Biodiversity and Conservation **6**, 1445–1451 (1997)

Did organochlorine pesticide use cause declines in Mauritian forest birds?

R. J. SAFFORD* and C. G. JONES

Mauritian Wildlife Foundation, Tamarin, Mauritius/Durrell Institute of Conservation and Ecology, The University, Canterbury, Kent CT2 7NZ, UK

Received 10 January 1997; revised and accepted 15 April 1997

We examine the hypothesis that organochlorine pesticide use in the 1950s and 1960s caused population declines and local extinctions in two endemic Mauritian birds, the Mauritius kestrel, *Falco punctatus*, and Mauritius cuckoo-shrike, *Coracina typica*. This hypothesis was suggested in the 1980s but is dismissed by authorities in Mauritius. The declines and subsequent increases in the populations and range areas of both species, the timing and location of the use of organochlorines for malaria control and in food crop production, the diets of the species, and the known mechanisms for transfer of organochlorine residues into organisms are all consistent with the hypothesis. No alternative explanation can at present account for these population changes. Organochlorine pesticide use cannot therefore be rejected as a reason for the declines and local extinctions of the kestrel and cuckoo-shrike.

Keywords: organochlorine; pesticide; tropical bird; gecko; population decline; Mauritius.

Introduction

Pesticides, in particular organochlorines, have killed large numbers of birds world-wide (Newton, 1979; Ratcliffe, 1980), and organochlorine residues and breakdown products are present in birds the world over (Stickel, 1973). Use of organochlorines has been widespread in tropical countries and may have been overlooked as a cause of avian declines and extinctions (Diamond, 1984).

The nine forest-living native bird species that survive on Mauritius, in the western Indian Ocean, include some of the world's rarest birds (Collar and Stuart, 1985). One of these, the Mauritius kestrel, *Falco punctatus*, was formerly widespread but declined disastrously this century, almost became extinct in the 1970s, and began to recover during the 1980s. Cheke (1987a; originally in Pasquier, 1980) suggested that this decline was caused by organochlorine pesticides used to control malaria-carrying mosquitoes and, to a lesser extent, in agriculture. According to this hypothesis, the last refuge of the kestrels was the only part of the island not sprayed. When widespread spraying ceased, pesticide residue levels in the environment decreased, allowing the kestrel population recovery to begin several years later.

Cheke's hypothesis has not been tested but was accepted as a likely explanation for the disappearance of the kestrel from much of its range in the 1940s and 1950s (Jones, 1987). Captive Mauritius kestrels that died in Black River Village on the south-west coast

* To whom correspondence should be addressed at: Royal Holloway Institute for Environmental Research, Huntersdale, Callow Hill, Virginia Water, Surrey GU25 4LN, UK. e-mail r.safford@rhbnc.ac.uk

during 1978–1980 showed evidence of organochlorine contamination, including clinical signs of poisoning. Captive kestrels between 1978 and 1983 laid thinner-shelled eggs than did wild birds between 1981 and 1983 (Jones, 1987). Pesticides were probably acquired from wild-caught lizards, mice and birds used as dietary supplements (Cooper *et al.*, 1981; Jones, 1987), and by the spraying of aviary support buildings with organochlorine pesticides for malaria control (Jones, personal observation). This shows that kestrels are vulnerable to organochlorine residues in prey items. However, some authorities in Mauritius contest Cheke's hypothesis. Most of the kestrel's distribution before the decline lay several kilometres from villages or the coast, yet malaria control was concentrated inside houses around the coast. Furthermore, insecticides have never been used on a large scale in the cultivation of sugar cane and tea, which account for nearly all agriculture in Mauritius.

Precise data on organochlorine spraying before 1970 no longer exist (Anon., 1991: 174; Pesticide Control Board, personal communication, 1993). Very few animal specimens which could be analysed for organochlorine residues appear to have been collected during the relevant period. However, since 1987, bird population trends have become better known, previously ignored documentation on pesticide use in Mauritius has been found, and the transfer of organochlorines into the food web is better understood. In this paper, we apply this new information to re-assess Cheke's (1987a) hypothesis. The possibility, hitherto ignored, is discussed that another carnivorous, native bird species, the Mauritius cuckoo-shrike, *Coracina typica*, was also affected, and implications for its conservation are discussed.

