a series of eastward moving anticyclones and depressions. To the north of each depression there is generally a cold front orientated in a northwest-southeast direction. Over the hot dry Australian continent these fronts often lose all their associated clouds ensuring an absence of rain and removing the risk of material being 'washed' back to ground level. As the cold front moves over inland Southern Queensland, New South Wales and Victoria, the air ahead is lifted as the colder air drives underneath it. This lifting of warm air is a suitable mechanism for starting an insect migration for two reasons. First, it occurs in dry conditions, and second, the warm air ahead of the cold front is subject to increasing north or northwest winds which could dislodge spores, pollen, seeds, insects, etc. and make them more susceptible to the frontal lifting process.

EFFECTS OF PRECIPITATION AND TEMPERATURE

Rain, or on rare occasions hail, over the Tasman Sea could easily clear the atmosphere of dispersing particles. There are three main types of rainfall.

1. Rain associated with major weather systems such as depressions, warm and cold fronts, and post-frontal areas of maximum vorticity;
2. orographic rain produced from condensation as air lifts over mountain ranges;
3. the convective rain of showers or thunderstorms.

Since orographic rain cannot occur over the ocean and convective rain is only of limited extent it is clear that rainfall over the Tasman Sea will be less than that over western parts of New Zealand. Detailed forecasting of rainfall over the Tasman Sea is not possible, but the high standard of weather map analysis does allow the delineation of those areas where the first and third types of rainfall are likely to occur.

Unfavourable temperatures may affect the dispersal of spores, seeds or insects. Up to 3000 m over the Tasman Sea there is generally sufficient information available to allow air temperatures to be given with an accuracy of $\pm$ 2°C. This fact, coupled with the small diurnal variation of temperature over the sea, means that any areas of harmful temperature extremes can be identified.

TRANS-TASMAN TRAJECTORIES

With weather observations from Australia, New Zealand and ships and aircraft in the Tasman Sea, area maps are drawn of the wind flow for daily forecasting use. These maps are drawn for various heights (called standard levels) from the surface to 12 km. Because of extremely low temperatures at higher levels, only the surface, 1 km, and 3 km standard levels need to be considered for insect dispersal, but levels of up to 12 km may be involved for some spores, pollen and dust particles. These maps can be redrawn to give very good horizontal velocity fields over the Tasman Sea. A series of these maps at intervals of 3 to 12 hours apart form a basis for horizontal trajectory drawing, using forward, centred or backward differencing to develop them. The uncertainties that arise are cumulative with distance and the main errors involved are those produced: (1) by time interpolation between successive maps; (2) from the uncertainty in the base maps; (3) by failing to consider vertical motion — this can lead to serious error when strong vertical wind shears are present.

Most dispersals occur when there are strong westerly wind flows at all levels and the errors (1), (2) and (3) can be assessed individually for each case. Variations of trajectories with starting time, though not an error, are highly significant. A difference of 12 h in start time at a point in Australia could mean the difference between passing north of the North Island or south of the South Island.

In assessing meteorological conditions for dispersal it is generally assumed that a trans-Tasman crossing takes place in no more than six days.

DESCENT PROCESSES

The main mountain ranges of New Zealand provide a partial barrier to the prevailing westerly winds and form a natural trap for windborne material.

Westerly winds blowing onto the South Island either rise over the Southern Alps or go round their northern or southern extremities. Consequently the straits between the three main islands are prone to gales, and, if conditions are right, areas east of the Southern Alps experience föhn winds. The air takes any of these three routes about the South Island and numerous eddies form in the main wind flows. Such eddies provide a natural descent process, and generally there is one main eddy associated with each of the three routes. The most effective one appears in Tasman Bay to the north of the South Island, and is reflected in the high frequency of north and north-easterly winds there in conditions of general westerly wind flow. Associated areas would therefore be natural landing places for windborne material. In the south of the South Island a strong north-westerly wind flow produces smaller eddies than those in the north. A rather different effect sometimes occurs on the West Coast. In a strong westerly flow some of the air, while still over the Tasman Sea, begins to rise to cross the Southern Alps. Not all of this air gets over the ranges and some descends down the western slopes to form a large vertical eddy. Surface and upper level wind measurements at Hokitika show that this eddy occurs quite frequently.

The mountain range system in the North Island has a lesser effect on the general wind flow, and the eddy effects are not so pronounced. The most favourable catch areas for windborne particles would be low lying areas south of Auckland where the westerly flow is commonly quite diffluent, and in eddy effects near New Plymouth and north of Wellington (Fig. 2).

Meteorological conditions can play a major role in subsequent survival of plant pathogens and other biological particles when they have reached land. If the time and place of their arrival can be plotted accurately and the climatic conditions favourable to their survival specified, then sufficient is known about the weather conditions over New Zealand to predict their chances of survival.

