J. Hyg., Camb. (1973), **71**, 299
With 1 plate
Printed in Great Britain

Macquarie Island: the introduction of the European rabbit flea *Spilopsyllus cuniculi* (Dale) as a possible vector for myxomatosis

By W. R. SOBEY and K. M. ADAMS
CSIRO, Division of Animal Genetics, P.O. Box 90, *Epping, NSW* 2121
G. C. JOHNSTON and L. R. GOULD
Department of Agriculture, GPO Box 192*b*, *Hobart, Tasmania*, 7000
K. N. G. SIMPSON
Department of Zoology, Monash University, Clayton, Victoria 3168
and K. KEITH
CSIRO, Division of Wildlife Research, P.O. Box 84, *Lyneham, ACT* 2602

(*Received* 30 *August* 1972)

SUMMARY

The European rabbit flea *Spilopsyllus cuniculi* (Dale) was first released on Macquarie Island in December 1968. The flea has survived and bred on the island and about 30% of the rabbits sampled from the original release area in January 1972 were flea-infested.

INTRODUCTION

Macquarie Island, Fig. 1, situated about half-way between New Zealand and Antarctica (54° 30′ S., 158° 57′ E.), is a long narrow ledge of land about 34 km. long by 4·5 km. wide and 120×10^6 m.^{2} in area. The island rises steeply out of the sea to a plateau ranging in height between 180 and 300 m. with peaks up to 433 m. Weather conditions are bleak, with a mean temperature of 4·4° C. and a mean diurnal range of 3·2° C. The average sunshine of only 1·8 hr. a day is concentrated in the period October–March. The relative humidity seldom falls below 90% and a figure of 100% is often maintained for 24 hr. or more. Windy conditions prevail, with an average velocity of about 10 m. s.$^{-1}$ and gusts exceeding 27 m. s.$^{-1}$ frequent at all times of the year. Although devoid of trees the island has a luxuriant vegetation including flowering grasses and broad-leafed succulents.

Rabbits, *Oryctolagus cuniculus* L., were introduced onto many of the sub-Antarctic islands during the latter half of the nineteenth century by sealers and whalers as a source of fresh meat more acceptable than penguin, seal or sea-elephant tongue. The first rabbits released on Macquarie Island were dispatched by William Elder of the Otago Whaling Company in 1879 or 1880 and were described as 'French rabbits' (Cumpston, 1968). They were of domestic origin (Shipp, Keith, Hughes & Myers, 1963). Fluctuating rabbit density was reported and often attributed to predation by feral cats. Another reason for the population

