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RECOLONIZATION OF THE KRAKATAU ISLANDS AND ADJACENT AREAS OF WEST JAVA, INDONESIA, BY BATS (CHIROPTERA) 1883–1986

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CONTENTS

Since the cataclysmic eruption of 1883, 25 species of bats, of which 11 are pteropodids, have recolonized the Krakatau Islands and adjacent areas of West Java, Indonesia. Sixteen have been recorded on the Krakatau Islands.

Documentation of the recolonization process has been sporadic, and almost certainly incomplete, but it is apparent that pteropodids have been the first bat colonists of the Krakatau archipelago. On the main island of Rakata, and on the more recently formed island of Anak Krakatau, *Cynopterus sphinx* had established itself about 20–30 years after the cessation of major eruptive activity. Movements of pteropodids between the islands and the mainland are of clear importance in the re-establishment of vegetation.

Microchiropterans have been recent arrivals, probably recolonizing Rakata between 50 and 70 years after the 1883 eruption, but they were still absent from Anak in 1986.

1. Introduction

There seems little doubt that the vertebrate fauna of Krakatau and adjacent low-lying areas was completely destroyed by the cataclysmic eruption of 1883. However, no records of the original fauna of the islands exist and documentation of the recolonization of the region by animals since 1883 has been sporadic and in the case of bats, where the use of specialized

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equipment is required for complete censusing, is almost certainly incomplete. Nevertheless, some events in the recolonization process can be dated with a fair degree of certainty.

In 1908 no bats were seen during three days of observation on the main island of Rakata (Jacobson 1909), but by 1919, 36 years after the eruption, a species of *Cynopterus* was common on both Rakata and Sertung (Dammerman 1922). In the following year a second species of the same genus was detected on Rakata, although it was not found until ten years later on Sertung. The two species were recorded as *C. brachyotis angulatus* (*C. sphinx angulatus*) and *C. horsfieldi* (*C. horsfieldi lyoni*), respectively, (Dammerman 1938). A single specimen of *Hipposideros diadema* was found on Rakata in 1928 and a colony of a fourth species, *Rousettus amplexicaudatus*, was found in a boulder cave on Panjang in 1933 (Dammerman 1938).

No further collections of bats were made from the islands until 1974, when *C. sphinx angulatus*, *C. titthaecheilus* and *Macroglossus sobrinus sobrinus* were recorded from Rakata (Hill 1983), bringing the total number of species to six. *C. titthaecheilus* had been reported earlier from the island of Sebesi (Dammerman 1938), along with *Pteropus vampyrus* (Dammerman 1948). In the intervening period bats (unspecified) were observed to be common on Rakata in 1951 (Hoogerwerf 1953*a*) and collections were made from two nearby areas that had been at least partially inundated by tsunami after the 1883 eruption: *Pteropus vampyrus*, *Cynopterus brachyotis javanicus*, *Tylonycteris pachypus*, *Pipistrellus macrotis* (probably *P. imbricatus*) and *Megaderma spasma* from Panaitan Island (Hoogerwerf 1953*b*) and *P. vampyrus* and *Hipposideros larvatus*, from Ujung Kulon (Hoogerwerf 1970).

In 1982 a seventh species, *Megaderma spasma*, was added to the known bat fauna of the Krakatau Islands and a single bat (*Cynopterus*, sp. probably *C. sphinx angulatus*) was observed for the first time on Anak Krakatau (Yukawa *et al.* 1984). Anak Krakatau had emerged as a result of renewed volcanic activity in 1927, stabilizing in its present form by 1959 (Bird & Rosengren 1984). Suyanto *et al.* (1983) collected bats in the vicinity of Sumur and adjacent Ujung Kulon National Park in 1982. Both areas had experienced partial devastation by tsunami in 1883. In addition to the two species reported by Hoogerwerf (1970) a further 15 species of bat were found to have recolonized 99 years after the eruption.