The fall and rise of Mauritian bird populations

In 1986, the 1865 km^2 land area of Mauritius was 48% cropland (mainly sugar cane), 35% forest, scrub and grassland (including forestry plantations) and 17% built-up (Anon., 1991). Fragments of native vegetation totalling 92.8 km^2 are concentrated in two mountainous regions: around the Black River Gorges in the south-west, and the Bambous Mountains in the south-east (Safford, 1997a), separated at their closest points by 18 km of open, cultivated land.

Until the 1930s, kestrels were present in all three of the main mountain areas of Mauritius (the above two, plus the northern Moka Range). Despite the presence of much apparently suitable habitat, they disappeared from the Moka and Bambous Ranges before the end of the 1950s (Jones, 1987). The remaining population around the Black River Gorges declined to a minimum of four known birds in 1974 (Temple, 1977). Studies on the population genetics of the kestrel suggest that this is a realistic minimum population estimate, based on the very high band-sharing between individuals shown by DNA fingerprints (M. Bruford and J. Groombridge, unpublished data, 1996).

However, the population increased without assistance to around 20 birds by 1985. This original kestrel population had very poor dispersal ability (Jones *et al.*, 1995), but a reintroduction programme after 1985 resulted in the restoration of the population to 222–286 birds in all three mountain ranges by 1994 (Jones *et al.*, 1995). The population was 400–500 birds, and still increasing, in 1997 (Jones, unpublished data). Most of the population in 1994 lived without conservation management, apart from provision of nestboxes (particularly in the Bambous Range). Therefore, kestrels were successfully reintroduced to former haunts where no large-scale habitat repair had been carried out.

Cuckoo-shrikes were once present throughout the island's forests, and occurred in the Bambous Range and the Black River Gorge area until the 1930s. Like the kestrel, by the end of the 1950s they had disappeared from the Bambous Range (Cheke, 1987b). The distribution was well surveyed in 1973–1975 (Cheke, 1987b) and 1989–1993 (Safford, 1997b). During this 20-year period, the area of occupancy increased by around 30%, mainly as a result of expansion into lowland areas contiguous with its 1975 extent, without management or obvious change in the re-occupied habitat. All available evidence indicates cuckoo-shrikes to be highly sedentary (Safford and Beaumont, 1996), and so it is not surprising that the isolated Bambous Range was not re-colonized.

Suggested causes of the decline of forest birds on Mauritius have included habitat fragmentation, predation on adults, cyclones, reduced food supply due to forest degradation by exotic plants and competition for food by exotic animals, competition for nest sites, disease, human persecution, nest predation, and pesticide use (Temple, 1977; Collar and Stuart, 1985; Cheke, 1987a; Jones, 1987).

The fall and rise of the kestrel and cuckoo-shrike since 1940 have occurred within areas of forest largely unaffected by habitat fragmentation. For the other suggested negative influences, only for the last three listed above has there been any suggestion of an amelioration during the last 20 years, which is needed to explain the observed range and population increases. Human persecution of native birds had almost ceased by the 1980s but may have affected the kestrel in the past (Jones, 1987). However, hunting does not seem to have been frequent enough to have caused the drastic declines this century, particularly for the cuckoo-shrike, which was never a target species (Cheke, 1987a).

Temple (1978) speculated that the recovery of the kestrel population was allowed by a 'tradition shift' in nesting habits, from tree cavities, where kestrel nests are accessible to crab-eating macaques, *Macaca fascicularis* (an introduced nest predator), to cliff cavities, which provide better protection from these predators. However, Jones (1987) showed that there was no clear evidence that kestrels nested primarily in tree cavities before 1974. Furthermore, data provided by Cade and Jones (1993) prove that kestrels do not necessarily choose a nest site similar to that from which they fledged; therefore, nesting traditions in Mauritius kestrels are not necessarily strong. The 'tradition shift' suggested by Temple (1978) probably never occurred.