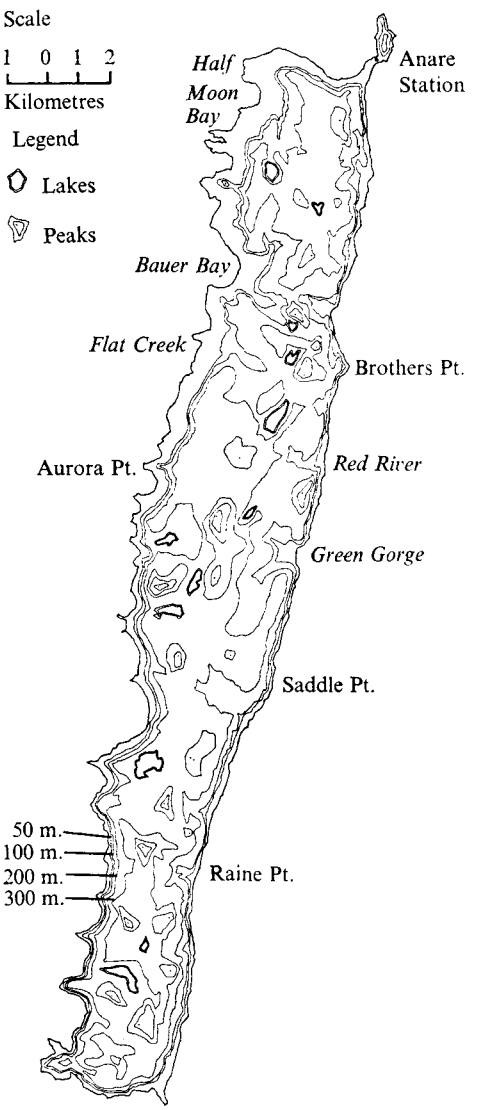


Fig. 1. Illustrating how Macquarie Island rises steeply from sea level to a plateau ranging between 180 and 300 m. in height.

fluctuations could have been pasture over-grazing by rabbits, resulting in denuded areas and consequent movements of rabbits to less denuded areas as suggested by Taylor (1955). Further, the amount of breeding in the denuded areas was found by Shipp *et al.* (1963) to be considerably reduced. Over-grazing by rabbits of the principal dominant, *Poa foliosa*, the only native species capable of stabilizing the soil on steep slopes, results in soil erosion, particularly in the form of soil slips in high moor peat areas. Rabbit over-grazing is also considered to be endangering the survival of a number of plant species (Costin & Moore, 1960; Holdgate & Wace, 1961; Taylor, 1955).

No systematic attempt has yet been made to reduce rabbit numbers on the island, although investigations into possible methods of control have been made (G. C. Johnston, unpublished data). The Glenfield strain of myxoma virus was introduced into about 100 burrows in aerosol form and 15 rabbits were injected with the virus. Reduced burrow activity suggested a localized kill but no sick rabbits were seen. Consistent with this observation, an examination of ectoparasites on rabbits at the time revealed one, *Haemodipsus ventricosus* (G. C. Johnston, 1965, unpublished data), as a possible vector for myxomatosis (Mykytowycz, 1958) at the level of contact infection. Thus in the absence of a suitable mobile vector, myxomatosis could not be considered as a useful means of rabbit control on the island. Poisoning with sodium fluoroacetate ('1080'), in the form of 'one-shot' oat bait (Gooding & Harrison 1964), proved moderately successful in terms of rabbits killed but presented logistic problems as the bait had to be carried and distributed by the operator over very difficult terrain. There was no evidence of poisoning of any natural fauna, although the carcases of two cats were found after poisoning. Burrow fumigation presented difficulties with regard to fauna conservation since rabbit burrows and bird-nest openings were often indistinguishable and co-habitation by rabbits and birds was observed (Johnston, 1966).

Clearly, a biological control which would limit rabbit numbers would be desirable as conventional rabbit control measures are difficult to use on Macquarie Island. The island is devoid of mobile biting insects (Watson, 1967), possibly because it is a narrow, wind-swept island and without such insects the usefulness of myxomatosis as a control measure seemed very doubtful. It therefore seemed a good idea to examine the possibility of introducing the European rabbit flea, *Spilopsyllus cuniculi* (Dale), as a vector for myxomatosis which, if successful, might provide a possible biological control of the rabbit.

Collecting data from a remote island of rugged terrain and unpredictable climatic conditions is difficult and often hazardous. Lone expeditions on the island are forbidden. A supply ship visits the island twice a year, in March and November, and periods ashore are limited to 3–4 days during turn-around (if the weather is fine), 4 months November–March, or 12 months November–November. Long-term observations by an individual are difficult to arrange. The data presented in this paper were collected by the different authors at different times with the help of numerous unnamed members of the Australian National Antarctic Research Expedition (A.N.A.R.E.) stationed on the island with a permanent base on the northern peninsular (see Fig. 1).

MATERIALS AND METHODS

Fleas

All the fleas taken to Macquarie Island were laboratory-bred fleas (Sobey & Conolly, 1971). In transit, fleas were refrigerated at 4° C. They were disseminated within 3 days of their arrival on the island. During 1971/2 6600 fleas collected from rabbits shot on the island were re-released. A small battery-operated aspirator was used to collect fleas off combs.

