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AIR-BORNE ARTHROPOD FALL-OUT ON ANAK KRAKATAU AND A POSSIBLE PRE-VEGETATION PIONEER COMMUNITY

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CONTENTS

Catches of arthropods in white water traps on ash-covered lava flows on Anak Krakatau, Indonesia, in August 1985 included more than 70 species representing 10 orders: Araneae, Collembola, Orthoptera, Dermaptera, Psocoptera, Hemiptera, Lepidoptera, Coleoptera, Diptera and Hymenoptera. Diptera and Hymenoptera made up more than half the total catch. The implications for colonization of Anak Krakatau by air-borne arthropods are discussed, and the possibility that there is a small resident community depending on aeolian debris is noted.

1. Introduction

Trans-oceanic dispersal by arthropods is widely documented and, as Farrow (1984) noted, can be detected at remote islands provided that catches of the local resident fauna are readily distinguished from those of immigrants, a factor that is related to the degree of impoverishment of the island fauna. Studies of over-water dispersal have accentuated one of two facets: the arrival of easily recognizable species such as pests, or immigration leading to progressive community development. Examples of the latter are well exemplified by studies on recently emerged volcanic islands, such as Surtsey in the north Atlantic (Lindroth *et al.* 1973), or Mot-Mot in a crater lake on Long Island, Papua New Guinea (Ball & Glucksman 1975). The classic studies of Simberloff & Wilson (1969, 1970), in which the fauna of small islets off the Florida keys was eradicated by methyl bromide fumigation and subsequent colonization by arthropods monitored, well represent what MacArthur & Wilson (1967) referred to as 'Miniature "Krakataus" which can be regenerated at will'.

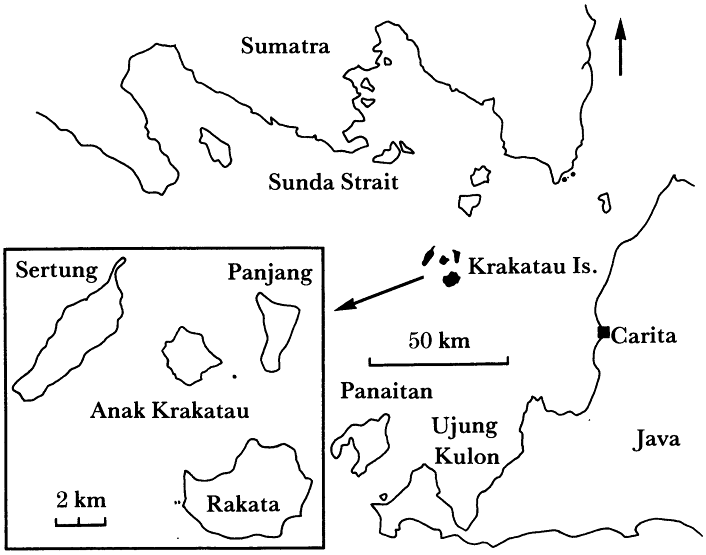

FIGURE 1. Sunda Strait and the Krakatau Islands, 1985.

The 'real Krakatau' has long been recognized as one of the greatest opportunities to study the development of tropical terrestrial communities. The earlier stages of succession on three of the four islands of the Krakataus (figure 1) are now well past, but Anak Krakatau (figures 1 and 2), which emerged in 1930, suffered a sterilizing eruption in 1952, and another severely damaging one in 1972, still offers the opportunity of studying the very early stages of community development (Thornton & Rosengren 1988). The island is waterless, and over 90% of its area consists of bare ash and lava. The volcano is active, and vegetation is well developed only round the northeast quarter of the coastline (figure 3). During visits to Anak Krakatau in September 1984 and August 1985 (Thornton & Rosengren 1988), samples of arthropods were collected from vegetation to indicate the communities present, reflecting colonization over a maximum of some 30 years.

This paper reports on the catches of arthropods in water traps positioned near the coast in an area of bare ash-covered lava on the non-vegetated western side of the island, as part of an attempt to monitor aerial 'fall-out' of animals on to the island and assess the potential for further colonization.