FREQUENCY OF SUITABLE METEOROLOGICAL CONDITIONS FOR DISPERSAL

These have been estimated from a study of 'good' trajectories, i.e. those which come direct from the Australian Coast (preferably New South Wales or Southern Queensland) to New Zealand and involve a passage time of two or three days. Very fast passages of one day can occur and may be suitable for fungal spores and seeds but not necessarily suitable for insects. Longer trajectories of up to seven days would result from meandering pathways which involve large errors in estimation.

For the transit level of 300 to 1,000 m and taking into account only wind speed and direction the average frequency of 'good' start days for trans-Tasman trajectories based on the years 1961-1970 is 30 days per year.

When suitable starting conditions and adverse route conditions are taken into account then these figures could be reduced and the probable average frequency of days for suitable trajectories is as follows:

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1.0	0.5	1.5	2.0	2.0	2.0	2.0	2.0	2.5	2.5	2.0	1.0	21.0

Although at levels above 1,000 m the frequency would increase appreciably this is less important than frequencies at lower levels.

PLANT PATHOGENS

The long distance dispersal of some plant pathogens has been discussed (Gregory, 1973; Hirst and Hurst, 1967; Zadoks, 1967). Meteorological factors affecting the epidemiology of wheat rusts have been reviewed (Hogg et al., 1969). Stem rust spreads from North Africa and southern Europe into the United Kingdom and in general this is correlated with the frequency of suitable trajectories. Similarly, stem rust moves from Mexico into USA, and then to Canada; maize rust has spread from the Americas to Africa and Asia over a period of years; while coffee rust appears to have moved in the reverse direction from Africa to Brazil (Bowden, Gregory and Johnson, 1971).

In the dispersal of fungal spores, there will be a decrease in spore concentration with time and distance from the source. Their viability also will be reduced by radiation, temperatures and humidities. After arrival of viable spores in an area, the number of available host plants and the current environmental conditions will determine the number of infections that occur. Thus only a few infection foci, which act as initial introductions for subsequent development and local spread of new fungal species and races are to be expected.

While there are documented examples for the Northern Hemisphere of long distance dispersal, there is little published evidence for the Southern Hemisphere. Five cases of trans-Tasman dispersal involving rust species are discussed.

STEM RUST OF WHEAT

Puccinia graminis Pers. f.sp. *tritici* Erikss. and E. Henn.

This pathogen exists as a number of strains and races and their classification is based on inoculation tests to a series of differential host varieties as described for the Australia-New Zealand (Anz) region by Watson and Luig (1963). The distribution and relative importance of races in this area was reviewed by Waterhouse (1952) and Watson and Cass-Smith (1962) who suggested that, in general, new races originate during urediniospore production in Queensland and then move south and east and occasionally to the west (e.g. race 21-Anz-2 to Western Australia). These movements have been reviewed (Hogg et al., 1969). In New Zealand Allen (1961) suggested that trans-Tasman dispersal of rust urediniospores occurs regularly, and further evidence was provided by McEwan (1966). Since 1958 scientists in New Zealand have been co-operating in the rust survey conducted by the University of Sydney. For each of the years 1958 to 1969, Luig and Watson (1970) present figures for the total number of samples submitted, and the number of each race identified. From this, and subsequent data it has been possible to compile Table 1, which shows that discovery of a new rust race in Australia is soon followed by its appearance in New Zealand. This is clearly shown by the data for races 21-Anz-2; 34-Anz-2; 21-Anz-5; 34-Anz-2,4; 21-Anz-2,3,7; 21-Anz-4,5. More recently races 21-Anz-2,3,4,5,7; 326-Anz-1,2,3,5,6; 21-Anz-1,2; 194-Anz-1,2; and 194-Anz-1,2,3,7,8,9 also seem to have been involved in trans-Tasman dispersal (I. A. Watson, personal communication). Watson has also suggested that some of the races could have been introduced into Australia from Africa and then spread to New Zealand.

Dispersal of stem rust urediniospores over long distances may well be successful because the spores are more resistant to radiation damage than those of other rusts (Maddison and Manners, 1972). In addition Orr and Tippetts (1972) have studied the aero-

Table 1. Occurrence of six races of stem rust of wheat during certain periods of time and in areas within the Australia-New Zealand region. The results are expressed as a percentage of the total number of stem rust samples submitted to the University of Sydney (data from Luig and Watson, 1970).