Blood samples

Blood samples from shot rabbits were collected by the method described by Sobey, Conolly and Adams (1966).

Rabbit ages

Eye lenses were collected for age determination (Lord, 1959; Myers & Gilbert, 1968).

RESULTS

Rabbit distribution

Rabbit distribution for the years 1956, 1965–6 and 1970–1 are shown in Fig. 2. Rabbits were distributed over the whole length of the island throughout the period of observations, but the areas of high density changed with time.

Estimates given by individual A.N.A.R.E. personnel of the numbers of rabbits in the areas labelled 'abundant' varied from 20 to 400 per 400 m.^{2}. Daylight counts made in April 1972 of rabbits seen in an area of approximately $1{\cdot}67 \times 10^4$ m.^{2} at each of the locations Half Moon Bay, Flat Creek, Red River and Green Gorge (see Fig. 1) are shown in Table 1. These are areas classified as 'abundant'. The counts are repeatable. In order to arrive at some estimate of the number of rabbits on the island the areas of the different density subdivisions have been estimated from Fig. 2 and these are presented in Table 2. The highest density was observed in 1965–6 and the lowest in 1956. The area of the island is about 120×10^6 m.^{2}. If the 'abundant' density is taken as 20 rabbits per 400 m.^{2} and the 'common' as 5 rabbits per 400 m.^{2}, estimates of about 50,000 rabbits in 1956 and 150,000 rabbits in 1965–6 for the whole island may be assumed.

Predators

There are three predators of rabbits on Macquarie Island: the feral cats (*Felis catus* L.), the Stewart Island Weka (*Gallirallus australia scotti*) and the Southern Skua (*Catharacta skua lonnbergi*). Cats were reported on the island in 1820, 60 years before rabbits were introduced (Cumpston, 1968). While it is clear that they can survive on the island in the absence of rabbits they are nevertheless considered to be an important predator of rabbits (Fenner & Ratcliffe, 1965).

Wekas, a flightless rail species, were introduced to the island in 1874 (Cumpston, 1968) from Stewart Island, New Zealand. Their distribution largely coincides with the distribution of *Poa foliosa*, and thus they are largely restricted to the coastal fringe (Fig. 3). They feed particularly on earthworms, kelp-fly maggots and small intertidal isopods. Wekas are opportunist feeders and are able to kill young rabbits.

In Plate 1A an adult weka is seen with a 542 g. rabbit kitten it has just killed.

The indigenous skuas are versatile and opportunistic in their choice of animal foods and quick to feed on a shot rabbit. Skuas were often observed to chase rabbits and they prey on both adults and small sickly animals. Rabbit remains were found in many skua-nest territories (Simpson, 1965). Plate 1B shows a skua feeding on an adult rabbit.