Organochlorine pesticide use on Mauritius

The organochlorines most damaging to birds in Europe and North America have been DDT, dieldrin and aldrin, although their relative contributions to bird declines are debated (Risebrough and Peakall, 1988; Risebrough, 1994). DDT spraying for malaria control took place from 1949 to 1965, then at reduced intensity until 1973; limited use of BHC and experimental spraying with other organochlorines, including dieldrin, also took place (Mamet, 1979). The island was declared malaria-free in 1973. Spraying was largely restricted to buildings but also open water, ditches and marshes; it took place mostly in coastal areas, and to a much lesser extent over the whole island (Mamet, 1979). DDT is still applied occasionally, but this is tightly controlled (Ragavoodoo, Malaria Control Unit, personal communication, 1993); in Black River, spraying took place two or three times per year even in 1979–1980 (Jones, personal observation).

Organochlorine pesticides were also used in agriculture. Neither sugar nor tea cultivation has involved the use of insecticides on a large scale (Sprinks, 1950; Ricaud, 1975;

Joomaye, 1988), yet in 1965 these crops accounted for 98% of cultivated land (excluding forestry) on Mauritius (Arlidge and Wong, 1975). However, the Ministry of Agriculture recommended the use of a wide variety of organochlorines (including DDT and dieldrin) on vegetables, fruit and tobacco (Orian, 1961, 1962). All available insecticides were widely used in the late 1950s (Joomaye, 1988; Joomaye, personal communication, 1993), then decreasingly so until most use was banned by the Pesticide Control Act in 1970 (Ricaud, 1975). Additional insecticide trials (apparently undocumented) took place in the 1950s and 1960s (Rouillard, personal communication, 1984). In 1965, only 2085 ha (1.1%) of the land area of Mauritius was continuously used for food and other crops other than tea and sugar; however, most such crops were instead grown inter-line or inter-rotation with sugar cane, which was not accounted for by the 1965 survey (Arlidge and Wong, 1975). It is therefore possible that organochlorines were used wherever sugar was grown: that is, around 50% of the island and in all regions except the coolest, wettest parts of the central plateau.

Transfer of organochlorines into the food web

A species' vulnerability to organochlorine poisoning depends upon its diet; carnivorous species, especially raptors, are most seriously affected (Newton, 1979). In native forest, Mauritius kestrels feed largely on day-geckoes *Phelsuma* spp., but also occasionally on insects, small birds and shrews, *Suncus murinus* (Jones, 1987). Birds introduced to previously unoccupied habitats take various other prey items, but this has probably only been so since the 1980s. Mauritius cuckoo-shrikes feed on large, arboreal arthropods (90% of items) and day-geckoes (10%); the latter, being much heavier, account for well over 10% of biomass eaten (Safford and Beaumont, 1996). Both species therefore have diets that render them liable to accumulate organochlorine residues.

Transfer of organochlorines into organisms may be both primary and secondary. Primary transfer could have occurred because the Moka and Bambous ranges and the lowland forests of the south-west, where kestrels and/or cuckoo-shrikes disappeared in the 1940s or 1950s, both rise from the coastal lowlands where spraying for malaria control was carried out. Food crops are cultivated on their lower slopes, immediately below the forest, and sugar cane is grown all around. Invertebrates that are dying from poisoning or have ingested small, sub-lethal amounts would all contribute to residues in geckoes that would ultimately be lethal, if the geckoes were not first eaten by a bird.

Secondary transfer is inevitable because all organochlorines are very mobile, volatilizing into the atmosphere. A net transfer occurs into all components that have an organic carbon matrix until thermodynamic equilibrium is achieved (Buckley, 1982; Gaggi and Bacci, 1985; Eriksson *et al*., 1989; Risebrough, 1990). In Mauritius, most organochlorines would be transferred to marine air but a portion would partition back into soils, vegetation and water in the local ecosystem.

Conclusion

It is certain that carnivorous birds in Mauritius were exposed to organochlorine pesticides during the 1950s and 1960s. Those inhabiting the Moka and Bambous Mountains and the south-western lowlands were probably exposed to the highest levels through primary contamination. The use of organochlorines cannot therefore be rejected as a reason for the

extinction of the kestrel and cuckoo-shrike in these areas. No alternative explanation can at present account for the declines and subsequent rise in the populations of these species. This assessment therefore provides circumstantial evidence to support Cheke's (1987a) hypothesis. On present knowledge, more direct evidence seems unlikely to be forthcoming.

