12. ARE WE DOING ENOUGH? A REVIEW OF THE CONSERVATION STATUS OF MEGAPODES AND THE IMPLEMETATION OF THEIR ACTION PLANS.

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Abstract

Over half of the megapode (Aves: Megapodiidae) species that once existed are now extinct. Almost half of the 22 extant species are classified as threatened with extinction, and all threatened species are declining in numbers. This vulnerability among megapodes is shaped by four characteristics of the family: large 'nests', large clutches, large eggs, and independent young. Conspicuous nests with many nutritious eggs leads to over-harvesting of eggs. Mound-builders are trapped and hunted while spending long periods at their mounds. Introduced predators kill birds and eggs, with dispersing chicks particularly vulnerable. Megapode habitat is being degraded by industries such as logging, oil palm plantations and farming. To facilitate the conservation of threatened megapodes, the World Conservation Union has produced two Megapode Conservation Action Plans that assess the conservation status of species and detail a 5-year plan of action. Of the 37 conservation actions recommended in the Megapode Conservation Action Plans only 24% were fully implemented. Case studies show when actions are implemented they produced positive conservation outcomes. The deterioration of nesting fields of the maleo (*Macrocephalon maleo*) have been reversed; closed seasons have been shown to dramatically increase the production of chicks in the Melanesian megapode (*Megapodius eremita*), and research into mound-building megapodes in New Guinea has produced management prescriptions that are useful to local people. Despite these few successes, not enough work is being done to conserve megapodes. If the actions identified in the Megapode Conservation Action Plans are not implemented, more species will be added to the list of extinct megapodes.

Introduction

Megapodes (Aves: Megapodiidae) are prone to extinction. Over half of the megapode species that existed when people first colonised Oceania are now extinct (Steadman 1999; Steadman 2006), and significantly more species in the family are threatened with extinction than would be expected by chance (Bennett and Owens 1997). There were perhaps 45-55 species of megapodes when humans arrived in the Pacific (Steadman 2006); there are now 22 species (Jones *et al*. 1995), nine of which are classified as threatened with extinction and eight of which are apparently declining (IUCN 2006, Table 1). Throughout the range of the family - from Niuafo'ou Island in the east to the Nicobar Islands in the west - there is cause for concern (Jones *et al.* 1995): megapode habitat is being degraded, megapode eggs are over-harvested, and megapode adults and chicks are killed by introduced predators (Dekker *et al*. 2000) and humans. The survival of many species is now beyond what nature alone can do; active management is needed to protect some megapode populations and species.

In this paper I will first give an overview of the distribution, behaviour and ecology of the megapodes. I will then outline the conservation status and threats to species, and review the two World Conservation Union (IUCN) Conservation Action Plans that have been published for megapodes to determine how successful we have been at implementing conservation actions. I will then end by outlining three case studies