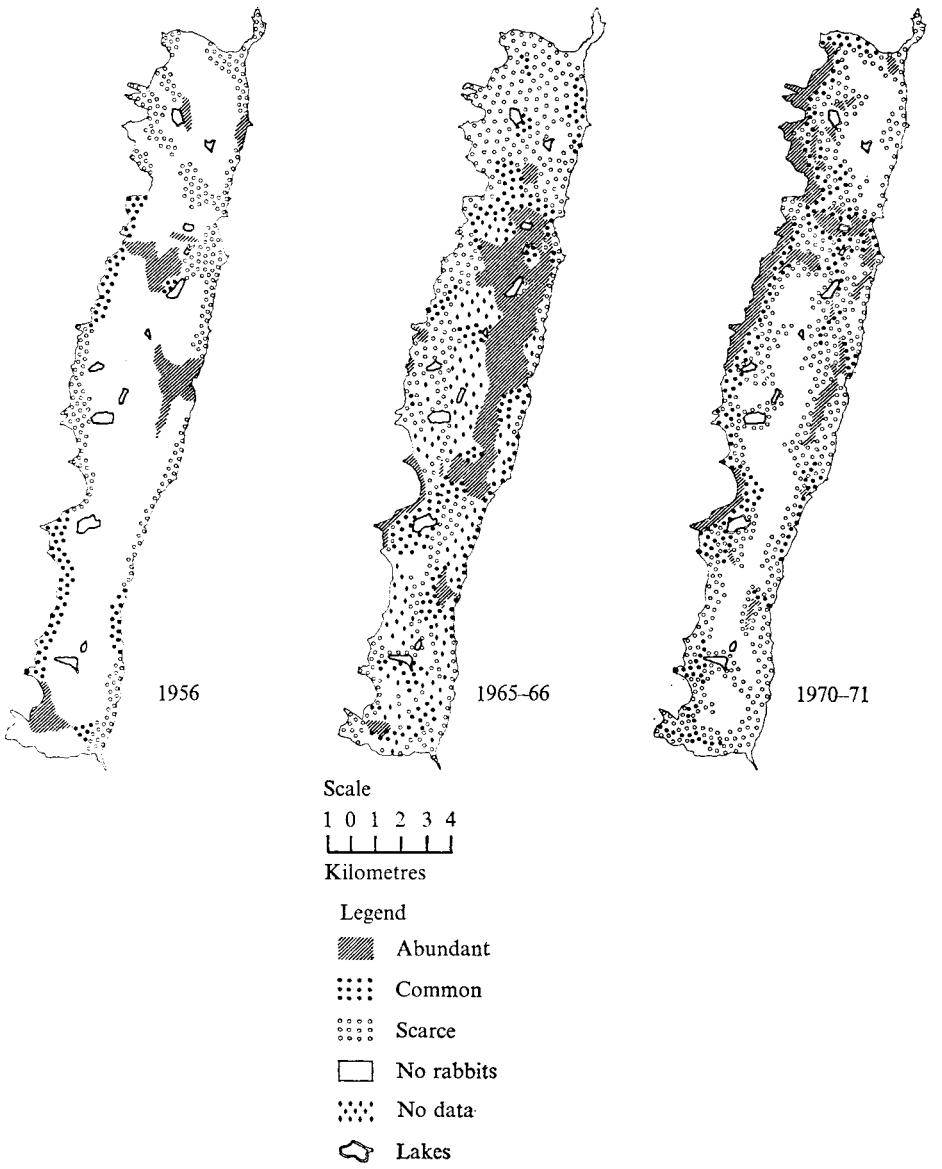


Fig. 2. The estimated density distributions of rabbits in the years 1956, 1965–6 and 1970–1.

Flea releases and recoveries

The first releases of fleas on the island were made in December 1968. The areas where these and subsequent releases were made are shown in Fig. 4A. During the period December 1971 to March 1972, 6600 fleas were collected from shot rabbits and re-released in the north of the island. Between 20 and 200 fleas were collected from females and 10–30 from males, although occasionally 200 were collected from a male. The areas where flea-infested rabbits were recovered are shown in Fig. 4B and the numbers of fleas released and flea-infested rabbits recovered are

https://doi.org/10.1017/S0022172400022762 Published online by Cambridge University Press

Table 1. *Rabbit counts made in April* 1972 *by A.N.A.R.E. personnel in 'abundant' rabbit areas in different locations based on an estimated* $1{\cdot}67 \times 10^4$ m.^{2} *in each case*

Location counted	Count ($1{\cdot}67 \times 10^4$ m.^{2}, 4 acres)
Half Moon Bay	77
Flat Creek	74
Red River	64
Green Gorge	84

Table 2. *The areas of each rabbit density subdivision estimated from Fig.* 1 *and expressed as a percentage of the area of the island*

	Area as a percentage of the island		
Rabbit density	1956	1965–6	1970–1
Abundant	8	18	13
Common	8	19	15
Scarce	23	38	44
No rabbits	61	8	28
No data	—	17	—

shown in Table 3. Clearly the fleas have survived and bred on the island and the numbers of flea-infested rabbits have increased since the fleas were first released.