	RACE 21-2				RACE 21-5				RACE 34-2		
	1956-57	1957-58	1958-59	1959-60	1959-60	1960-61	1961-62	1962-63	1957-58	1958-59	1959-60
Number of samples	317	114	584	774	774	472	934	1,215	114	584	774
Queensland	5.6*	22.8	9.5	4.5	1.2	2.3	4.2	1.8	—	0.6	0.6
N. N.S.W.	10.7*	47.3	32.8	18.8	1.0	1.0	4.7	2.7	1.7	3.7	8.6
S. N.S.W.	2.5*	0.9	30.8	23.7	2.8	3.3	2.7	2.7	—	2.0	2.0
Victoria	1.2*	1.7	4.4	3.2	0.1	0.2	—	—	—	0.1	0.6
S.A.	—	—	2.5	4.7	—	—	0.1	—	—	0.3	1.0
Tasmania	—	1.7	2.2	1.1	—	0.2	0.2	0.4	—	0.3	0.3
New Zealand	—	—	0.3	3.4	—	—	0.2	2.0	—	—	0.3
Total	20.0*	74.4	82.5	59.4	5.1	7.0	12.1	9.6	1.7	7.0	13.4

	RACE 32-2,4						RACE 21-2, 3, 7						RACE 21-4, 5		
	1959 -60	1960 -61	1961 -62	1962 -63	1963 -64	1964 -65	1960 -61	1961 -62	1962 -63	1963 -64	1964 -65	1963 -64	1964 -65	1965 -66	1966 -67
Number of samples	774	472	934	1,215	1,104	730	472	934	1,215	1,104	730	1104	730	316	690
Queensland	0.1	—	0.5	8.9	4.4	3.9	0.8	5.5	5.1	3.3	7.0	1.1	10.4	15.5	6.3
N. N.S.W.	—	0.2	2.7	14.0	8.0	11.2	—	9.2	12.0	5.1	12.0	1.1	8.6	0.9	6.5
S. N.S.W.	—	—	—	1.9	1.3	0.6	—	1.7	1.9	2.0	3.2	—	1.0	3.4	7.2
Victoria	—	—	—	—	0.1	—	—	—	0.1	0.2	—	—	—	—	0.7
S.A.	—	—	—	—	0.1	—	—	—	—	—	—	—	—	—	—
Tasmania	—	—	—	—	0.1	—	—	0.1	—	0.1	—	—	0.1	—	—
New Zealand	—	—	—	—	0.3	0.8	—	0.1	0.4	—	1.5	—	2.8	0.3	0.4
Total	0.1	0.2	3.2	24.8	14.3	16.5	0.8	16.6	19.5	10.7	23.7	2.2	22.9	20.1	21.1

* Percentage of total number of samples submitted.

dynamic properties of the urediniospores and concluded that these could contribute significantly to long range travel.

Air-borne inoculum from Australia is the means whereby new races of this pathogen are introduced into New Zealand. However, these urediniospores probably contribute little to the initiation and development of severe local outbreaks. There is evidence (Close, 1967; McEwan, 1966) that stem rust of wheat overwinters in New Zealand on volunteer wheat and this is a source for spring infections. A similar situations occurs in Queensland (Rees, 1972) where large-scale long-distance aerial transport of urediniospores was not necessary for the recurrence of the disease.

Antirrhinum RUST *Puccinia antirrhini* Diet. and Holw.
In October 1952 this disease was found in Australia on *Antirrhinum majus* L. in a nursery near Sydney and was identified as race 2. Within 5 months the disease was located up to 160 km from the source. After 12 months it was widespread over eastern Australia (Walker, 1954).

In December, 1953, it was first detected in New Zealand and was soon found in a number of localities. It was also identified as race 2 (Close, 1958). Thus the almost simultaneous appearance of the disease at a number of widely-spaced localities is indicative of trans-Tasman dispersal. This is supported by the fact that race 2 appeared in New Zealand but not until the disease had become established in Australia. It could be argued that seed-borne urediniospores were the way it entered New Zealand. However, Walker (1954) sowed seed heavily contaminated with spores and seedlings did not become infected. In addition, seed had been imported for many years previously and this rust had never been detected.

Euphorbia RUST *Melampsora euphorbiae* (Schub.) Cast.
In September, 1953, in New South Wales, *Euphorbia* rust was recorded on milkweed *Euphorbia peplus* L. The infection was severe and it was apparent that the disease had been present for some months. In February, 1954 it was first collected on this host at Auckland, and within two years was found on this common weed host in a number of localities throughout New Zealand (Dingley, 1969).

SUNFLOWER RUST *Puccinia helianthi* Schw.
Sunflower rust was first recorded in Australia in 1893. It has only recently been found in New Zealand (Laundon, 1973) even though small areas of sunflowers (*Helianthus annuus* L.) have been grown in various localities for a number of years. The first record of this disease was at Pukekohe, south of Auckland, on 20 April 1971, and the outbreak seems to have been eradicated.

POPLAR RUSTS
Melampsora medusae Theumen and *Melampsora larici-populina* Klebahn.
In January 1972, poplar rust *Melampsora medusae* was detected near Sydney, Australia (Walker and Hartigan, 1972). By mid-April 1972 it had spread to Victoria (Marks and Walker, 1972). In early 1973 a second species *Melampsora larici-populina* was identified and found in a number of localities in eastern Australia. The outbreaks and subsequent development of these rusts is reviewed by Walker, Hartigan and Bertus (1974).