An initial trial in 1984 indicated that water traps could be useful for this purpose. Twenty-three traps, 9 yellow and 14 white, captured 52 arthropods in 48 h, mainly Diptera (36 specimens) but also including Orthoptera, Hemiptera, Thysanoptera, Coleoptera, Hymenoptera and spiders. The more systematic 1985 study is detailed below.

2. METHODS

(a) *The site*

The area on the west of the island selected for water trapping is indicated in figures 2 and 3: a barren area of (1975?) lava (Oba *et al.* 1982) partly covered with ash and some loose pieces of lava, extending from about 2 to 8 m above sea level (a.s.l.), and about 1 km from the nearest vegetation towards the north. The site was chosen because it was bare, relatively flat, on the windward side of the island, and separated from the vegetated area by the volcanic cone. Thus not only was there no local vegetation that might harbour insect contaminants of the traps, but the site was also the least likely on the island to receive fall-out of arthropods originating from the plant communities to the northeast and east. The gravel beach to the south afforded access to seawater for use in the traps. Just inland from the trap site the island slopes steeply to the volcanic cone, effectively blocking all view of vegetation. The wind was from the southwest quarter during most of the trapping period. Rakata is about 4 km to the south, and Sertung about the same distance to the west; the next nearest land to the southwest is Panaitan Island, about 50 km away (figure 1).