Rabbit ecology

Very little is known about the ecology of the rabbit on Macquarie Island. Kittens and young rabbits are very rarely seen on the island and this observation may be related to predation. The age structure of the rabbits on the island has not been determined in detail because the rabbits are of domestic origin and lens weights follow a different age/weight curve from that determined for wild rabbits in Australia (Myers & Gilbert, 1968). Only ten out of a sample of 444 lenses collected in January 1972 and aged on an age/weight curve determined from laboratory rabbits (W. R. Sobey, unpublished data) were less than 1 year old.

A very interesting problem of age distribution was found in a separate investigation by G. C. Johnston. He discovered (unpublished data) that lens weights of rabbits on Macquarie Island greatly exceeded those found for any wild rabbits and suggested that many of the rabbits could be old, possibly 5 years or more. In the present samples lens weights exceeding any previously found for laboratory rabbits up to 3 years of age were discovered.

During 1956, while digging out burrows in order to capture rabbits, it was observed that a number of burrows contained nests in which the kittens had been drowned.

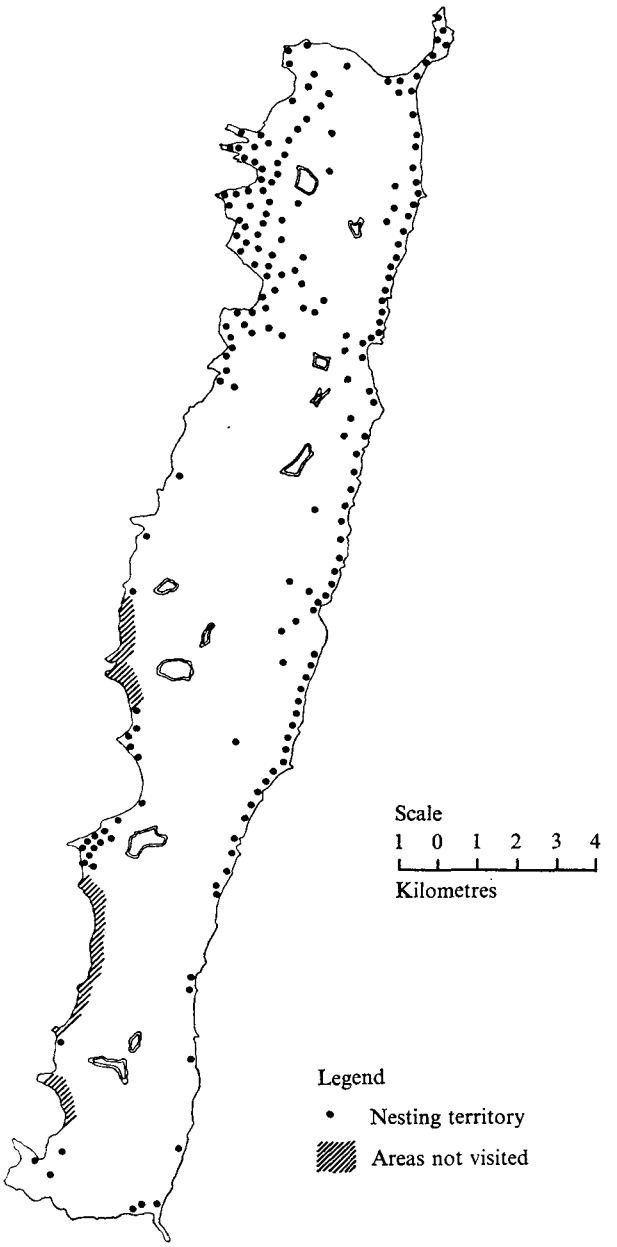


Fig. 3. The distributions of the Stewart Island weka, 1964–6.