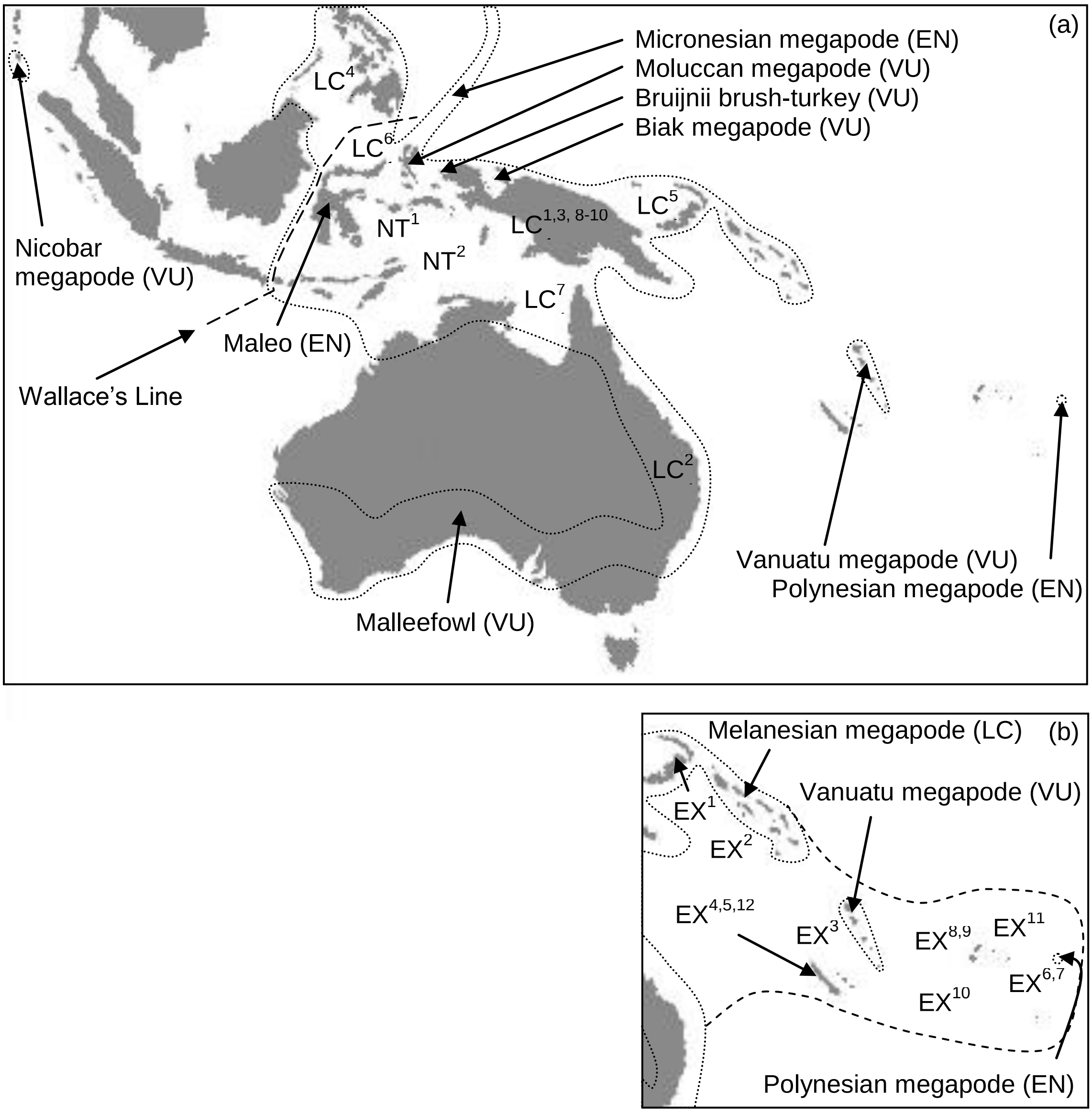

Figure 1. The distribution and status of megapodes (Aves : Megapodiidae). (a) The present distribution of the family (dotted line) and the conservation status of species. The (IUCN 2006) risk categories are given in Table 1: LC^{1} = wattled brush-turkey (*Aepypodius arfakianus*); LC^{2} = Australian brush-turkey (*Alectura lathami*); LC^{3} = New Guinea megapode (*M. decollatus*); NT^{1} = Sula megapode (*M. bernsteinii*); LC^{4} = Tabon megapode (*M. cumingii*); LC^{5} = Melanesian megapode (*M. eremita*); LC^{6} = dusky megapode (*M. freycinet*); LC^{7} = orange-footed megapode (*M. reinwardt*); NT^{2} = Tanimbar megapode (*M. tenimberensis*); LC^{8} = red-billed brush-turkey (*Talegalla cuvieri*); LC^{9} = black-billed brush-turkey (*T. fuscirostris*); LC^{10} = brown-collared brush-turkey (*T. jobiensis*). (b) The present distribution of megapodes (dotted line) and past distribution (dashed lined) in the SW Pacific showing extant and extinct species: EX^{1} = *Megapodius* undescribed sp. A; EX^{2} = M. undescribed sp. B; EX^{3} = *M.* undescribed sp. C; EX^{4} = *M.* undescribed sp. D; EX^{5} = *M.* undescribed sp. E; EX^{6} = *M.* undescribed sp. F; EX^{7} = Unknown genus undescribed sp.; EX^{8} = *M. amissus;* EX^{9} = *M. altirostris;* EX^{10} = *M. molistuctor;* EX^{11} = *M. alimentum;* EX^{12} = *Sylviornis neocaledoniae*. (Data from Jones *et al.* (1995); IUCN (2006); Steadman (2006).

that highlight conservation management of megapodes: conservation of the maleo[1] (*Macrocephalon maleo*) in Sulawesi, the experimental management of nesting fields on islands in northern Melanesia, and the management of mound-building megapodes in New Guinea.

Distribution and biology of Megapodes

[1] I follow Jones *et al.* (1995) for the names of megapodes, except *Megapodius cumingii*, which I call the Tabon megapode.

Megapodes are of Gondwana origin and probably evolved on the Australian Plate before dispersing east into Oceania and west though the Indonesian Archipelago (Dekker 2007). Their present range is restricted to the Indo-Pacific region (Figure 1), with all but the Nicobar megapode (*Megapodius nicobariensis*) and some populations of the Tabon megapode (*M. cumingii*) occurring east of Wallace's Line (Jones *et al*. 1995). Wallace's Line is a zoogeographical boundary between fauna with affinities to Asia and those of Australasia (Whitmore 1982). Two theories have been proposed for the western limit of the megapodes: competitive exclusion by the pheasants (Phasianidae) (Olson 1980) or predation by cats (Felidae) and civets (Viverridae) (Dekker 1989b), while the eastern limit of Samoa (Steadman 2006) is probably due to the increasing distances among islands being a physical barrier to dispersal.

Most genera of megapodes have a restricted range with the monotypic genera *Alectura* and *Leipoa* restricted to Australia, *Macrocephalon* to Sulawesi and *Eulipoa* to the Moluccas Islands, while two species of *Aepypodius* and three species of *Talegalla* are found only on New Guinea and surrounding islands. Conversely, the polytypic 'super-genus' *Megapodius* has 13 species distributed across the range of the family.

Habitat use and diet

Megapodes typically inhabit tropical rainforests, with only the atypical malleefowl (*Leipoa ocellata*) inhabiting arid regions of southern and Western Australia (Frith 1956a). They occur in habitat ranging from primary forests through to early secondary regrowth, gardens and even monocultures like coconut plantations (e.g., *Megapodius* spp.)(Broome *et al*. 1984; Sinclair *et al*. 1999), although less disturbed areas may be required for successful breeding (Sinclair *et al*. 2002; Gorog *et al*. 2005). It seems that in general members of the genus *Megapodius* are most able to persist in areas that are degraded, and in a study of three sympatric genera they were found to use a wider range of habitat for breeding than either *Talegalla* or *Aepypodius* (Sinclair 2002).

Megapodes are generalist omnivores taking a wide range of plant and animal material by foraging on the ground (Jones *et al*. 1995).

Heat sources and incubation sites

Megapodes are different from all other bird families in using heat from the environment to incubate their eggs and in having young that are entirely independent after hatching (Frith 1956a). This freedom from brooding has shaped much of the behaviour and ecology of the family (Jones & Birks 1992), which in turn has contributed to their vulnerability and desperate conservation status.

Megapodes use three sources of heat to incubate their eggs: geothermal heat, solar radiation and heat generated by the microbial decomposition of organic material (Frith 1956a); in the case of the malleefowl the latter two heat sources are used in tandem at mounds (Frith 1956b) but this is atypical of mound-builders in the family (Jones *et al*. 1995).

The most common incubation method is mound-building where piles of organic material and soil are raked together on the forest floor. These mounds require specific conditions for successful incubation (e.g. a critical mass of material before the mound becomes a stable homeotherm (Seymour & Bradford 1992)) and are located non-randomly (e.g., under a closed canopy that may reduce temperature fluctuations and desiccation, Jones 1987; Sinclair 2002). In addition to building mounds, some megapode species burrow into existing sources of microbial heat, like the decaying roots of dead trees, and these sites are also located non-randomly (e.g., at very large trees that may provide a sufficient biomass of dead roots to generate enough heat for incubation, Sinclair *et al*. 2002). Sites for both mounds and burrows into decaying roots are located in forest that is generally less disturbed than random points in the same habitat (Jones 1987; Sinclair 2002; Sinclair *et al.* 2002).

Burrows in dead trees contain few eggs and few egg chambers, and pairs may use more than one such incubation site (Sinclair *et al*. 1999). Mounds, on the other hand, generally have one chamber that can contain many eggs (Jones 1988a; Sinclair 2001b) and usually only one mound is used by a male or pair (Jones 1990a; Birks 1997). Both mounds and burrows in the decaying roots of dead trees are widely scattered, and may be in the core area of the home range of territorial species (e.g., Crome & Brown 1979).

Geothermal or solar burrows differ in many respects to mound sites. Rather than being dispersed like microbial sites, they are highly clustered at localised sites in the form of large colonies of 'nests'[2], often called 'nesting fields'. Within these fields, however, burrows may be located non-randomly. For example, geothermal sites of the Melanesian megapode (*M. eremita*) on Lihir Island, Papua New Guinea differed significantly from random points in having a more closed canopy and a higher proportion of thicket species in the vicinity (Samson 2007). In addition, at these sites the conditions in burrows were also different from random points, with smaller substrate particles in burrows and higher soil temperature.

Mating systems and breeding behaviour

Without the energetic input of brooding, females of all species of megapode seem to pursue a similar strategy of maximising their clutch size (Jones 1994): they lay an unusually large clutch of 10-20 eggs over an extended period of about 3 months (Jones *et al*. 1995). Males, on the other hand, pursue one of two strategies, they either monopolise the reproductive output of a mound (e.g., the resource-defence polygyny of the Australian brush-turkey, *Alectura lathami*) or that of a female (e.g., the female-defence monogamy of the orange-footed megapode, *M. reinwardt*) (Jones 1992). In the former system, the male guards the mound so other megapodes do not have access to it, while unattended females may copulate with more than one male (Jones 1990a). In a study of the Australian brush-turkey 23% of eggs in mounds were fertilised by males other than the mound 'owner' (Birks 1997). In the latter system, the male and female are most often together as the male 'guards' the female, so incubation sites are not defended and are often used by more than one pair (Crome & Brown 1979; Sankaran & Sivakumar 1999) or more than one species (Sinclair 2002). As with so many other aspects of megapode biology, the exception to this is the malleefowl, where within a monogamous mating system (c.f., Weathers *et al.* 1990) the male stays close to the mound and does not 'guard' the female (Frith 1959), leading to this being described as resource-defence monogamy (Jones *et al*. 1995).