It was not unexpected (MacMillan, 1972) when on 21 March 1973, the first poplar trees infected with rust, *M. medusae,* were found in the northern part of the North Island. A subsequent survey throughout New Zealand showed that poplar rust occurred over a wide area in the North Island, revealed the presence of a second rust species *M. larici-populina,* and mixed infections of the two species at two localities (Fig. 2). This initial outbreak in New Zealand has been documented (van Kraayenoord, Laundon and Spiers, 1974). Although trials of recently introduced poplar species and cultivars were located throughout New Zealand, most of these were initially free of infection. Thus the disease could not have been introduced nor spread during the distribution of

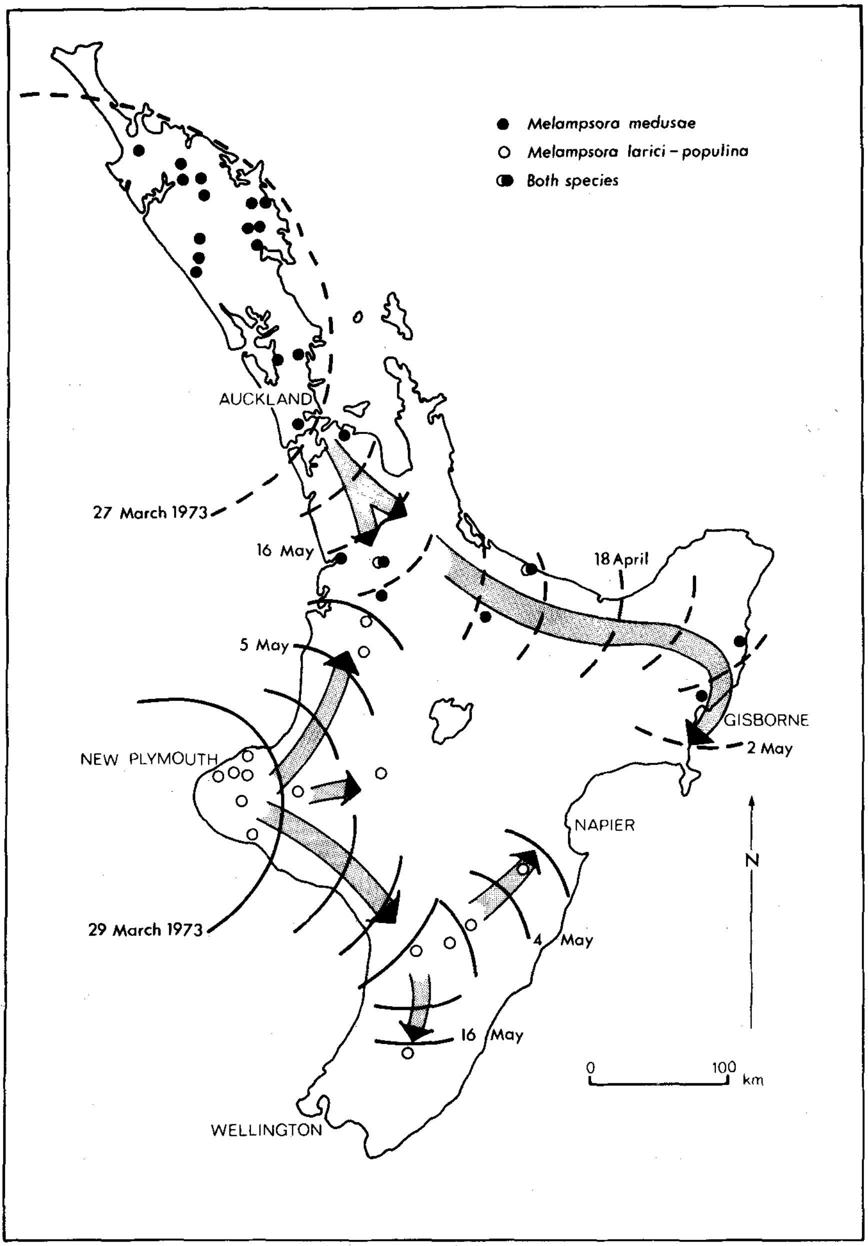

Fig. 2. Distribution of the two poplar rusts in the North Island, New Zealand during the period March to May 1973. (Redrawn from Van Kraayenoord et al., 1974).