This paper describes the results of surveys of bats that were done during the La Trobe University expeditions to the Krakataus in 1984, 1985 and 1986.

2. Materials and methods

In 1984, bat collecting was done (by R. A. Zann) as an adjunct to mist-net censuses of birds; braided nets set for birds were left in position after dark. Collecting sites were as follows: Anak Krakatau (one night) in the wooded portion of the southeastern foreland; Rakata (three nights), in the closed forest behind the beach at Zwarte Hoek; in the closed forest behind South Bay; at 250 m on West Ridge. Two harp-traps (Tidemann & Woodside 1978) were left in position for 11 days near boulder caves at Zwarte Hoek. Collecting was not carried out on Panjang or Sertung.

In 1985 all of the sites censused in the previous year (with the exception of the 250 m site on West Ridge) were re-surveyed (by C. R. Tidemann). A combination of one or more monofilament mist-nets and an ultrasound detector (Uppsala D-940) was used at each site. Nets were usually left set for about 2 h after dusk and ultrasound recordings were made on to a cassette tape-recorder (Sony WM-D6C) for the same period. On Anak Krakatau repeated

transects in the hour after dusk and the hour before dawn were made with the ultrasound detector across the wooded portion of the southeastern foreland on three consecutive days. Mist-nets were also set in this area. Eight nights were spend on Rakata in the Zwarte Hoek, Owl Bay and South Bay areas. One night was spent on Sertung in the northeastern part of the island and at the water soak one third of the way down the east coast. Two nights were spent on Panjang near the observation bunker on the northwest coast and near the northern edge of the lava on the west coast. Daytime searches were made along cliff lines and other likely areas for bat roosts. Harp-traps were not used routinely, but they facilitated the capture of bats from boulder caves on Zwarte Hoek and fissure caves on Panjang. At Carita, on the Javan mainland, bats were collected and ultrasound recordings were made on two nights.

In 1986 collections (by D. J. Kitchener) with monofilament mist-nets were made as follows: Sertung (one night) on the beach adjacent to the closed forest at the interface of the sand spit and the main island, and over the soak on the east coast; Panjang (two nights) at caves on the