In the brush-turkey genera *Aepypodius* and *Alectura* the male alone builds and maintains the mound and the female comes to copulate and lay only (Jones 1990b;

Table 1. The risk categories, population trends, threats and activities detailed in IUCN Conservation Action Plans for megapode species (Aves : Megapodiidae) that are threatened or near threatened with extinction. Red Risk categories are Endangered (EN), Vulnerable (VU), Near Threatened (NT), and Least Concern (LC) and threats are egg harvesting (E), hunting (H), introduced predators (P), habitat degradation (D), natural disasters (N), fire (F), grazing by introduced herbivores (G), disturbance at nesting grounds (I), natural predators (B), competition with introduced animals (C), tourism (T), and invasive vegetation (V). The trends in megapode populations are either declining (⇩), stable (⇨) or not quantified (NQ). Activities in action plans were either implemented (I), partially implemented (P) or not implemented (N). Two species have recovery plans so did not have actions listed in the 2000-2004 action plan.

Species name	Risk[1] Threats[3]	Trend 1995[2]	 2006[1]	IUCN Conservation Action Plan (1995-1999)[2]	 (2000-2004)[3]
Maleo (*Macrocephalon maleo)*	EN E, D, I, B, V	⇩	⇩	Protect fields (P) Awareness (P) Survey (I)	Protect fields (P) Awareness (P) Harvest plan (N)
Micronesian megapode (*Megapodius*)	EN E, H, P, N, G,	?⇨	⇩	Monitoring (I)	(Recovery plan)
Polynesian megapode (*M. pritchardii*)	EN E, H, P, N, C	⇨	⇩	Monitoring (N) Awareness (P) Translocation (N) Research (N)	Monitoring (N) Awareness (P) Translocation (N)
Bruijn's brush-turkey (*Aepypodius bruijnii*)	EN[4] H, F[5]	NQ	NQ	Survey (P)	Survey (I) Manage. plan (N)

[2]Megapode nesting fields are commonly referred to as 'communal' but share little with avian communal nesting systems in the classic sense and are more adequately described as 'colonial'.

Malleefowl (*Leipoa ocellata*)	VU H, P, F, G	⇩	⇩	Monitoring (I) Research (I) Manage. plan (I)	(Recovery plan)
Moluccan megapode (*Eulipoa wallacei*)	VU E, D, I, B	⇩	⇩	Survey (P)	Protect fields (P) Awareness (N) Harvest plan (P)
Biak megapode (*M. geelvinkianus*)	VU E, H, P, D	⇩	⇩	Survey (N)	Survey (N) Manage. plan (N)
Nicobar megapode (*M. nicobariensis*)	VU E , D, H	⇨	⇩	Survey (I) Research (I)	Protect habitat (N) Awareness (P) Monitoring (I) Research (P)
Vanuatu megapode (*M. layardi*)	VU E, H, P, D, N,	⇨/⇩	⇩	Survey (P)	Harvest plan (P) Survey (P)
Tanimbar megapode (*M. tenimberensis*)	NT E,H, P, D[2]	⇨/⇩	⇩	Survey (N)	None
Sula megapode (*M. bernsteinii*)	NT E,H, P, D[2]	⇨/⇩	⇩	None	None
Overall (spp./spp.)	E, H 9/11 P, D 7/11	7/10 ⇩	10/10 ⇩	I = 7, P = 6, N = 5	I = 2, P = 9, N = 8

[1]IUCN (2006)
[2]Dekker *et al*. (1995b)
[3]Dekker *et al*. (2000)
[4] Up-graded from Vulnerable to Endangered in 2008 (BirdLife International and IUCN in prep.), while all other species remain unchanged.
[5]Mauro 2006.

Birks 1997). For all other species of mound-builders the male and the female are both involved in building or maintaining the mound or both (Jones *et al*. 1995).

The use of some mounds by more than one species has been described for megapodes (e.g., Dwyer 1981; Sinclair 2002; Rand & Gilliard 1967) and assumed to be a form of brood parasitism (Diamond 1983; del Hoyo *et al.* 1992), although it is not clear that there is a cost to the 'host' and if this relationship is best described as parasitic (Sinclair 2000a).

Hatching success and survival

Megapodes have higher hatching success (about 65%) than most tropical birds (about 30%) because their large 'nests' and asynchronous laying and hatching reduce the likelihood that predators can take the entire clutch (for a review see Sinclair in prep.). This is counterbalanced by megapode chicks suffering extremely high mortality with very few chicks surviving to 1 month (e.g., Priddel and Wheeler 1990; Göth & Vogel 2002), with almost no chicks surviving in the presence of introduced mammalian predators (a review in Sinclair in prep.; Figure 3).

Megapodes are long-lived birds with captive individuals known to have lived for up to 20 years (D. Bruning *pers. comm.* in Dekker & Wattle 1987). That said, the longevity of birds in the wild is not known and is likely to be considerable less (e.g., in one study all 12 New Guinea megapodes (*M. decollatus*) marked as adults all had disappeared from their mounds within 5 years; RS unpubl. data).

Threats to megapodes

According to the IUCN (Dekker *et al*. 1995b; Dekker *et al*. 2000; IUCN 2006) the threats faced by megapodes range from predators of eggs and young to disturbance at nesting sites from things like tourism (Table 1, Figure 2).

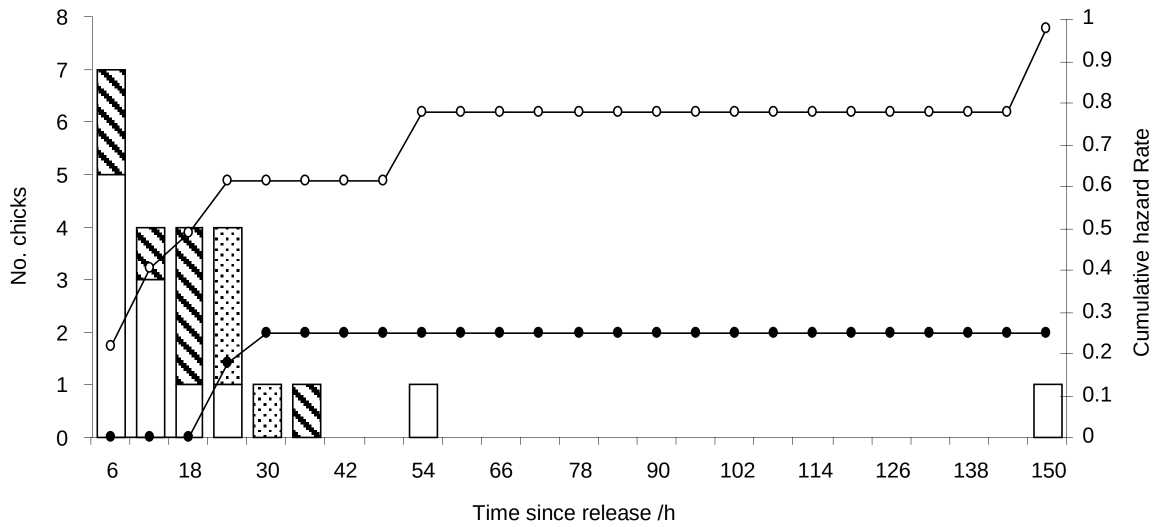

Figure 2. Cumulative hazard rates (probability of mortality) for Melanesian megapode (*Megapodius eremita*) chicks dispersing from nesting fields of the megapode on Simbo Island. Bars are the number of chicks killed by introduced mammalian predators (hollow), died by other causes (shaded) and missing (hatched). Chicks faced a 98% risk of being preyed upon by an introduced predator in the first week after emergence and a significantly higher risk from cats (*Felis silvestris catus*) and dogs (*Canis lupus familiaris*) (hollow circles) than from all other causes combined (filled circles). (Reproduced with permission from Sinclair (in prep.)