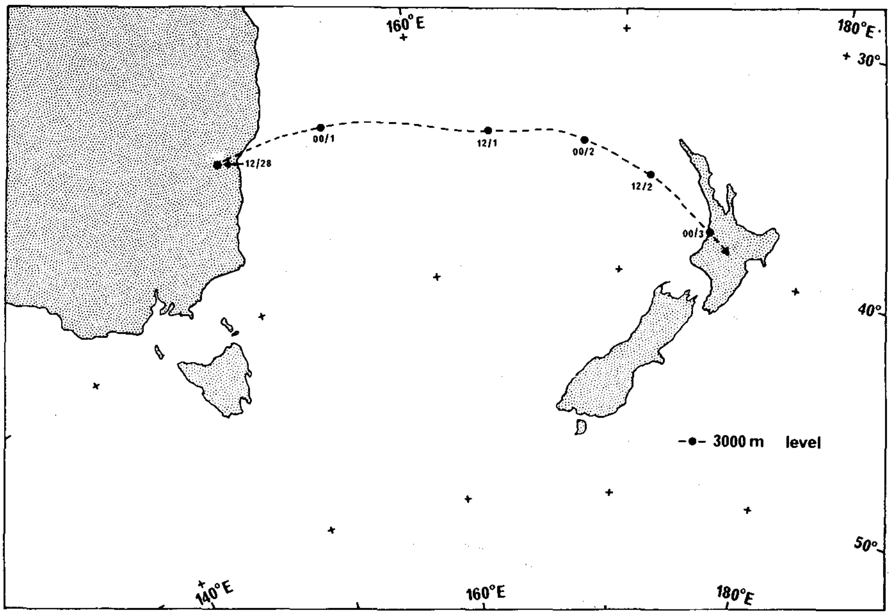

Fig. 3. Trans-Tasman trajectory, at 3,000 m, of air movement between Australia and New Zealand in early March 1973. The figures 12/28 etc. refer to GMT on 28 February, etc. The first sightings of poplar rust were on 21 March 1973, possibly after two generations of rust.

poplar cuttings in New Zealand. In one location, cuttings of a particular species were established several miles from the parent stock, and subsequently the cuttings were found to be infected but the parent stock was healthy.

On the basis of present evidence there can be no doubt that poplar rust represents a case of trans-Tasman dispersal. This is further supported by the meteorological evidence. Figure 3 is of a trajectory in early March 1973, which shows that the time of arrival of urediniospores could have been about 3 March. Under ideal conditions (24° C) the latent period of both poplar rusts is 8 to 10 days (A. G. Spiers, personal communication). Thus the time (18 days) between arrival of the spores and the first detection of the rust would have allowed two generations to develop. It is considered that the first uredinia would have been few in number and may not have been noticed. The introduction and subsequent distribution of these two poplar rusts in New Zealand has been reviewed (Wilkinson and Spiers, 1976).

PLANT PATHOGENS NOT YET RECORDED IN NEW ZEALAND

There are other pathogens in Australia which might yet successfully spread across the Tasman and become established in New Zealand.

Maize rust *Puccinia polysora* Underw. was first detected on maize in Queensland, Australia in 1959 (Simmonds, 1960). It has not spread from that state into New South Wales nor to New Zealand even though it appears from previous evidence (Wood and Lipscomb, 1956) to be adapted for long-distance dispersal.

Blue mould of tobacco *Peronospora tabacina* Adam is indigenous to Australia (Rayner and Hopkins, 1962) but it has never been recorded in New Zealand. For many years, two thousand hectares of tobacco has been and is still grown in the northern part of the South Island, and from November to April, these plants would be available to trap airborne mildew spores. The non-appearance of blue mould indicates that its spores do not remain airborne or viable for the distance or time involved.

INSECTS

Johnson (1969) reviewed the literature on insect migration and dispersal, and found that in many cases dispersal could be correlated with known meteorological pathways.

Gressitt (1961) reviewed the zoogeography of Pacific insects and concluded that ample evidence exists to indicate dispersal across open ocean by suitable air currents. Insect trapping at sea has included catches of whole live insects of several species at up to 1500 km from land, with Lepidoptera up to 3000 km from land (Holzapfel and Harrell, 1968; Holzapfel, Tsuda and Harrell, 1970).