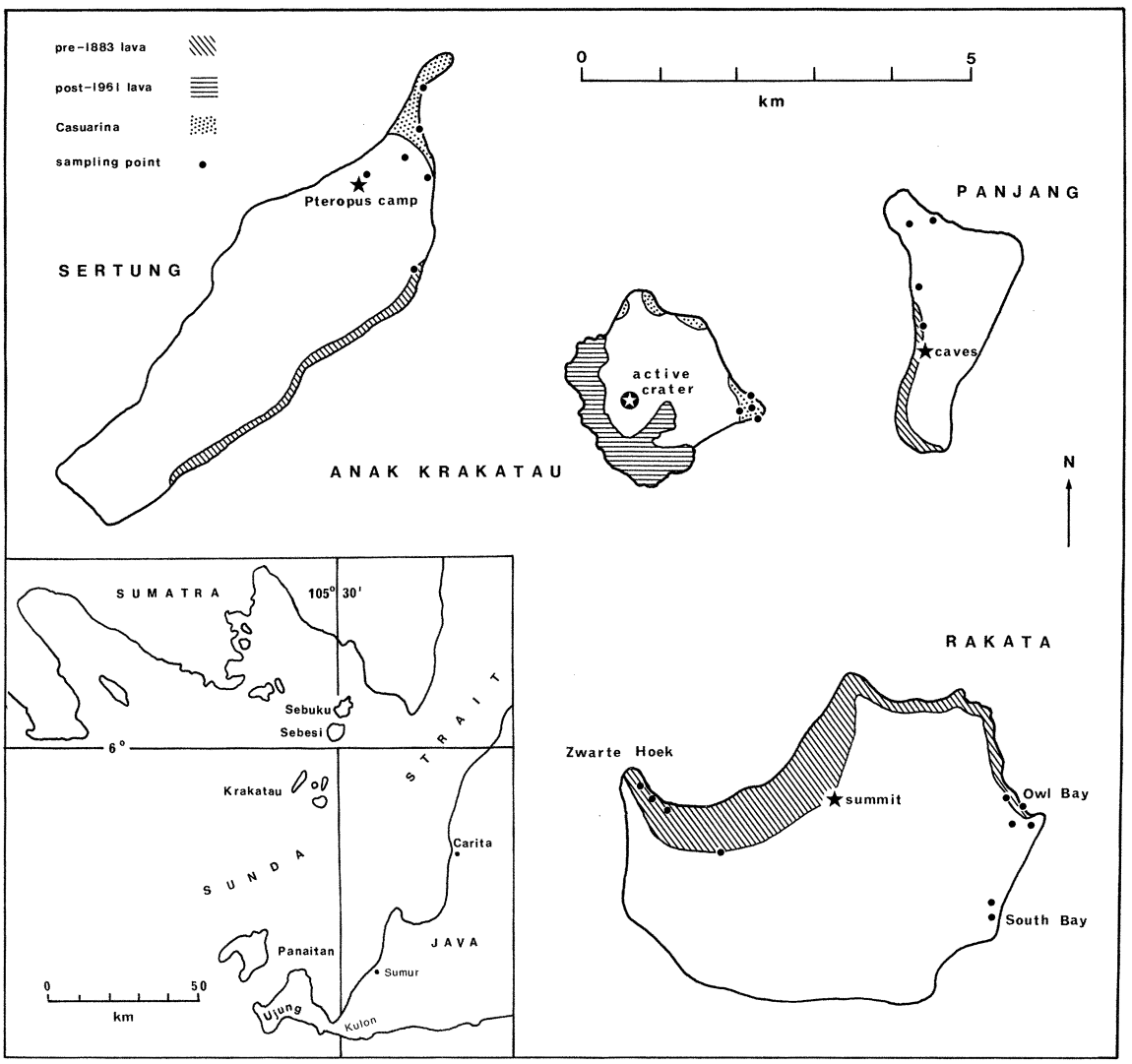

FIGURE 1. Location of sites at which collections of bats were made in 1984, 1985 and 1986 and other places mentioned in the text.

central west coast and at the observation bunker; Rakata (two nights) on the beach at Zwarte Hoek and in the closed forest behind it; Anak Krakatau (six nights) on the beach of the south-eastern foreland and amongst the casuarinas. Collections from within 10 km of Carita were made with the assistance of local people between 17–22 September and on 28 September.

Collecting locations and other places mentioned in the text are shown in figure 1.

3. Results

The results of bat collecting in 1984–1986 and of previous studies in the region are summarized in table 1.

In 1984 five species of bat were recorded from the Krakatau Islands, including three species not previously encountered: *Hipposideros larvatus*, *Emballonura monticola* and *Myotis muricola*. *Cynopterus sphinx angulatus* was found to be common in the wooded portion of Anak Krakatau. In 1985 11 species were collected from the islands, of which four were new records: *Pteropus vampyrus* (a camp of about 250 individuals on Sertung), *Hipposideros cineraceus*, *Rhinolophus celebensis javanicus* and *Scotophilus kuhlii temminckii*. All of the species collected in 1984 were also taken in the following year, but of those which had been recorded before the 1980s, *Macroglossus sobrinus*, *Cynopterus horsfieldi lyoni* and *Hipposideros diadema* were not found. There still appeared to be but a single species, *C. sphinx angulatus*, present on Anak Krakatau, but no microchiropterans were detected. Four out of the nine species found in the Carita area were not found on the Krakataus: *Macroglossus minimus*, *M. sobrinus* (although this had been reported earlier by Hill 1983), *Murina suilla* and *Tylonycteris pachypus*.