The most serious threats to megapodes are in many ways shaped by four interesting characteristics of the family: (1) large 'nests' - incubation mounds are the largest nesting structures built by birds (Jones 1989); (2) nesting fields can cover several hectares (e.g., Broome *et al*. 1984); (3) a large 'clutch' of big yolk-filled eggs - eggs weigh 75-232 g (Dekker & Wattle 1987) and have among the highest yolk contents of any avian egg (about 50-70% by weight, Brom & Dekker 1992); and (4) independent young.

Hunting and harvesting eggs

Hunting and harvesting of eggs are the most common threats cited for megapodes with a conservation status (Table 1). Megapode 'nests' are large and conspicuous and are therefore easily found by humans and other predators. Furthermore, because megapode eggs are large, nutritious, and often in great numbers at incubation sites, harvesting is a worthwhile expenditure of time and energy for a predator. As a result, eggs of all species of megapodes are harvested by humans, except perhaps Bruijn's brush-turkey *(Aepypodius bruijnii*, Mauro 2006) and the three species occurring in Australia (Dekker *et al*. 1995b). For the colonial nesters, harvesting can be highly efficient with almost all eggs collected (MacKinnon 1978; Heij 1997; Sinclair 2001a) and unsustainable harvesting has led to abandonment of nesting fields and local extinctions (Argeloo and Dekker 1996; Baker & Butchart 2000). For example, in the Tangkoko-DuaSudara Nature Reserve in Sulawesi a nesting field disappeared within 6 years of a village being established nearby (MacKinnon 1981), and continued over-harvesting of eggs at the remaining fields in the reserve is believed to be responsible for sending the local population to the verge of extinction (O'Brien & Kinnaird 1996). Furthermore, because many species spend long periods of time at their incubation sites (Jones *et al*. 1995), snaring and hunting of adult birds is widespread (Baker & Butchart 2000; Mack & West 2005; Sivakumar 2007), although some communities that collect eggs do not hunt megapodes (Sankaran 1995; Sinclair 2001a).

Introduced predators and habitat degradation

The next most common threats cited for megapodes are introduced predators and habitat degradation (Table 1). Megapodes and their eggs are preyed upon by a bewildering array of introduced predators; both eggs and birds are taken by pigs (*Sus* spp.)(Kisokau 1976; MacKinnon 1981a; Heij *et al*. 1997), dogs (*Canis lupus familiaris*)(Kisokau 1976; Jones 1988b; Benshemesh 1992; Heij *et al*. 1997), foxes (*Vulpes vulpes*)(Frith 1959; Brickhill 1986; Priddel & Wheeler 1994; Priddel & Wheeler 1996; Göth & Vogel 2002), and cats (*Felis silvestris catus*)(Weir 1973; Jones 1988b; Benshemesh 1992; Priddel & Wheeler 1994; Heij *et al*. 1997; Göth & Vogel 2002). Although in a 5-year study of

Malleefowl, foxes raided 48% of nests (n = 71) and took 37% of eggs (n = 1094) (Frith 1959), introduced predators are not generally a major threat to the hatching success of megapode eggs for the reasons detailed above. These predators are, however, a serious threat to the birds. The natural ranges of megapodes and mammalian predators do not widely overlap and the vulnerability of the former to the latter has been used to explain this allopatry (Dekker 1989a).

Growing human populations in developing countries modify increasing amounts of habitat, but these subsistence activities pale in comparison to rampant logging and oil palm plantations in the tropical lowlands, mining in the mountains of places like New Guinea, and land clearance for industrial agriculture in places like Australia.

The remaining threats are not as widely applicable across the family, but are often highly significant to individual species or populations.

Catastrophes, weeds and tourism

Catastrophes and natural disasters poise a serious threat to species of megapode with small populations or highly restricted distributions. For example, it is estimated that the 2006 Asian tsunami wiped out nearly 70% of the Vulnerable Nicobar megapode (Sivakumar 2007). Fire threatens the malleefowl (Benshemesh 1999) and Bruijn's brush-turkey (Mauro 2006), severe weather events threaten island populations of the Vanuatu (*M. layardi*, Foster 1999) and Micronesian megapodes (*M. laperouse*) (Dekker *et al*. 2000), while volcanic eruptions pose a threat to the Polynesian megapode (*M. pritchardii*, Dekker *et al*. 1995b). Small populations of some species are also considered to be at threat from natural predators, such as varanids preying on eggs in remnant nesting fields (e.g., the maleo, MacKinnon 1981) and Moluccan megapode (*Eulipoa wallacei*, Heij 1997). Invasive vegetation is covering some nesting fields and reduces the area available for nesting (e.g., the maleo, MacKinnon 1981; Gorog *et al*. 2005). Disturbance from tourism is also cited as a threat (e.g., Micronesian megapode, Stinton & Glass 1992); one maleo nesting field may have been abandoned due to disturbance from tourism (Gorog *et al*. 2005).

The conservation status of megapodes

The result of the multitude of threats facing megapodes is that the family is at risk. Four species of megapodes are classified as Endangered, five as Threatened and two as Near Threatened (Table 1). Among these species, declines seem to be continuing unabated. When the first IUCN Megapode Conservation Action Plan was published in 1995 (Dekker *et al*. 1995b), seven of 10 species were considered as either declining (4 spp.) or stable/declining (3 spp.), with only three species considered stable (IUCN 2006; Table 1). The seemingly perilous situation in 1995 had deteriorated to the point where by 2008 all megapodes that are threatened or Near-Threatened for which there are data are declining (Table 1); at least half of all extant megapode species are in decline (IUCN 2006). Furthermore, local people in Papua New Guinea and the Solomons Islands report recent declines in the numbers of *Talegalla* spp., wattled brush-turkeys (*Aepypodius arfakianus*) and Melanesian megapodes (Sinclair unpubl. data), all species that are classified as Least Concern and considered widespread and abundant (IUCN 2006). Declines in such ‘safe’ species are likely to be common in the family, meaning several further species will require reclassification as threatened if sustainable management is not implemented.

From 2000-2008 three species of megapode have been reclassified: the Polynesian megapode was downgraded from Critically Endangered to Endangered, while both the maleo and Bruijn's brush-turkey were upgraded from Vulnerable to Endangered (IUCN 2006) (see species accounts below for details).

Megapode species threatened with extinction

In this section I will give a brief overview of each species of megapode that is threatened with extinction, detailing the estimated size of the global population, the main threats to populations, and their conservation status. I will not discuss the two threatened species for which there are recovery plans because they are not dealt with by the Megapode Conservation Action Plan. (For details of the recovery plans see Benshemesh (1999; 2000) for malleefowl and USFWS (1998) for the Micronesian megapode.)