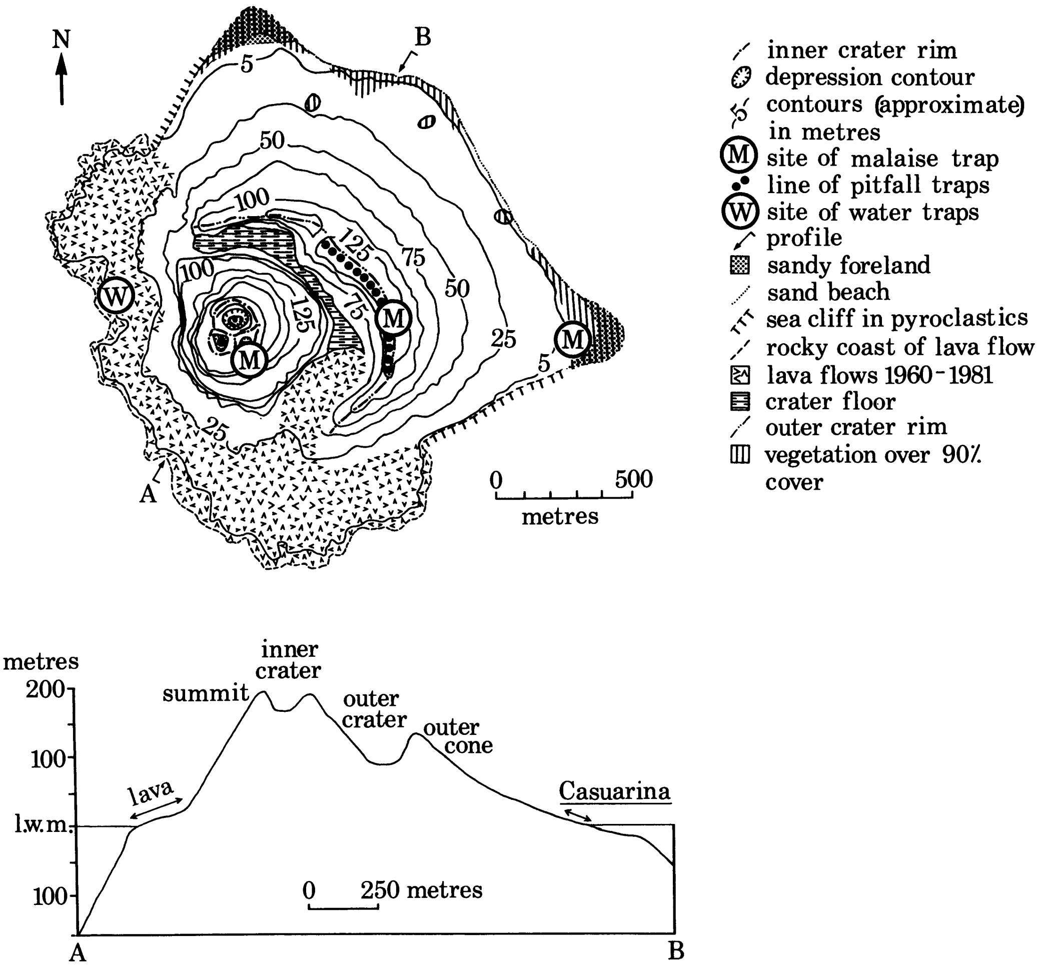

FIGURE 2. Map of Anak Krakatau showing sites of water, pit and Malaise traps.

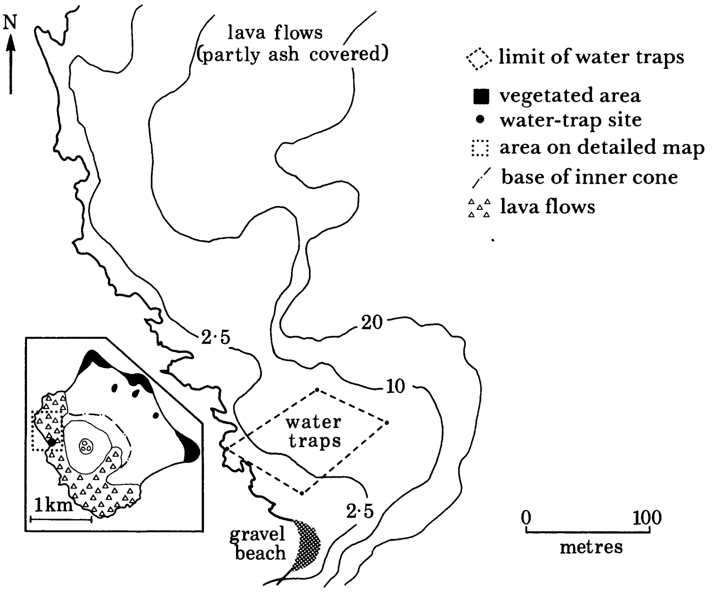

Figure 3. Outline of Anak Krakatau, indicating site of water traps and vegetated areas, and detail of locality of water traps.

(*b*) *The traps*

Square white plastic containers, side 19 cm and depth 10 cm, containing seawater and a small amount of detergent to a depth of about 5 cm were used as water traps. Twenty-five traps were placed on levelled ground and settled against the wind by surrounding them with pieces of lava. A further 25 traps were supported on wooden poles about 1.5 m above ground, each being set inside a similar container nailed through a supporting metal plate to the top of the pole. The two sets were intermingled in the area shown in figure 3, which extended from within a few metres of the sea to about 100 m inland. The traps were inspected on six occasions over a 10-day period (14–24 August 1985), and all arthropods were removed with brush or forceps and preserved in alcohol (80 % by volume). The catch from each individual trap was kept separately, and water lost by evaporation from the traps was replenished as necessary. No rain fell during the trapping period, and no traps were upset by wind, or otherwise disturbed. Traps were emptied in the early morning and no attempt was made to discriminate between nocturnal and diurnal catches.

Malaise traps were employed on the vegetated eastern foreland, at about 130 m a.s.l. on the rim of the outer ash cone, and at about 190 m a.s.l. on the southern rim of the active crater (figure 2). Forty pitfall traps consisting of plastic cups were aligned along the rim of the ash cone.

3. RESULTS

The arthropod captures are summarized in table 1. The 424 individuals trapped represent 10 orders: Araneae, Collembola, and eight of Insecta, some of them in very small numbers. The most abundant group, Diptera, far outnumbered any other order, with more than twice as many individuals as the next most common, Coleoptera. Of the others, only Hymenoptera, Orthoptera, Hemiptera and Araneae reached double figures, and several (Collembola, Dermaptera, Psocoptera) were represented by singletons.