The evidence presented here has implications for the conservation of the cuckoo-shrike. According to the hypothesis, the habitat in the Bambous Mountains may now be suitable for this species. It cannot be assumed that it will re-colonize the Bambous on its own, and so reintroduction may be appropriate, as has been carried out successfully for the kestrel. Reintroduction could allow the cuckoo-shrike to occupy all 26 km^2 of this native forest area (Safford, 1997a), allowing a 75% increase over the present range area.

Of the other nine native land-bird species, only the Mauritius black bulbul, *Hypsipetes olivaceus*, eats day-geckoes (Safford, in press), but this species is mobile (Safford, 1997b) and so can re-colonize areas where it has been exterminated. Pesticides may well have affected some of these species in the past, but nothing is apparent in their current status that reflects this and their population histories are too poorly known to detect any local declines that organochlorines might have caused. As a result of their breeding and feeding ecology and dispersal abilities, other factors, especially nest predation and impoverishment of food supply, are believed to be more important as causes of decline and limiting factors than are pesticides (Jones, 1987; Cheke, 1987b; Safford, 1997b).

Acknowledgements

Our work on Mauritius was carried out with the support and collaboration of the Ministry of Agriculture (National Parks and Conservation Service), Government of Mauritius. CGJ is employed on Mauritius by the Jersey Wildlife Preservation Trust. Work on the kestrel was also supported by the Peregrine Fund and Mauritian Wildlife Foundation, the latter being RJS's employers on Mauritius. Dr R.W. Risebrough made detailed comments, suggestions and encouragement to assist the completion of this paper. A.S. Cheke, G. Rouillard, Dr A. Joomaye (Pesticide Control Board and Ministry of Agriculture), Dr S. Ragavoodoo (Malaria Control Unit) and Dr J.R. Williams (Mauritius Sugar Industry Research Institute) provided valuable discussions.

References

Anon. (1991) *State of the environment in Mauritius*. A report prepared for presentation at the United Nations Conference on Environment and Development, Rio de Janeiro, Brazil, June 1992. Port Louis, Mauritius: Ministry of the Environment and Quality of Life.

Arlidge, E.Z. and Wong You Cheong (1975) Notes on the land resources and agricultural suitability map of Mauritius. *Occasional Papers of the Mauritius Sugar Industry Research Institute* 29.

Buckley, E.H. (1982) Accumulation of airborne polychlorinated biphenyls in foliage. *Science* **216**, 520–2.

Cade, T.J. and Jones, C.G. (1993) Progress in restoration of the Mauritius Kestrel. *Conservation Biology* **7**, 169–75.

Cheke, A.S. (1987a) An ecological history of the Mascarene Islands, with particular reference to extinctions and introductions of land vertebrates. In *Studies of Mascarene Island birds* (A.W. Diamond, ed.) pp. 5–89. Cambridge, UK: Cambridge University Press.

Cheke, A.S. (1987b) The ecology of the smaller land-birds of Mauritius. In *Studies of Mascarene Island birds* (A.W. Diamond, ed.) pp. 151–207. Cambridge, UK: Cambridge University Press.

Collar, N.J. and Stuart, S.N. (1985) *Threatened birds of Africa and related islands. The ICBP/IUCN Red Data Book*. Third edition, part 1. Cambridge, UK: ICBP.

Cooper, J.E., Jones, C.G. and Owadally, A.W. (1981) Morbidity and mortality in the Mauritius Kestrel (*Falco punctatus*). In *Recent Advances in the Study of Raptor Diseases* (J.E. Cooper and A.G. Greenwood, eds) pp. 31–5. UK: Chiron Publications.

Diamond, J.M. (1984) Island population biology: possible effects of unrestricted pesticide use on tropical birds. *Nature* **310**, 452.

Eriksson, G., Jensen, C., Kylin, H. and Strachan, W. (1989) The pine needle as a monitor of atmospheric pollution. *Nature* **341**, 42–4.

Gaggi, C. and Bacci, E. (1985) Accumulation of chlorinated hydrocarbon vapours in pine needles. *Chemosphere* **14**, 451–6.