Polynesian megapode – Endangered

The Polynesian megapode lays in geothermal areas and once occurred on many island in Tonga (Steadman 1993; 2006). At the beginning of both Megapode Conservation Action Plans it was confirmed to have a population of less than 1000 occurring on only Niuafo'ou Island, a small island in northern Tonga (Göth and Vogel 1995; 1999). The remnant population on Niuafo'ou Island was threatened by volcanism, hunting and competition from pigs (Table 1), although the harvesting of eggs and predation by cats were seen as the main threats (Göth & Vogel 1995). Between 1991-1993 about 100 eggs and chicks were transferred to Late and Fonualei islands. Although anecdotal evidence suggested some birds survived on the islands (e.g., Rinke 1993), there were no formal surveys until 2003. In 2003 a survey of Fonualei Island found a population of 300-500 birds (Watling 2003), significantly reducing the risk to this species and resulting in it being down-graded to Endangered (IUCN 2006).

Maleo – Endangered

The Maleo is endemic to Sulawesi and nearby islands in Indonesia, and lays eggs in geothermal and solar colonies (Jones *et al*. 1995). The global population is estimated to be 8,000-14,000 (Butchart & Baker 2000) but is declining rapidly (Dekker *et al*. 2000). Although probably given more attention from conservationists than any megapode outside Australia, the maleo remains in serious trouble. It faces habitat degradation, disturbance at nesting fields, where invasive weeds are also problem, and the over harvesting of eggs (Table 1). Some fields are now so small, predation by natural predators may be contributing to local declines (MacKinnon 1981). There have been several thorough surveys of nesting fields of maleo (i.e., Dekker 1990; Argeloo 1994; Baker & Butchart 2000; Butchart & Baker 2000; Gorog *et al*. 2005) that have unfortunately shown dramatic declines in the quality and number of nesting fields - only 3% of the 142 fields known are not threatened (Baker 2002) - while wildlife surveys have shown associated declines in the bird population (O'Brien and Kinnaird 1996). Gorog *et al*. (2005) found nesting fields most likely to be abandoned if they were in coastal areas, near human settlements, or not in protected areas, and connectivity of fields to forest was the best predicator of abandonment.

Bruijn's brush-turkey – Endangered

Bruijn's brush-turkey is a mound builder that is restricted to cloudforest above 620 m on Waigeo Island, west of New Guinea (Mauro 2006). Until recently this species was virtually unknown, with the most recent record from 1938 and no observations in the wild despite at least 15 expeditions to find it (Jones *et al*. 1995; Dekker 2000). Given its very restricted distribution and a population assumed to be less than 2,500, Bruijn's brush-turkey was originally classified as Vulnerable in both Megapode Conservation Action Plans, and hunting and mining were seen as potential threats. Recent surveys (Mauro 2005; 2006) have estimated a global population of less than 1000 and the major threat to its small and fragmented habitat is fire (Table 1), resulting in it being up-graded to Endangered in 2008 (IUCN 2006). See Mauro (this volume) for a detailed description of the threats and status of this species.

Moluccan megapode – Vulnerable

Moluccan megapodes lay their eggs in solar heated soil at colonial sites (Dekker *et al*. 1995a), with one field on Halmahera Island and another on Haruku Island used by most birds (Dekker *et al*. 1995b). Unlike other megapodes, this species lays at night, with lunar synchrony in laying; more birds visit nesting fields on bright nights (Baker & Dekker 2000). Moluccan megapodes face habitat degradation, disturbance at nesting fields and high levels of egg predation from natural predators (Table 1), but egg collecting is the major threat to the species (Heij *et al*. 1997; Dekker *et al*. 2000). Unlike many areas where traditional control of egg harvests have broken down, this system is still enforced for the Moluccan megapode but may still not prevent over-exploitation of eggs (Argeloo & Dekker 1996). The global population is estimated at about 10,000 and status as Vulnerable (IUCN 2006).

Nicobar megapode – Vulnerable

Nicobar megapodes are mound-builders endemic to the Nicobar Islands, where 90% of incubation sites are found within 100 m of the coast (Sankaran 1995). At least 65% of mounds are used by more than one pair, and a strong hierarchy exist among the pairs that use the mound (Sankaran & Sivakumar 1999). This species is at threat from over-harvesting of eggs, the hunting of birds and habitat degradation (Table 1). On-going declines in the population and habitat fragmentation has led to Nicobar megapode being classified as Vulnerable (IUCN 2006). The population was estimated at 4,000-8,000 (Sankaran 1995), but was reduced by about 70% by the 2004 Asian Tsunami, after which habitat degradation and hunting of adults has increased (Sivakumar 2007).

Biak megapode – Vulnerable

The Biak megapode (*M. geelvinkianus*) is endemic to Biak and surrounding islands, and is very poorly known (Jones *et al*. 1995). Although the threats to this species are not documented, they are assumed to be the harvesting of eggs, hunting of birds, introduced predators and habitat degradation (Table 1). These possible threats and the assumption of a small and declining population result in a classification of Vulnerable (IUCN 2006).

Vanuatu megapode – Vulnerable

The Vanuatu megapode is endemic to Vanuatu, and displays considerable behavioural plasticity in using all the heat sources and all the types of incubation sites described for the family (Jones *et al*. 1995). At colonial nesting sites eggs are heavily harvested (Bowen 1996), and this is considered a major threat (Foster 1999), as is logging (O'Brien *et al*. 2003). Other threats are hunting, introduced predators, habitat degradation, natural disasters and fire (Table 1). Although it occurs in two protected areas (Kratter *et al*. 2006), this species is classified as Vulnerable due to a population that is assumed to be small and declining (IUCN 2006); the latter trend being reported by local people (Bowen 1996; Foster 1999; O'Brien *et al*. 2003).

Conservation action plans

Conservation Action Plans are produced by specialist groups like the Megapode Specialist Group that are comprised of volunteers affiliated to the Species Survival Commission of the IUCN (Fuller *et al*. 2003). Plans assess "… the conservation status of species and their habitats, and [specify] conservation priorities." (Dekker *et al*. 2000, back cover). Action plans contain an overview of the conservation issues facing the group, a summary of their conservation status, accounts for each threatened species with information on range, population, ecology, threats, conservation and targets. They also detail a 5-year plan of action (e.g., see Dekker *et al.* 2000).

The changing conservation status of species and the implementation of actions can be measured against the plans (Fuller *et al*. 2003). Although action plans have been criticized (e.g., Collar 1994), a review of three plans - including the 1995-1999 Megapode Conservation Action Plan - found considerable conservation oriented activity had occurred that was related to the recommendations in the plans (Fuller *et al*. 2003). One criticism of the plans has been their emphasis on surveys and research rather than practical actions. The 1995-1999 Megapode Conservation Action Plan followed this pattern with 72% of recommendations (n = 18) being surveys, research or monitoring (Table 1). Given at this time our lack of knowledge of almost all species was profound (Jones 1999), this emphasis was reasonable. The next Megapode Conservation Action Plan had only 32% of such recommendations (n = 19), indicating that as our knowledge increased, recommendations became more focused on practical actions. Given my experience working on six species of megapodes from four genera in three countries, the recommendations in the two Megapode Conservation Action Plans were both sensible and needed if megapodes are to be conserved. In that sense, my analysis of our success in implementing conservation actions for megapodes over the past 12 years and two Megapode Conservation Action Plans is not a comment on the plans themselves, but on our effectiveness at implementing their recommendations.