Table 1. Summary of arthropod captures in water traps on Anak Krakatau, August 1985

(Numbers of individuals given for each trap series.)

	number of specimens				
taxon	ground traps	pole traps	total	order total	number of species
Araneae	25	14	39	39	5
Collembola	1	—	1	1	1
Orthoptera	33	—	33	33	1
Dermaptera	1	—	1	1	1
Psocoptera	—	1	1	1	1
Hemiptera					
Aphididae	11	8	19	—	1
Delphacidae	1	—	1	—	1
Cicadellidae	—	1	1	—	1
Naucoridae	3	—	3	—	3
Miridae	1	3	4	—	1
Lygaeidae	1	2	3	—	2
Anthocoridae	2	—	2	33	1
Lepidoptera	7	1	8	8	5
Coleoptera					
Curculionidae	52	24	76	—	1
9 other families	4	11	15	91	10
Diptera					
Chloropidae	24	115	139	—	3
6 other families	17	12	29	168	10
Hymenoptera					
Formicidae	2	13	22	—	5
3 aculeate families	2	1	3	—	
11 Parasitica families	11	13	24	49	19
totals	205	219	424	—	72

The two sets of traps caught similar numbers of individuals (ground traps 205, pole traps 219), and the distribution of numbers of individuals in the traps is shown in figure 4. The largest catch (42 individuals) was in a pole trap, but relatively few traps yielded more than 10 individuals. The most common numbers were 5 or 6 (12 traps). Arthropods were captured in all 50 traps, one yielding but a single individual.

The influence of trap site was examined by comparing the catches of the five 'most coastal' and five 'most inland' traps of each type (table 2). Although the overall catches from the two trap types were very similar, the coastal traps of both types caught about twice as many individuals as the inland traps. Individual variability was, however, considerable.

Analysis of size classes of the captured arthropods (figure 5) revealed that about half the arthropods were 2 mm or less in body length, with the next largest group 2–4 mm. Very few individuals were larger than 10 mm. The latter were predominantly Hymenoptera (up to 17 mm) and the single dermapteran (11 mm).

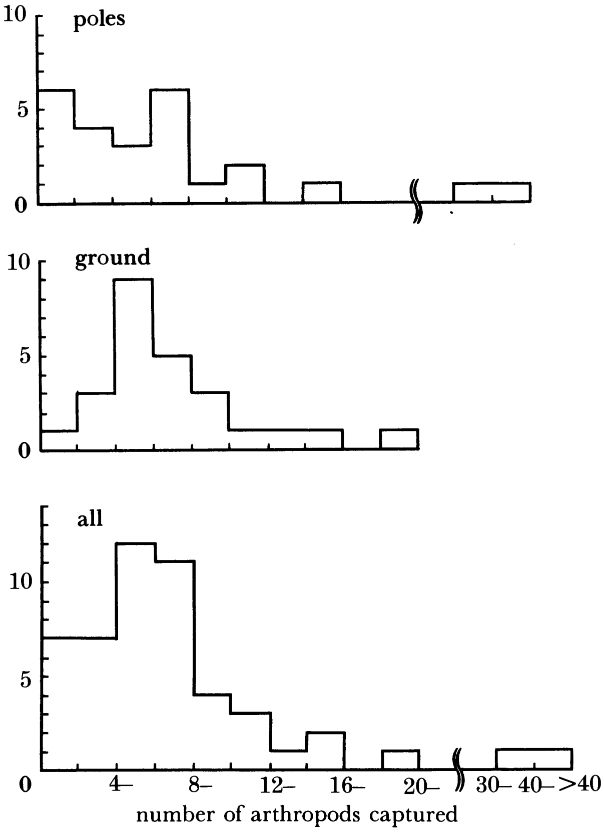

FIGURE 4. Distribution of numbers of individuals of arthropods captured in water traps, Anak Krakatau, August 1985.

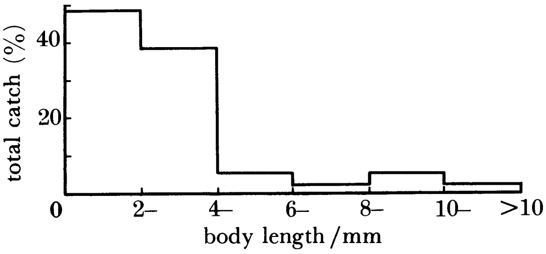

FIGURE 5. Size classes of arthropods captured in water traps, Anak Krakatau, August 1985.