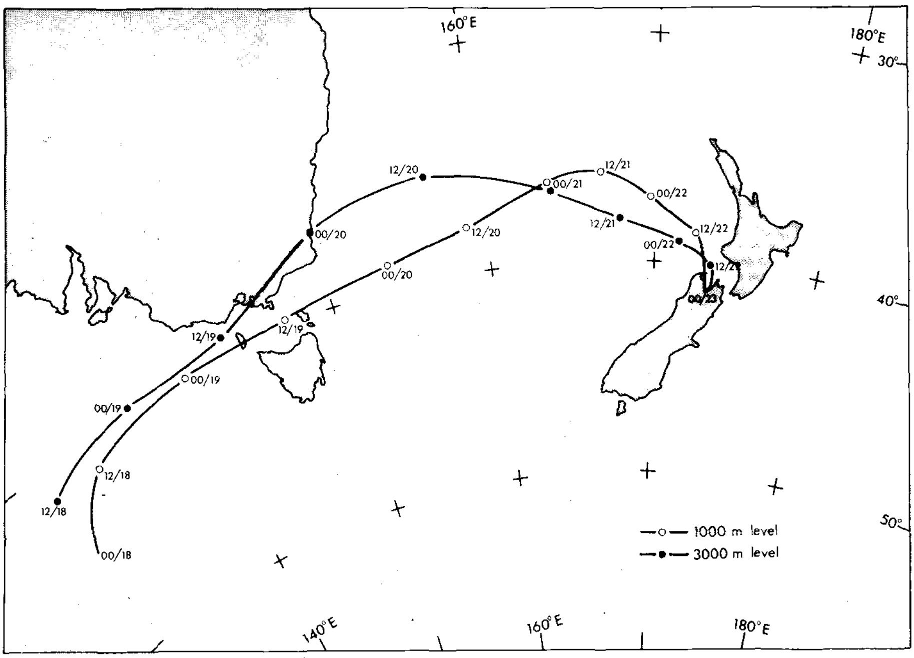

Fig. 4. Trans-Tasman trajectories, at the 1,000 and 3,000 m levels, which were plotted backwards from a probable arrival time, 23 April 1971, of blue moon butterflies in the northern part of the South Island (redrawn from Tomlinson, 1973).

There appears, therefore, no reason to doubt flight transfer of insects from Australia to New Zealand. The pattern of weather movement is constantly favourable, and suggestions of such transfer have been made for Lepidoptera and Homoptera. Points relevant to dispersal in the area have been made by Lamb (1974) for the Aphididae, and by Wise (in Lowe, 1973a), who recorded catches of live insects in shipborne traps throughout much of the Tasman Sea area.

Early records are vague, but suspected migration from Australia appears to date from the records of Philpott, Castle and Andersen (1925). Thomson (1922) listed many Australian arthropods found in New Zealand, some of the records being from the last century. None of these records give direct confirmation of arrival by flight of a live adult insect.

Recent trapping records, however, have recorded migration by live Lepidoptera, sometimes in considerable number. Records of individual species are by Fox (1969), Gaskin (1969), Gibbs (1969), Perrott (1969), Ramsay (1954, 1971), Ramsay and Ordish (1966), Rosenberg (1973). Those published by Fox in a series of papers (1969, 1970, 1971, 1973a, b, c, 1975, 1976) are by far the clearest evidence of migration. He has recorded 30 species of Lepidoptera arriving on the western coast of the North Island; 7 are of frequent occurrence, 8 occasionally, and the remainder rare. The frequent migrants are *Hypolimnas bolina nerina* (F.), *Cynthia kershawi* (McCoy), *Agrotis ypsilon aneituma* (Walker), *Agrotis infusa* (Boisd.), *Helicoverpa punctigera* (Wallengren), *Achaea janata* (Linn.), and *Ectopatria aspera* (Walker).

Meticulous seasonal records and their relationship to prevailing weather patterns

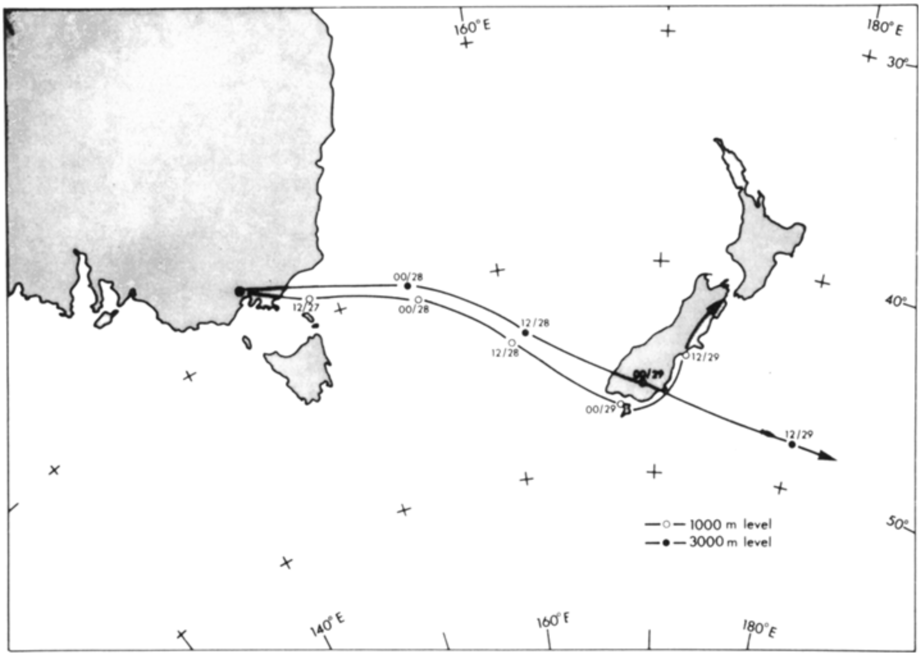

Fig. 5. Trans-Tasman trajectories, at the 1,000 and 3,000 m levels, originating at Melbourne on 27 October 1967. (Redrawn from Tomlinson, 1973).

add considerable value to his data, as also do trapping records from a seaborne oil rig 50 km from the coast (Fox, 1970). There can be no doubt of the accuracy of his statement (1970) that Australian Lepidoptera arrive in "a more or less continual process whenever strong and prolonged westerly winds" suitable for such transfer are prevalent and coincide with the flight period.