Jones, C.G. (1987) The larger land-birds of Mauritius. In *Studies of Mascarene Island Birds* (A.W. Diamond, ed.) pp. 364–402. Cambridge, UK: Cambridge University Press.

Jones, C.G., Heck, W., Lewis, R.E., Mungroo, Y., Slade, G. and Cade, T.J. (1995) The restoration of the Mauritius Kestrel *Falco punctatus* population. *Ibis* **137**, S173–S180.

Joomaye, A. (1988) Pest control in Mauritius and Rodrigues. *Technical Bulletin of the Ministry of Agriculture, Fisheries and Natural Resources, Réduit, Mauritius*.

Mamet, J.R. (1979) Chronology of events in the control and eradication of malaria in Mauritius. *Revue Agricole et Sucrière de I'lle Maurice* **58**, 107–46.

Newton, I. (1979) *Population Ecology of Raptors*. Berkhamsted, UK: T. and A.D. Poyser.

Orian, A.J.E. (1961) Les insecticides. *Revue Agricole et Sucrière de I'lle Maurice* **40**, 322–5.

Orian, A.J.E. (1962) Pest control recommendations made by the division of entomology of the Department of Agriculture, Mauritius. *Revue Agricole et Sucrière de I'lle Maurice* **41**, 87–116.

Pasquier, R. (1980) Report and management plan on ICBP's project for the conservation of forest birds on Mauritius. Unpublished report to International Council for Bird Preservation, Cambridge, UK.

Ratcliffe, D. (1980) *The Peregrine Falcon*. Calton, UK: T. and A.D. Poyser.

Ricaud, C. (1975) Pesticide use and hazards in Mauritian agriculture. *Revue Agricole et Sucrière de I'lle Maurice* **54**, 143–8.

Risebrough, R.W. (1990) Beyond long-range transport: a model of a global gas chromatographic system. In *Long Range Transport of Pesticides* (D.A. Kurtz, ed.) pp. 417–26. Chelsea, Michigan, USA: Lewis Publishers Inc.

Risebrough, R.W. (1994) Toxic chemicals and birds of prey: discussions in Berlin in 1992. In *Raptor Conservation Today* (B.-U. Meyburg and R.D. Chancellor, eds) pp. 685–92. Sussex, UK: World Working Group on Birds of Prey/Pica Press.

Risebrough, R.W. and Peakall, D.B. (1988) The relative importance of the several organochlorines in the decline of peregrine falcon populations. In *Peregrine Falcon Populations: Their Management and Recovery* (T.J. Cade, J.H. Enderson, C.G. Thelander and C.M. White, eds) pp. 449–62. Boise, USA: Peregrine Fund.

Safford, R.J. (1997a) A survey of the occurrence of native vegetation remnants on Mauritius in 1993. *Biol. Conserv*. **80**, 181–8.

Safford, R.J. (1997b) Distribution studies on the forest-living native passerines of Mauritius. *Biol. Conserv*. **80**, 189–98.

Safford, R.J. (in press) Notes on the biology of the Mauritius Black Bulbul *Hypsipetes olivaceus*. *Ostrich* (accepted).

Safford, R.J. and Beaumont, J. (1996) Observations on the biology of the Mauritius Cuckoo-shrike *Coracina typica*. *Ostrich* **67**, 15–22.

Sprinks, F.O. (1950) Some aspects of tea planting in Mauritius. *Revue Agricole et Sucrière de I'lle Maurice* **29**, 270–7.

Stickel, L.F. (1973) Pesticide residues in birds and mammals. In *Environmental Pollution by Pesticides* (C.A. Edwards, ed.) pp. 254–312. London, UK: Plenum.

Temple, S.A. (1977) The status and conservation of endemic kestrels on Indian Ocean islands. In *World Conference on Birds of Prey*, *Vienna*, *1–3 October 1975: Report on Proceedings* (R.D. Chancellor, ed.) pp. 74–81. London. UK: International Council for Bird Preservation.

Temple, S.A. (1978) Manipulating behavioral patterns of endangered birds: a potential management technique. In *Endangered Birds*: *Management Techniques for Preserving Threatened Species* (S.A. Temple, ed.) pp. 435–46. Madison, USA: University of Wisconsin Press.