TABLE 2. CATCHES BY 'COASTAL' AND 'INLAND' WATER TRAPS ON ANAK KRAKATAU, AUGUST 1985

	individual catches of five traps of each		totals		
site	pole	ground	pole	ground	all
coastal	8, 11, 37, 2, 5	7, 10, 20, 16, 5	63	58	111
inland	8, 7, 7, 2, 4	9, 6, 5, 2, 6	28	28	56

4. Discussion

The broad taxonomic spectrum of arthropods captured includes various ecological categories, and individuals of several possible origins.

(a) *The resident ground-dwelling fauna*

A proportion of the catch, particularly of the ground traps, undoubtedly consists of the existing, but sparse, local ground-dwelling fauna. This is reflected in some considerable differences between the two kinds of trap. All 33 Orthoptera caught were of a single flightless species of cricket (*Speonemobius* sp.), and all occurred in the ground traps: they were caught in 11 traps. Adult crickets represented a high proportion (22/30 individuals) of the 6–10 mm size categories and further emphasize the small size of most arthropods captured. Spiders were captured in 14 ground traps and 8 pole traps, and included several characteristically ground-dwelling spiders. The overall size distribution of spiders in the two trap types was similar. Crickets and spiders were also captured in the series of pitfall traps along the north and east rim of the barren outer cone (figure 2), and are clearly substantial faunal elements of this rather extreme habitat.

Ants and earwigs were also taken in the pitfall traps. The single earwig found in a ground water trap could thus also be a ground 'contaminant'. Ants were caught in relatively similar numbers in the two types of water trap, but were present in nine ground traps and only four pole traps: most specimens were winged, and all appear to represent species resident on the island, although this does not preclude an over-sea landfall.

The apparently resident ground fauna near the summit includes a large species of mantid, of which both adults and nymphs were found. It, and the crickets and spiders at the water trap site, may largely depend on aerial fall-out as food. Howarth (1979) found that a cricket was the predominant animal inhabiting both unvegetated pahoehoe lava flows (one less than four months old) and ash fields near Kilauea volcano, Hawaii Island, but it was not trapped in an adjacent vegetated area. On Hawaii this insect, together with a wolf spider, colonizes very young flows before plants are established, and both evidently survive on allochthonous aeolian debris. Howarth also recorded from this habitat an introduced mantid that does not persist once vegetation cover develops.

Precise identification of all species trapped is awaiting treatment of our collections by specialists in the various groups. Preliminary advice indicates that several are undescribed.

(b) *The air-borne fall-out*

Most of the remaining captures are likely to unambiguously represent fall-out from the aerial 'plankton'. The Malaise traps sited on rims of the ash cone and the summit crater both captured substantial numbers of arthropods, although not as many as the Malaise trap sited near sea level on the vegetated eastern foreland. Fewest specimens were caught in the Malaise trap at the summit, where winds were often strong and the trap enveloped in volcanic fumes. Clearly air-borne insects are widely distributed on this small island.

(i) *Estimate of rate of fall-out*

It is well known that differently coloured water-traps, and those with differing degrees of UV reflectance, may differentially attract various insect groups, and Kirk (1984) has gone some way towards categorizing some possible parameters of such differences. For insects living naturally on Gramineae, white traps catch at least as many insects as the more commonly employed yellow traps, which are presumed to evoke a more positive response by many plant-feeding insects. Some predators and parasites also appear to be attracted to white. The degree of UV reflectance of the present traps is low, but the white contrasted markedly with the black background of the lava, and attraction (to an unknown extent) is likely or, at least, cannot be dismissed. As in many 'relative sampling methods', quantitative inferences from water-trap data are dangerous, and any extrapolation should be conservative.

Trap size itself may affect catch size. Costa & Lewis (1967), using aphid catches in yellow water traps, showed that an approximately 8-fold increase of trap area was associated with an approximate halving of number of aphids per 100 cm^2, and species were attracted to traps of different areas differentially.