Megapode Conservation Action Plans 1995-1999 and 2000-2005

Not enough work has been done to conserve megapodes. Of the 18 conservation actions recommended for 1995-1999 (Dekker *et al*. 1995b) about a third each were implemented, partially implemented, and not implemented (Table 1). This rate of implementation did not become any better for the period of the second Megapode Conservation Action Plan for 2000-2005 (Dekker *et al*. 2000), with only two of 19 actions implemented and 10 partially implemented, while six were not implemented (Table 1). Review of the actions in both Megapode Conservation Action Plans suggests that for most, partial implementation is not sufficient to ensure the conservation of the species involved. The most positive outcome over the period was the implementation of recovery plans for two species (i.e., the malleefowl and Micronesian megapode, Dekker *et al*. 2000).

For the Polynesian megapode, the 1995-1999 Megapode Conservation Action Plan called for research into sustainable harvest of eggs, while both Megapode Conservation Action Plans called for monitoring, translocations of more eggs to islands and a public awareness campaign. Only the later was partially implemented (e.g., Rinke *et al*. 1993; Table 1).

The first Megapode Conservation Action Plan for maleo called for surveys, which were implemented (Dekker 1990; Argeloo 1994; Baker & Butchart 2000; Butchart & Baker 2000; Baker 2002; Gorog *et al*. 2005), while the harvesting plan recommended in the second Megapode Conservation Action Plan was not developed. Both Megapode Conservation Action Plans called for protection of nesting fields and awareness campaigns, which were partially implemented (Table 1). Below I will discuss the conservation actions being taken for this species.

Both Megapode Conservation Action Plans for Bruijn's brush-turkey called for surveys, which were implemented (Mauro 2005; 2006), while no management plan has yet been developed (Table 1).

The surveys recommended in the first Megapode Conservation Action Plan for the Moluccan megapode were partially implemented (Anonymous 1995; Dekker *et al*. 1995a; Heij *et al*. 1997). Several nesting fields of this species are formally managed by local people (Argeloo and Dekker 1996; Heij *et al*. 1997), so in that sense the protection of nesting fields and harvesting plan recommended in the second Megapode Conservation Action Plan were partially implemented, while an awareness campaign has not been implemented (Table 1).

The surveys and research recommended in the first Megapode Conservation Action Plan for the Nicobar megapode were implemented (Sankaran 1995), as was the monitoring called for in the second Megapode Conservation Action Plan (Sivakumar 2007), but not the protection of nesting habitat. The pubic awareness and research into population dynamics and social organisation (Sankaran & Sivakumar 1999) were only partly implemented (Table 1).

Neither the surveys nor management plan for the Biak megapode recommended in the Megapode Conservation Action Plans have been implemented (Table 1).

The surveys and harvest plan (Bowen 1996; Foster 1999; O'Brien *et al.* 2003) recommended in the Megapode Conservation Action Plans for the Vanuatu megapode have both been only partially implement (Table 1).

Three case studies of megapodes conservation

In this section I detail three case studies of conservation projects on megapodes. I start by detailing the background to the species and its conservation not covered above, then give the rationale and objectives for the project, before detailing the methods used and the results obtained.

Maleo in Sulawesi - enforcement, protection of nesting fields, use of hatcheries

There are several conservation projects for the maleo (e.g., Summers 2007; Tasirin 2007; van As 2007). These projects are based around the enforcement of current laws, the protection of nesting fields and eggs, the enhancement of nesting fields and the use of hatcheries to increase the production of megapode chicks.

The maleo is a large (1.3-1.7 kg) monogamous species found only in the lowland and lower montane rainforests of Sulawesi, Indonesia (Jones *et al*. 1995). Males and females dig burrows together in solar or geothermal fields where females lay 8-12 eggs per year (Dekker 1990; c.f. ~ 30, MacKinnon 1978). Although illegal, eggs are heavily harvested throughout the range (Baker & Butchart 2000) with harvesters collecting up to 100% of eggs in some areas (MacKinnon 1978). There is a trend of deteriorating quality of nesting fields across the entire island (Baker and Butchart 2000).

The rationale for conservation of maleo is that it is classified as Endangered, is fully protected under Indonesian law (MacKinnon 1981), and that it is in serious decline (IUCN 2006). Maleo eggs are not the major protein or income source for local people at nesting fields (Argeloo & Dekker 1996), so reducing the harvest will not result in economic hardship or reduced food security. Furthermore, local people close to some fields are supportive of conservation efforts (e.g., Summers 2007; Tasirin 2007; van As 2007) and active management has been shown to be successful for this species (e.g., MacKinnon 1981)

The three projects are located at Bogani Nani Wartabne National Park (Christy and Lentey 2002; Tasirin 2007, John Tasirin *in litt*. 2007) and Tangkoko (van As 2007) in North Sulawesi, and Taima in Central Sulawesi (Summers 2007). They have the following broadly similar objectives: to increase the maleo population, to raise awareness of the importance of conservation, to increase the involvement of the local community in conservation, and to promote a broader understanding of conservation (John Tasirin in litt. 2007).

Protection of nesting fields is the main recommendation made by those who study maleo conservation (e.g., MacKinnon 1981; Dekker 1990; Argeloo & Dekker 1996; Baker & Butchart 2000; Gorog *et al*. 2005). All three projects feature moratoriums on collecting eggs and the use of guards at nesting fields; guards are either ex-harvesters (Summers 2007; van As 2007), other local people, or park rangers (John Tasirin in litt. 2007).

Two projects are based around the protection of eggs, where they are either left in situ (Summers 2007) or transferred to semi-natural hatcheries (Christy and Lentey 2002; Tasirin 2007); hatcheries have been used in maleo conservation efforts in the past (e.g., MacKinnon 1981; Dekker & Wattle 1987) and are widely recommended. That said, at some sites hatcheries have been inadequately managed and their benefits are not well studied (Baker and Butchart 2000).

The improvement of nesting habitat by removing invasive and dense vegetation has been widely recommended (MacKinnon 1981; Dekker 1990; Baker & Butchart 2000; Gorog *et al*. 2005). This intervention is not well studied (Sinclair 2000b) and the removal of all dense vegetation may be counter-productive given chick survival is higher when there is escape cover (Göth and Vogel 2002; 2003).

The largest maleo conservation project in recent times is run by the Wildlife Conservation Society and Bogani Nani Wartabne National Park (Tasirin 2007). This site has hatcheries in three geothermal locations that are fenced against predators and poachers. Eggs are collected from fields, marked, measured and then transported to hatcheries. Emergent chicks are weighed and measured before being realised in nearby forest, while the adult population is monitored by counts of birds laying in fields (John Tasirin in litt. 2007).