In 1986 a further species, *Rhinolophus pusillus*, was added to the known bat fauna of the Krakataus bringing the total to seventeen. Furthermore, *Pteropus vampyrus* and *Rousettus amplexicaudatus* were seen on Anak Krakatau for the first time (although insectivorous species were still not detected) and *C. titthaecheilus*, *R. amplexicaudatus* and *H. larvatus* were new records for Sertung, as was *C. sphinx* on Panjang. As a result of much more thorough collecting in the Carita area in 1986, nine species additional to those recorded in 1985 were collected. Of these, *Nycteris javanica*, *Tylonycteris robustula*, *Pipistrellus imbricatus*, *Kerivoula hardwickei* and *Chaerephon plicata* were completely new records for the Krakatau–Carita–Ujung Kulon area. The combined total of all species recorded from the region is 26, of which seventeen have been found on the Krakatau Islands.

The taxonomy used in this paper generally follows that of Honacki *et al.* (1982), with the following exceptions after Hill (1983):

1. We recognize that *C. sphinx* is specifically distinct from *C. titthaecheilus*.
2. *Rhinolophus celebensis* and *R. borneensis* are specifically distinct.
3. *Myotis muricola* is specifically distinct from *M. ater*. The species from Sumur referred to by Suyanto *et al.* (1983) as '*M. mystacinus*' is, in fact, *M. muricola* (A. Suyanto, personal communication).

We have no measurements to refer to for the record of *Pipistrellus macrotis* from Panaitan Island by Hoogerwerf (1953*b*), but consider it probably *P. imbricatus*. Specimens were taken of all species collected in 1984–1986 and representatives are held in the Western Australian Museum. The remainder of the collection is in the Museum Zoologicum Bogoriense, which also holds specimens collected by Suyanto *et al.* (1983) from Sumur and Ujung Kulon.

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TABLE 1. BAT SPECIES RECORDED FROM THE KRAKATAU ISLANDS AND ADJACENT AREAS IN WEST JAVA SINCE 1908 WHEN NO BATS WERE OBSERVED DURING THREE DAYS OF OBSERVATION ON RAKATA

	location							
species	Rakata	Sertung	Panjang	Anak	Panaitan	Sebesi	Carita	Sumur Ujung Kulon
Pteropodidae								
Pteropus vampyrus (Linnaeus, 1758)	9	12	—	13	5	4	—	6
Cynopterus horsfieldi lyoni Andersen, 1912	2, 3	2, 3	—	—	—	—	13	8
C. sphinx angulatus Miller, 1898	2, 3, 7, 11–13	2, 3, 12, 13	13	10–13	—	—	13	8
C. titthaecheilus titthaecheilus (Temminck, 1825)	7, 12	13	12, 13	—	—	3	12	—
C. brachyotis brachyotis (Muller, 1838)	—	12	—	—	5	—	12, 13	8
Rousettus amplexicaudatus infumatus (Gray, 1870)	12, 13	13	3, 12, 14	13	—	—	—	8
Macroglossus minimus minimus (E. Geoffrey, 1810)	—	—	—	—	—	—	12	8
M. sobrinus sobrinus Andersen, 1911	7	—	—	—	—	—	12, 13	—
Eonycteris spelaea (Dobson, 1871)	—	—	—	—	—	—	—	8
Chironax melanocephalus (Temminck, 1825)	—	—	—	—	—	—	—	8
Megaerops kusnotoi Hill & Boeadi, 1978	—	—	—	—	—	—	—	8
Emballonuridae								
Emballonura monticola monticola Temminck, 1838	11, 12	—	12, 13	—	—	—	—	—
Nycteridae								
Nycteris javanica E. Geoffroy, 1813	—	—	—	—	—	—	13	—
Megadermatidae								
Megaderma spasma trifolium E. Geoffroy, 1810	10–13	—	—	—	5	—	13	8
Rhinolophidae								
Rhinolophus celebensis javanicus Andersen, 1918	—	12	—	—	—	—	—	—
R. pusillus Temminck, 1834	13	—	—	—	—	—	—	—
R. affinis Horsfield, 1823	—	—	—	—	—	—	—	8
R. acuminatus Peters, 1871	—	—	—	—	—	—	—	8
Hipposideridae								
Hipposideros cineraceus Blyth, 1853	12, 13	—	—	—	—	—	—	—
H. diadema (E. Geoffroy, 1813)	2	—	—	—	—	—	—	—
H. larvatus larvatus (Horsfield, 1823)	11–13	13	12, 13	—	—	—	12, 13	6, 8
Vespertilionidae								
Myotis muricola muriola (Gray, 1846)	11, 12	—	—	—	—	—	12, 13	8
Pipistrellus javanicus (Gray, 1838)	—	—	—	—	—	—	13	8
P. imbricatus (Horsfield, 1824)	—	—	—	—	?5	—	13	—
Tylonycteris pachypus (Temminck, 1840)	—	—	—	—	5	—	12, 13	—
T. robustula (Thomas, 1915)	—	—	—	—	—	—	13	—
Scotophilus kuhlii temminckii Leach, 1822	12	12	—	—	—	—	12	—
Murina suilla (Temminck, 1840)	—	—	—	—	—	—	12, 13	8
Kerivoula hardwickei hardwickei (Horsfield, 1824)	—	—	—	—	—	—	13	—
K. picta (Pallas, 1767)	—	—	—	—	—	—	—	8
Molossidae								
Chaerephon plicata (Buchanan, 1800)	—	—	—	—	—	—	13	—
number of species:	14	9	5	3	5	2	18	17
totals	Krakatau Islands: 16					mainland: 26		