Our 50 traps had a total combined water area of 1.8 m^2. Excluding the crickets and assuming that 11 of the spiders caught in the ground traps were not the result of air-borne fall-out, the catch was about 20 individuals per square metre per day. Extrapolating this (and unrealistically assuming no attraction and a uniform density of insects in the air) directly to the area of Anak Krakatau, approximately 2.34 km^2, suggests that an upper limit of about 50 million arthropods per day could reach the island. At the other extreme, extrapolating only from numbers of insect groups unlikely to be resident and also unlikely to have been attracted (i.e. excluding also Diptera, Coleoptera, Hemiptera and Hymenoptera), i.e. two specimens per square metre per day (cf. actual catch of about 20 per square metre per day), the fall-out on the island would still represent about 5 million individuals per day, 10 times less than the upper limit. Variation in catch sizes is likely to depend heavily on such features as short term vagaries of weather, time of the year, seasonality and life cycles of the air-borne species, as well as the trap, and the difficulties of refining the trap form to more accurately quantify the fall-out are formidable when considered against the background of largely unknown variables affecting arthropod incidence and density in the air at any given time. We therefore do not attempt to quantify the fall-out beyond stating that the number of potential colonists arriving on Anak Krakatau either from a nearby island in the group (involving a distance of only 2–4 km), or from more distant regions of Indonesia, is assuredly very large. Trap colour can markedly affect catch size; if it does so by a factor of as much as 100, from 5000 to 500000 individuals could be falling on the island each day.

(ii) *Composition of the catches*

Because white traps are differentially attractive to many insect groups, it is not possible to extrapolate from the relative representation of orders in the trap catches to that of insects in the air; the spectrum of insect groups is distorted in the traps. All that can be said is that presence in the traps, with the exception of groups mentioned in §4*a* above, indicates presence in the air; absence from the catch does not necessarily indicate absence in the air. We make the following brief comments on catch composition because it is not known when further experiments with various types of trap will be possible.

The taxa represented in the catches are ecologically diverse, and include several particularly noteworthy groups. Aphids occur only very rarely in beating or sweep samples from vegetation on Anak Krakatau. The Naucoridae would be unlikely to colonize because of their dependence on freshwater and there is no permanent freshwater on the island. Fig wasps (Agaonidae) have been swept from vegetation on the island but, because the island's figs have only recently commenced fruiting, they must be a relatively recent resident component of the fauna. The absence of Thysanoptera in 1985, particularly because a specimen was taken in the 1984 pilot study, reflects the high degree of 'chance' in capturing any given taxon by this method.

The considerable diversity of Diptera and parasitic Hymenoptera parallels water-trap catches recorded from elsewhere in the world, and also the bulk samples of insects captured in various habitats on Anak Krakatau. Estimation of fall-out after the eruption of Mount St Helens in Washington (Edwards *et al.* 1984), for example, indicated a preponderance of Diptera. Many of the Diptera trapped on Anak Krakatau appear conspecific with resident fauna found on all the islands, and possibly represent highly dispersive taxa. The low numbers of some of the Hymenoptera, and most Hemiptera, include species that have not been found in more comprehensive samples of the resident fauna. The Lepidoptera include five individuals of a small pyralid (apparently unnamed) which has been captured in considerable numbers on bare lava up to the summit of the island, and which may be a migrant species.

The present study, as well as indicating the presence and extent of wind-borne fall-out on Anak Krakatau, has also shown that a pre-vegetation arthropod fauna exists in this barren environment, probably, like that of Hawaii, deriving its energy from air-borne input from outside the habitat and, in this case, probably from outside the island itself. The existence of such a specialized fauna in such habitats would not be surprising considering the long history and widespread extent of volcanism in Indonesia.

We are grateful to our colleagues on the 1984 and 1985 Expeditions for their companionship and help, and also thank Dr S. Adisoemato for his cooperation. We acknowledge permission to work in Indonesian national parks granted by the Indonesian Institute of Sciences, the National Institute of Biology and the National Parks Authority.

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