All three projects are considered successful in that they have at least achieved high levels of community support and involvement. They have also resulted in more birds using enhanced nesting fields; one apparently abandoned nesting field has become active again (van As 2007) and cleared areas have significantly more activity and eggs laid that unclear areas (Christy & Lentey 2002). Voluntary moratoriums on collecting eggs have been put in place by local people to allow maleo populations to recover (Summers 2007), and many eggs have been protected and chicks hatched; at Taima over 1200 eggs were protected in the first 11 months of the project to July 2007, while at the Wildlife Conservation Society- Bogani Nani Wartabne National Park project the 4000th maleo chick was released in May 2007 (Tasirin 2007).

It appears that projects in areas where there is community support, using increased protection of nesting fields, hatcheries for eggs, and habitat improvement, are successful in reversing the deterioration of fields and in producing substantial numbers of megapode chicks. That said, there are several areas of research requiring attention to fully asses the validity of the methods used for the maleo: monitoring population changes independent of nesting fields is needed to determine if chick production results in more adult birds, and studies of population genetics are required to determine if there are high levels of natal philopatry (John Tasirin in litt. 2007). Comparisons of hatching success *in situ* versus in hatcheries are required to determine if hatcheries are the best approach, as is the study of adult movements from fields, and their home range and habitat use (Summers 2007).

Melanesian megapode in the Solomon Islands - sustainable harvests of eggs

The second case study is for the Melanesian megapode in the Solomon Islands where a research driven project was used to develop a sustainable harvest plan for eggs. (Unless other citations are given, the following is taken from Sinclair 1999b; 2001a; in prep.)

Melanesian megapodes (*M. eremita*) display considerable behavioural plasticity in their use of incubation sites and heat sources but are best known for the huge nesting fields from which hundreds of thousands eggs were harvested in the past (Bishop 1980; Broome *et al*. 1984). The species is sexually monomorphic, socially monogamous, territorial away from fields, and forage in both primary and secondary forest. The species occurs in the Bismarck Archipelago, Papua New Guinea, and Solomons Islands (Jones *et al*. 1995). Melanesian megapodes are considered to be widespread and abundant, and are classified as a species of Least Concern (IUCN 2006). Despite this classification, the over harvesting of eggs is widespread (King 1989; Kisokau 1991) and management is needed to protect many populations (Sinclair pers. obs.).

The rationale for this project is that there are no management models for nesting fields of megapodes (Jones 1999), yet over half of the species threatened with extinction use this system (IUCN 2006). This project is an opportunity to conduct management experiments with a common species that can be applied to problems with threatened species. Furthermore, eggs are an important source income and nutrition for people close to large fields (e.g., Dureau 1993) who therefore are supportive of these interventions and actively manage the megapode fields.

The objectives of the main research project were to conduct research to develop a community-based management plan on Simbo Island, Solomon Islands. At the start of the project local management involved a 2-month closed season and formalised local enforcement, but these were considered inadequate by the local people as the megapode population was believed to be declining. The research questions were broadly based around determining if eggs were escaping the harvest, and if not, whether closed seasons or hatcheries are the best management option. The risks faced by dispersing chicks were also studied.

On the island birds lay in two nesting areas where heat is generated by volcanic activity (Sibley 1946). Local people say they earn more than 60% of their cash-income from the sale of megapode eggs and their extensive Traditional Ecological Knowledge of the natural history of megapodes influences their interactions with them. In the 1970-1980s locals noticed declines in the megapode population and harvest of eggs, and in 1990 approved the Simbo Megapode Management Ordinance which featured 2-months closed to harvesting eggs, no killing of birds and other activities. Unfortunately, local people noticed continuing declines through the 1990s, which lead to the project detailed here.

The methods used in this project were participatory, involving the local people in all aspects of the project. Initially their Traditional Ecological Knowledge was surveyed to generate hypotheses to be tested. The size of the egg harvest was then determined by household surveys, the efficiency of harvesters estimated using a mark-recapture experiment with eggs, and the incubation period, hatching success and effectiveness of hatcheries investigated by marking and following eggs. The risks faced by dispersing chicks were estimated by radio-tracking.

In the 12-months of the study about 200,000 eggs were harvested, which equates to about 40 days of the average rural wage per family, confirming the harvest is economically important. The efficiency of harvesters was very high meaning that eggs had < 1% chance of escaping the harvest. The conclusion from these studies was that there was a need to manage harvests of megapode eggs.

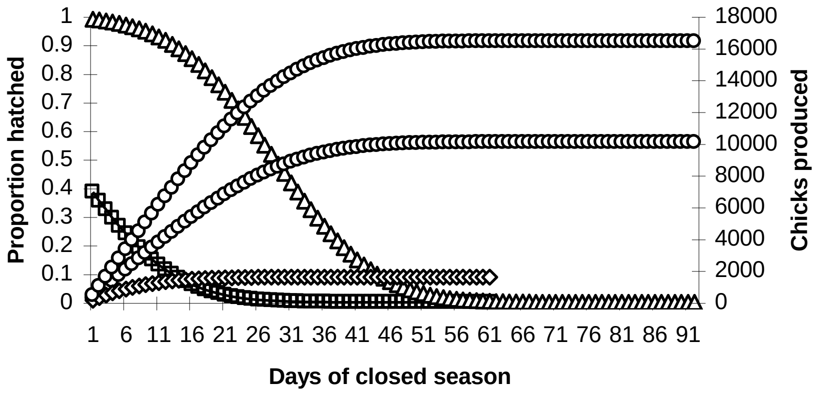

Figure 3. Results of a preliminary model for closed seasons of 61 days (61d) and 91 days (91d). The left scale shows proportion of eggs laid on each day of the 61d (squares) and 91d (triangles) closed seasons that hatch before the end of the closed season. For example, of the eggs laid on the first day of the 91d closed season, 98% will hatch, whereas for the 61d closed season 38% hatch. The right scale is the cumulative number of chicks produced during the 61d (diamonds) and 91d (circles) closed seasons, with 95% Confidence Intervals. The Confidence Interval for the 61d closed season is too small to be seen on this scale. (Reproduced with permission from Sinclair (1999a)

The mean incubation period of eggs (about 65 days) was longer than the 2-month (61 days) closed season, indicating the closed season was too short to achieve its stated objective of allowing sufficient eggs to escape the harvest. A preliminary model developed to examine the productivity of closed seasons of different lengths estimated that a for 61-day closed season only 6% of eggs laid actually hatch
producing between 1,200-2000 chicks, whereas for a 91-day closed season 31% of eggs hatch producing between 10,000-16,500 chicks (Figure 3).

In the hatchery experiment mortality was strongly dependent on treatment, with moving early-stage eggs resulting in significantly higher mortality than moving late-stage eggs, while the late-stage eggs did not have a significantly higher mortality than those left *in situ*. It was therefore concluded that hatcheries were a viable management option.

Hatching success was high for eggs of the Melanesian megapode (i.e., 65% hatched, 26% addled, 3% died in ground), but chick survival was very low (i.e., most chicks died < 48 hrs; all were dead or missing < 1 week). Megapode chicks face a significantly higher risk of death from cats and dogs than all other causes combined (Figure 2). The recommendation from this research was that natural predators should not be controlled, whereas introduced predators should be controlled if possible.

The most important outcomes of this project were a broad acceptance of the results of research leading to amendments to the management ordinance, including the closed season being extended to 3 months and a new community-based enforcement system. An extension of the close season to 3 months produces as many chicks as 60 hatcheries, so closed seasons are a more practical approach than hatcheries for community management.