The arrival of the blue moon butterfly in the autumn of 1971 is well documented (Ramsay, 1971). A number of specimens in excellent condition were recorded in the Nelson area on and about 23 April. Figure 4 shows trajectories at the 1 km and 3 km levels which were drawn backwards from this known arrival time. It is believed that the butterflies came from southern New South Wales or Victoria, as weather conditions there were favourable for dispersal (Tomlinson, 1973).

Two families of the Homoptera may have been subjected to wind transfer across the Tasman Sea. In a study of the Coccoidea, Hoy (1959) suggested that some species of *Eriococcus* infesting *Leptospermum,* a plant genus common to both countries, were carried as first instar nymphs across the Tasman Sea. The suggestion, by Lowe (1973b) that there was some evidence for trans-Tasman transfer of aphids (Aphididae) was supported by Close and Tomlinson (1975) who discussed the sudden and widespread appearance in New Zealand wheat crops of the aphid *Macrosiphum miscanthi.* This infestation followed an outbreak of the same species in Australia, at a time when weather appeared favourable (Fig. 5) for transfer between the two countries. Palmer (1974) summarised the records of aphids from the subantarctic islands (Fig. 1) south of New Zealand. Most of these normally infest horticultural plants, an important point when it is realised that the islands are rarely visited by man, and have few plants of horticultural interest. These records include cases of aphid occurrence on the Campbell Islands, 800 km south of New Zealand.

POLLEN

The possibility of long-distance pollen transport in the Southern Hemisphere was first raised by Erdtman (1924) who speculated that the podocarp pollen he found in Chatham Islands peats had blown there 800 km from New Zealand.

An attempt to demonstrate trans-Tasman pollen transport was made by Newman (1948) when he trapped pollen and spores on slides exposed through the astro-hatch of a flying boat travelling from New Zealand to Australia. Later, indirect evidence of long range dispersal began to accumulate when podocarp and *Nothofagus* pollen grains were found hundreds of kilometres from their source in peat samples from the Subantarctic Islands (Snares Island, Harris, 1953; Bounty Islands, Harris, 1955 p. 162; Auckland and Campbell Islands, Cranwell, 1963; and Marion Island, Schalke and van Zinderen Bakker, 1971). More direct evidence came from pollen analysis of surface samples from Antipodes Island (Moar, 1969a) and Chatham Island (Dodson, 1976) and from post-glacial and last glacial Chatham Island peat (Mildenhall, 1976). Pollen types derived from plants not growing on the islands included *Dacrydium cupressinum, Phyllocladus* and *Podocarpus* spp., and *Nothofagus fusca* type, the nearest source being the New Zealand mainland 700-800 km to the west.

Evidence of trans-Tasman dispersal of pollen grains was strengthened by the discovery of *Casuarina* pollen in snow collected at 2100 m above sea-level near the head of the Tasman Glacier just to the east of the Main Divide (Moar, 1969b). Because this Australian tree is rare in New Zealand it was concluded that the few pollen grains recorded had been carried 2000 km across the Tasman Sea from Australia. Since then *Casuarina* pollen has been found in surface samples, and in post-glacial and Otiran (Last Glacial) peats from sites in both the North and the South Islands (Lintott and Burrows, 1973; McGlone and Topping, 1973; Moar, 1969b, 1970, 1973), the Chatham Islands (Mildenhall, 1976) and the Auckland Islands (Fleming, Mildenhall and Moar, 1976).

Eucalyptus pollen, amongst others, was also found in the Tasman Glacier snow sample. Later, from South Westland, it was recorded in post-glacial peat from Gillespies Beach Road (Moar, 1973) and the Horace Walker moraine site (Wardle, 1973). Because *Eucalyptus* is commonly planted in New Zealand it was considered earlier, that unlike *Casuarina,* the pollen was locally derived. In view of present records, which are unlikely to be a consequence of contamination from New Zealand sources, it is possible that *Eucalyptus* pollen also has been blown across the Tasman Sea.