Blood samples

A total of 640 blood samples were examined for the presence of antibodies to the soluble antigens of Myxoma virus and all were negative. An examination of the immunoglobulin allotypes whose frequency suggests a founder effect are reported elsewhere by Curtain, Wood & Sobey (1972).

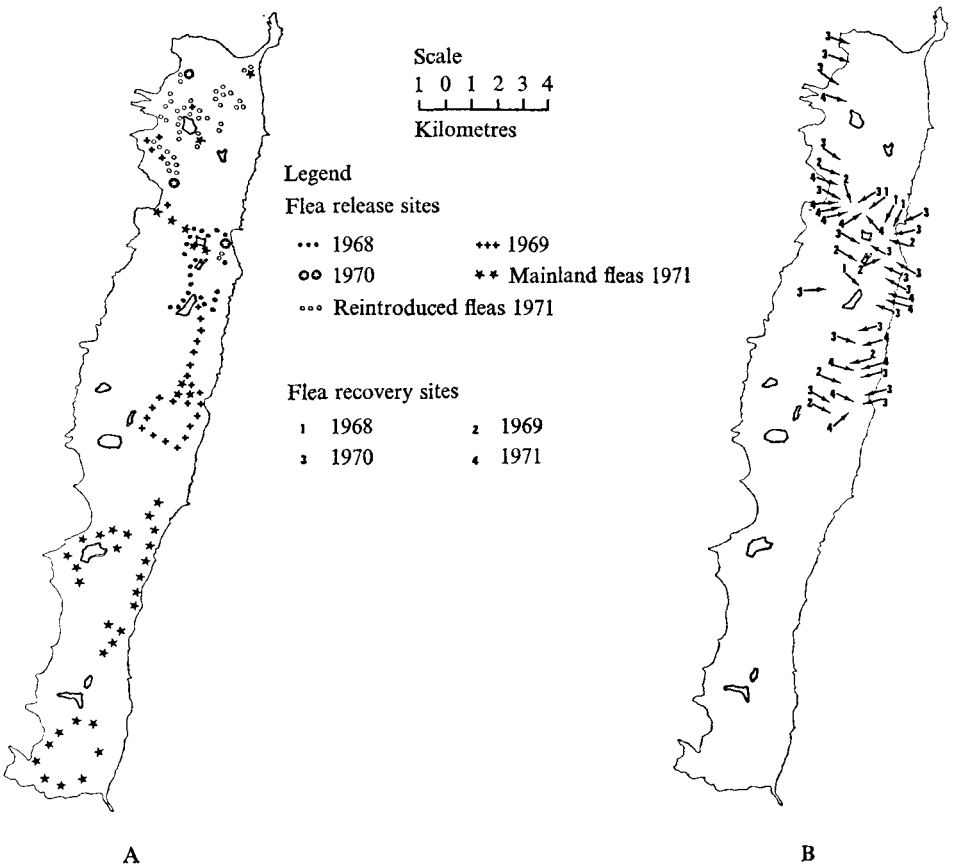


Fig. 4. (A) Flea release sites during the years 1968–72. Fleas were released directly into burrows in lots of 100 or 200. (B) Flea recovery sites during the years 1968–72. The southern half of the island was not sampled in 1971 after fleas were released.

Table 3. *Fleas released on Macquarie Island between* 1968 *and* 1972 *together with the proportion of rabbits in shot samples which were flea infested*

(In 1971, 6600 of the 16,600 fleas released were collected from rabbits on the island and re-released.)