[a] Sources of data: (1) Jacobson (1909); (2) Dammerman (1922); (3) Dammerman (1938); (4) Dammerman (1948); (5) Hoogerwerf (1953*b*); (6) Hoogerwerf (1970); (7) Hill (1983); (8) Suyanto *et al.*, (1983); (9) P. J. Vaughan (unpublished observation, 1984); (10) Yukawa *et al.* (1984); (11) La Trobe expedition (1984); (12) La Trobe expedition (1985); (13) La Trobe expedition (1986); (14) Ibkar-Kramadibrata *et al.* (1986).

4. Discussion

Almost certainly the census of bats on the Krakatau Islands remains incomplete. Although most islands were visited only briefly in 1986 and no new sites additional to those visited in 1985 were examined, a new species was recorded and the species known from the individual islands were changed considerably. Furthermore, an examination of the species of bats recorded from the adjacent mainland shows the presence of a number of widespread species there that have the potential to inhabit the Krakataus (for example, *Murina suilla*, *Rhinolophus* spp., *Pipistrellus* spp., *Chaerephon plicata* and *Kerivoula* spp.). Given the irregularity with which several species have been collected on past expeditions to the Krakataus, it seems likely that some of the above mainland species are indeed present on the islands. More species may also remain to be discovered on the mainland.

The situation may be complicated further because some of the larger species, particularly the pteropodids, may move freely between the islands, and perhaps the mainland, to feed. The observations of the flying foxes, *Pteropus vampyrus*, *Cynopterus* spp. and *Rousettus amplexicaudatus* on the islands are erratic and suggest movements between them. Dammerman (1948) observed large numbers of *Pteropus* moving between Sebesi and Sebuku or the Sumatran coast and in some cases they appeared to fly in the direction of the Krakataus. In 1984 a solitary animal was seen near the summit of Rakata (P. J. Vaughan, unpublished data), and in 1989 the species was fairly common in the vicinity of Owl Bay (K. Richards, personal communication); in 1986 one was seen on the wooded foreland of Anak Krakatau, whereas none had been seen in the previous two years. The camp of about 250 *Pteropus* observed on Sertung in 1985 was not there the following year. *Rousettus amplexicaudatus* was collected on Anak in 1986, although not in the previous two years, despite fairly extensive netting. On Panjang it was not observed in 1985, although a number of caves suitable as roosts were examined, but it was present in 1986. *Cynopterus horsfieldi lyoni* has not been collected on the Krakataus since 1933 (Dammerman 1948), but was found at Sumur in 1982 and at Carita in 1986. Bats dependent on flowers and fruit commonly change their feeding locations in response to the seasonal availability of these resources and the water gaps between the islands would not be difficult for these species to traverse, as all are excellent fliers.