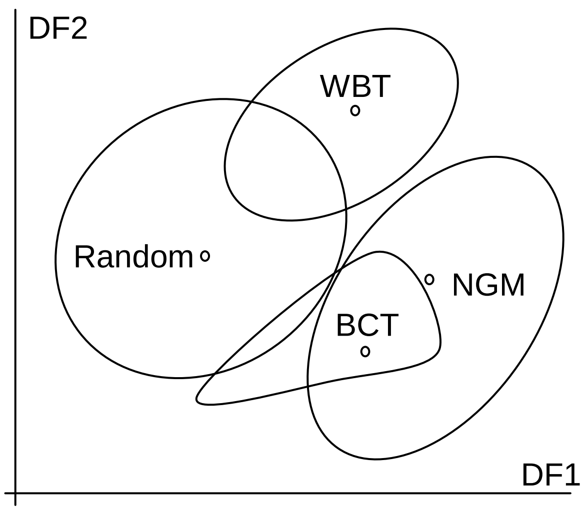

Figure 4. Distribution of scores from a Discriminant Function Analysis showing separation of mound sites of Wattled Brush-turkeys (WBT), New Guinea Megapodes (NGM) and Brown-collared Talegallas (BCT) and random points along two discriminant axes (DF1 and DF2). Going from habitat at random points to that at mound sites along the DF1 axis is moving from more disturbed forest to a more mature closed-canopy forest. Ellipses are 95% contours with points being the locations of group means. (Reproduced with permission from Sinclair (2002)

Mound-building megapodes in Papua New Guinea - management prescriptions, local empowerment

The third case study is for mound-building megapodes in Papua New Guinea. (Unless other citations are given, the following is taken from (Sinclair 1997; 2000a; 2000b; 2001b; 2002).

The nine species in three genera of megapodes on the mainland of New Guinea are all mound builders (Jones *et al*. 1995) and are all considered species of Least Concern (IUCN 2006). This research involved the New Guinea megapode (a socially monogamous species that nests year-round with >1 pair sharing some mounds), the wattled brush-turkey (a polygynous and polyandrous species that has a short breeding season where the male alone builds and maintains the mound), and the brown-collared talegalla (*T. jobiensis*; a little known species that shares mounds with other species over a short breeding season).

The rationale for this project is that very little is known about New Guinea megapodes, yet all species are heavily harvested and local extinctions have occurred Sinclair pers. obs.). This project is designed to provide information for local people to manage megapodes because 97% of land in Papua New Guinea is in customary ownership (Marat 1991), so local people control the harvesting of megapodes and their eggs. Local people base resource management decisions on their astounding Traditional Ecological Knowledge. Traditional Ecological Knowledge is based on long-term observations (Baines & Hviding 1992) and often involves management prescriptions (Gadgil & Berkes 1991). If research will benefit local people it must provide recommendations in a form local people can use and that makes sense to them in the context of their Traditional Ecological Knowledge.

The main objective of the study was to learn the basic natural history of the species. The habitat variables associated with mounds were investigated by comparing them to random points so recommendations could be made about the habitat modification that occurs throughout New Guinea. Given harvesting of eggs from mounds is widespread, its effects were investigated by putting temperature loggers in mounds. The behaviour of megapodes was studied by erecting hides at mounds and tagging and radio-tracking them.

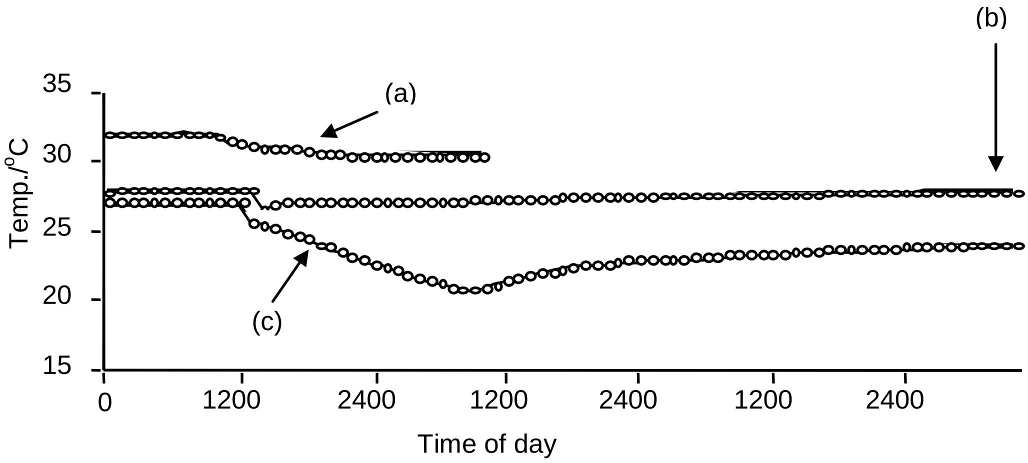

Figure 5. Temperatures in the core of megapode mounds when they are (a) excavated and covered by birds in the process of laying eggs, (b) excavated then left uncovered by harvesters in search of megapode eggs and, (c) excavated then covered by harvesters. The change in temperature at about 1200 hrs in (c) is when the megapodes returned to the mound and covered the hole left by the harvesters. (Sinclair, unpublished data)

Compared to random points, forest at mound sites of all species is in relatively undisturbed primary forest with a very closed canopy (moving along DF1 in Figure 4). It was therefore recommended that gardens are not established within 100 m of mounds and no trees at all are cut within 20 m of a mound. It was also recommended that areas be excluded from logging concessions in which harvests of megapode eggs are required in the future.

Because most megapode activity at mounds is in the morning, and that Brush-turkeys at least readily desert mounds if disturbed, it was recommended that egg collectors visit mounds only in the afternoon.

From temperature-loggers buried in mounds excavated by megapodes and egg harvesters, it appears humans and birds have a similar effect on the temperature of the mound provided the mound is closed after excavation. When the mound is left open after harvesting, as is the practice of many egg collectors, mounds cool rapidly and take a long time to recover to incubation temperatures (Figure 5). Leaving mounds uncovered could result in increased egg mortality when not all the eggs have been found and may lead to abandonment of some mounds. Given this, it was recommended that egg collectors close mounds after excavating them.

As with most species of megapode, the potential exists for over-harvesting of eggs, especially as the human population expands rapidly. In addition, wattled brush-turkeys may experience greater impacts than other species due to their shorter breeding season and concentration of eggs in some mounds. Accordingly, it was recommended that egg collectors visit mounds of wattled brush-turkeys only once per season and those of the other species not more than three times per year.

These recommendations were made to landowners at the study site through a series of meetings, and used in a curricula developed for environmental education in Papua New Guinea. Posters with these recommendations are now being trialled in villages in Papua New Guinea as a way to disseminate the information more widely .

Conclusion

The megapode family is at serious risk, and most if not all threatened species are in decline (IUCN 2006). With these levels of risk, if current decline continue, more species will be added to the list of extinct megapodes. The actions needed to address these declines have been identified and published in two Megapode Conservation Action Plans (Dekker *et al*. 1995b; Dekker *et al*. 2000). Those few actions that have been fully implemented have been largely successful. Most actions, however, have not been implemented sufficiently to conserve the species concerned (Table 1). We know what to do to conserve most megapodes; now we need to do it.

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