Year	Fleas introduced	Rabbits with fleas	Sample size	Flea-infested rabbits (%)
1968	10,000	—	—	—
1969	10,000	14	624	2
1970	6,000	50	1418	3·5
1971	16,600	386	1879	21
1972	—	109	356	31

https://doi.org/10.1017/S0022172400022762 Published online by Cambridge University Press

DISCUSSION

The high proportion of adults in the population and their extended age-range as compared to that of the Australian mainland rabbits suggests either heavy predation of young with an absence of predation of adults or some high disease or environmental mortality of young rabbits associated with the inhospitable environment. The presence of known predators in the form of cats, wekas and skuas makes predation a likely explanation, at least in part. The high water table, with resulting boggy nature of the ground and the observation that kittens are drowned, offers another direct explanation.

The large fluctuations in population density reported here and in the literature could be related to predation or the effects of selective over-grazing or both.

The extended ages of the adult rabbits suggests a low rate of predation of adults and therefore fluctuations in population density are most likely due to the eating-out of areas by rabbits with movement and decrease of the population. Subsequent regeneration of the vegetation occurs, but there is a continual deterioration of the vegetation as a result of soil erosion and fears have been expressed for the survival of some plant species.

The European rabbit flea was introduced onto the island in 1968 as a possible vector for myxomatosis. Initial recoveries of flea-infested rabbits in 1969 and 1970 were disappointing but by 1972 30% of the rabbits sampled in release areas were infested. There seems little doubt that the flea has survived and bred on the island. When all, or nearly all, of the rabbits on the island are flea-infested it is proposed to introduce myxoma virus. Being a fully susceptible population a high mortality should result, although it is unlikely that all rabbits will be killed even if all infected rabbits die. Regeneration of the rabbit population should be slow, particularly if predation of young is important. None of the three predators is rabbit-dependent for its food and is not, therefore, likely to diminish in numbers; but the relative predation pressure should be great, resulting in a reduced build-up of rabbit numbers. If the virus remains active as a result of reactivation (Williams, Dunsmore & Parer, 1972) or by retention on the mouthparts of fleas (Chapple & Lewis, 1965) it could act as a continuing biological control, decreasing slowly in effectiveness as genetic resistance (Sobey, 1969) builds up. If, however, the virus disappears after the first outbreak it could be effectively reintroduced when the regenerating rabbit population reached a level sufficient to warrant further control.

We wish to thank the Director, Antarctic Division, Department of Supply, Australia, for the facilities afforded to make this project possible and to the members of the numerous expeditions who have assisted either by personal participation or by providing information from their observations.

REFERENCES

Chapple, P. J. & Lewis, N. D. (1965). Myxomatosis and the rabbit flea. *Nature, London* **207**, 388–9.

Costin, A. B. & Moore, D. M. (1960). The effects of rabbit grazing on the grasslands of Macquarie Island. *Journal of Ecology* **48**, 729–39.

CUMPSTON, J. S. (1968). *Macquarie Island.* Antarctic Division, Department of Ex Affairs, Australia.

CURTAIN, C. C., WOOD, D. H. & SOBEY, W. R. (1972). The distribution of immunogl allotypes in rabbit populations in Australia and Macquarie Island. *Animal Blood G and Biochemical Genetics.* (In the Press.)

FENNER, F. & RATCLIFFE, F. H. (1965). *Myxomatosis.* Cambridge University Press.

GOODING, C. D. & HARRISON, L. A. (1964). 'One shot' baiting. *Journal of Agricultu Western Australia* **5**, 1.

HOLDGATE, M. W. & WACE, N. M. (1961). Influence of man on the floras and faunas of sout islands. *Polar Record* **10**, 475–93.

JOHNSTON, G. C. (1966). Macquarie Island and its rabbits. *Tasmanian Journal of Agricu* **37**, 277–80.

LORD, R. D. (1959). The lens as an indicator of age in cottontail rabbits. *Journal of Wil Management* **23**, 358.

MYERS, K. & GILBERT, N. (1968). Determination of age of wild rabbits in Australia. *Jour of Wildlife Management* **32**, 841.