The role of the movements of fruit-eating bats in the dispersal of the plants upon which they feed was discussed by Docters van Leeuwen (1935, 1936) after he had visited the Krakatau Islands and Dammerman (1948) commented upon finding the seeds of many different species in the droppings of bats and beneath their roosts. During our study the floors of caves on Panjang occupied by *Cynopterus titthaecheilus* were littered with the seeds of *Terminalia catappa* and the excreta of *Cynopterus* spp. and *Rousettus* contained many fig seeds. In 1984 *Cynopterus sphinx* caught in mist nets on Anak Krakatau regurgitated and defaecated fig seeds, although at that time no fruiting figs were found there. In 1985 *Ficus* seedlings were found in several places on the bare lava, attesting to the movements of bats over these areas. They are clearly of prime importance in the recolonization of these islands by vegetation.

The absence of some species of bats that are present on the mainland but not on the Krakataus can be explained by the lack of a suitable habitat there for them. *Chironax melanocephalus*, for example, appears to be restricted to primary forest (Suyanto *et al.* 1983) and *Tylonycteris* spp. roost almost exclusively in bamboos (Medway & Marshall 1970). Primary forest has not established on the Krakataus (Whittaker 1982) and bamboos do not occur there (Whittaker & Flenley 1982).

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The occurrence of *Hipposideros diadema* on the islands is rather puzzling. It has been recorded from one specimen only, collected at 600 m on Rakata in May 1928. There is no doubt as to the identity of this animal (M. Z. B. 1541; Boeadi, personal communication). However, the species has not been recorded since 1928 on the Krakataus, nor at all on the adjacent mainland. It may represent a chance immigrant or it could have become extinct after an initial colonization. It seems unlikely that this large, cavernicolous species would not have been collected by the relatively thorough surveys of Suyanto *et al.* (1983) and by the 1985 and 1986 La Trobe expeditions, had it been present in the area.

The collection of the much smaller species *Emballonura monticola*, *Rhinolophus pusillus* and *Hipposideros cineraceus* from the Krakataus, but not the adjacent mainland is not so surprising and may simply be the result of inadequate collecting. Knowledge of the bat fauna of the region is too scanty to enable further comments to be made.

The course of recolonization of Anak Krakatau may be more rapid than on the other islands because they themselves are now proximal reservoirs of source fauna, but the process itself is likely to be similar. Thus *Cynopterus sphinx angulatus* was present on Anak Krakatau in 1982, 23 years after the 1959 eruption and it established on Rakata between 1908 and 1919, somewhere between 26 and 36 years after the 1883 eruption. Insectivorous species had not colonized Anak Krakatau by 1986, although one suspects that a suitable habitat may soon exist there for them if it does not already. With the exception of *Hipposideros diadema* it is not possible to accurately date the arrival of microchiropterans on the islands of Rakata, Sertung and Panjang. Dammerman's last recorded trip to the group was in 1939 (Dammerman 1948) and it is, perhaps, possible to assume that these species were not obviously present at this time. By 1952, 69 years after the eruption they probably were present, for Hoogerwerf (1953*a*) reported that 'bats' were common on Rakata.

It seems clear that the relatively unspecialized roosting requirements and good dispersal abilities of the fruit-eating bats have enabled them to be the first bat colonists of these islands. Their activities as seed vectors have been integral to the re-establishment of vegetation and this has probably paved the way for later immigrations by microchiropterans.

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