Although the main islands of New Zealand are not large there are marked regional differences in vegetation, so that it is possible to detect instances of pollen or spore dispersal from one region to another. Thus Moar (1970, 1971) and Myers (1973) record *Dacrydium cupressinum* pollen, derived from Westland, in the modern pollen rain at mountain and plain sites in Canterbury east of the Main Divide. Harris (1961) considers that *D. cupressinum* pollen in peat from Little Barrier Island on the northern fringes of the Hauraki Gulf has been blown there from the mainland, 24 km distant, by the prevailing westerly winds. Licitis (1953) and Myers (1973) record *Nothofagus* pollen trapped at sites on the Canterbury Plains which are up to 60 km east of the source forest, and McKellar (1973) finds that the pollen of the *Nothogagus fusca* type is disseminated for greater distances, and in greater numbers, than is the pollen of *N. menziesii.* According to Harris (1955, p. 161) the spores of *Lycopodium deuterodensum (L. densum)* have been dispersed from Marlborough to Wellington where it does not naturally occur. Earlier, Clark (1951) discussed dispersal of pollen at several North Island centres.

SEEDS

Although there is no direct evidence of movement across the Tasman Sea, there are plant groups common to both countries with seeds light enough to be carried in prevailing winds or in jet streams.

Hatch (1951, 1952) emphasises the affinities between the orchids of eastern Australia and New Zealand and believes that these can be accounted for by continuing drift of the minute seeds in the west to east air currents moving across the Tasman Sea. Moore and Edgar (1975) accept twenty-one genera and seventy-two species of orchid for New Zealand and of these, eighteen genera and at least one third of the species are common to both countries. In this context it is of interest to note that two colonies of the Australian orchid, *Cryptostylis subulata,* have recently been found in swampland north of Auckland (Graham, 1976). The plant could well be a recent introduction as a consequence of aerial transport of its seed. Similarly, Brownlie (1962) has noted that more than 50% of fern species in New Zealand also occur in Australia.

Epilobium, Juncus and members of the Compositae which could be distributed by air over great distances are noted by Thomson (1922) and Raven (1973). According to Edgar (1964) eight of the ten species of leafless rush *(Juncus Genuini)* indigenous to New Zealand also occur in Australia and Raven and Raven (1976) note that of the nine Australian species of *Epilobium* four are also native to New Zealand. The prevailing westerlies, between the two countries, would provide the plumed *Epilobium* seeds with an obvious means for dispersal.

The recent discovery (Moore, 1969) of *Sprengelia incarnata,* an epacrid of eastern Australia, at several localities in south-west South Island is relevant. Gold prospectors may have introduced the plant in some places late last century, but its presence in more remote and almost inaccessible localities cannot be explained in this way. The status of this species remains uncertain, but its fine and light seed may have been carried by wind from Australia.

Although there is good circumstantial evidence for aerial transport of seed there is no evidence of seed being carried by sea from Australia to New Zealand. However, water-dispersed fruits and seeds, from tropical sources to the north, have been found on beaches in northern New Zealand, the Kermadec Islands and Macquarie Island (Costin, 1965; Mason, 1961; Sykes and Godley, 1968).

DUST

The aerial transport of dust and other solid particles is a well known phenomenon (e.g. Jackson et al., 1973; Lamb, 1970; Lundquist and Bengtsson, 1970) and there is ample evidence of this in the New Zealand region. The distribution of tephra in the North

Island (e.g. Druce, 1966; Healy, Vucetich and Pullar, 1964; Vucetich and Pullar, 1969) and of loess in the North and South Islands (e.g. Cowie and Wellman, 1962; Raeside, 1964; Young, 1964) are obvious examples of this. In terms of long distance transport Cockayne (1928) speaks of smoke from mainland forest fires travelling 800 km to the Chatham Islands and there are similar records of smoke, dust, and other particles reaching New Zealand from Australia (Dixon and Dove, 1903; Glasby, 1971; Healy, 1970; Kidson, 1930; Marshall, 1903; Marshall and Kidson, 1929; Moar, 1969b; Mokma et al., 1972; Thomson, 1922). It is clear that New Zealand is favourably situated for a study of the transport of aeolian material across the Tasman Sea from Australia.

DISCUSSION

It is clear that aerial dispersal of biological particles from Australia to New Zealand does occur. It is also apparent that some of the particles are viable on arrival and this can lead to the establishment of species new to New Zealand.

Because of its unique geographical position, New Zealand is ideally situated as a base for studies on long-distance dispersal. However, an overall study of trans-Tasman dispersal has never been attempted probably because of the difficulties in co-ordinating the inter-disciplinary approach required in aerobiology. Much of the work reported here has come from observations, from unrelated projects, or from ad hoc projects on specific topics. The results demonstrate the need for a formal research programme. This would be important not only for Australia and New Zealand but also for further studies on all the factors involved in long-distance dispersal. Such studies would undoubtedly require the co-operation and support of international agencies in this field. A first step would be the selection and establishment of aerobiological monitoring sites in the Australasian region. Although initially these need only have limited objectives they would require to be in areas for which detailed meteorological data are available. The geographic location in New Zealand of such a station is important. A site on the west coast of the South Island would be most useful as it is west of the Main Divide and in the path of the prevailing wind.

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