MYKYTOWYCZ, R. (1958). Contact transmission of infectious myxomatosis of the rab *Oryctolagus cuniculis* (L.). *C.S.I.R.O. Wildlife Research* **3**, 1–6.

SHIPP, E., KEITH, K., HUGHES, R. L. & MYERS, K. (1963). Reproduction in a free-livi population of domestic rabbits, *Oryctolagus viniculus* (L.), on a sub-Antarctic islan *Nature, London* **200**, 858–60.

SIMPSON, K. G. (1965). The dispersal of regurgitated Pumice Gizzard-stones by the Southe Skua at Macquarie Island. *The Emet* **65**, 119–24.

SOBEY, W. R. (1969). Selection for resistance to myxomatosis in domestic rabbits (*Oryctolagu cuniculus*). *Journal of Hygiene* **67**, 743.

SOBEY, W. R. & CONOLLY, DOROTHY (1971). Myxomatosis: the introduction of the Europea rabbit flea, *Spilopsyllus cuniculi* (Dale), into wild rabbit populations in Australia. *Journa of Hygiene* **69**, 331–46.

SOBEY, W. R., CONOLLY, D. & ADAMS, K. M. (1966). Myxomatosis: a simple method of sampling blood and testing for circulating soluble antigens or antibodies to them. *Australian Journal of Science* **28**, 354.

TAYLOR, B. W. (1955). The flora, vegetation and soils of Macquarie Island. *A.N.A.R.E. Reports* B, vol. II, pp. 1–192. Commonwealth of Australia, Department of External Affairs.

WATSON, K. D. (1967). The terrestrial orthropods of Macquarie Island. *A.N.A.R.E. Scientific Reports* B (i), *Zoology Publication,* no. 99.

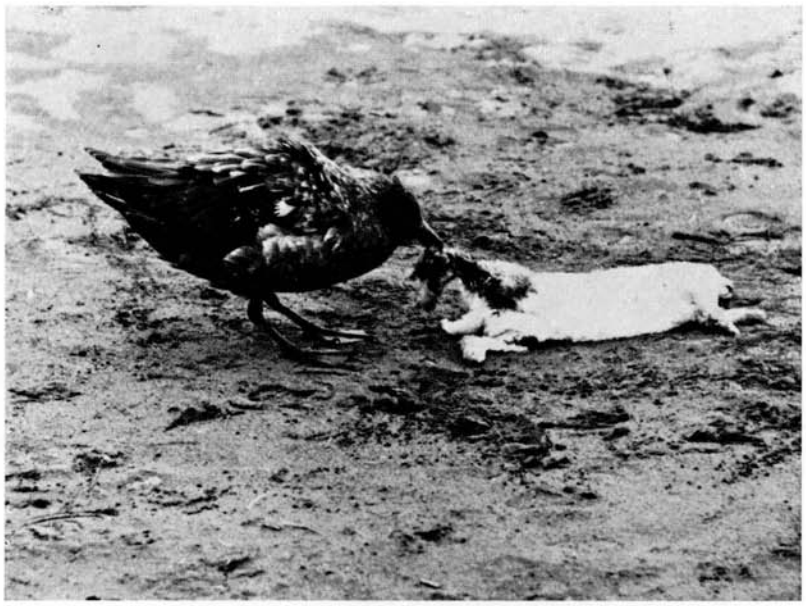
WILLIAMS, R. T., DUNSMORE, J. D. & PARER, I. (1972). Evidence for the existence of latent *Myxoma* virus in rabbits (*Oryctolagus cuniculus* L.). *Nature, London* **238**, 99–101.

EXPLANATION OF PLATE

(A) An adult female weka with a 542 g. rabbit kitten it has just killed.

(B) A skua feeding on an adult rabbit.

Anare photo: K. N. G. Simpson



Anare photo: K. N. G. Simpson

https://doi.org/10.1017/S0022172400022762 Published online by Cambridge University Press