Vertebrate Fauna Recolonization of Restored Bauxite Mines—Key Findings from Almost 30 Years of Monitoring and Research

Owen G. Nichols[1] and Carl D. Grant[2,3]

Abstract

Studies into the processes of vertebrate fauna colonization of Alcoa's restored bauxite mines began around 1975. This recognized the key role of vertebrate fauna in jarrah forest ecosystem processes, and also the fact that some species were rare, so priority was given to determining their status in unmined forest, and promoting their return to restored areas following mining. Long-term studies have since taken place on mammals, birds, and reptiles both in unmined forest and in restored areas of varying ages and techniques. Mammal recolonization varies between species depending on species' food and shelter requirements and their distribution and abundance in the surrounding forest. Birds rapidly recolonize and 95% of species have been recorded in restoration. Bird community structure changes with restoration type and age, and in current restoration, it is similar to that of unmined forest by the age of 10 years. Studies on reptiles have shown that 21 of 24 species have recolonized. The remaining three include one legless lizard and two snakes, all of which feed on small vertebrates (e.g., skinks) and require shelter in the form of logs, stumps, and coarse woody debris. Some other reptile species consistently occur in restoration in lower densities than in unmined forest, and current studies are investigating the causes of this. Together, studies on these three vertebrate fauna groups have provided valuable, complementary information on their habitat requirements, and the extent to which Alcoa's restoration program has been successful in reestablishing this important component of the jarrah forest's biodiversity.

Key words: bauxite mining, birds, fauna recolonization, jarrah forest, mammals, reptiles, restoration, vertebrates.

Introduction

The vertebrate fauna of southwestern Australia's jarrah forest is well documented due to numerous studies carried out by government authorities responsible for managing the forest and its water resources, academic institutions, and private industry, principally bauxite mining companies. A review of the forest's vertebrate fauna found that it supports 29 mammal, 150 bird, and 45 reptile species (Nichols & Muir 1989); however, it is recognized that the number of species inhabiting the region where bauxite mining occurs, and specifically those landforms and vegetation types where mining takes place, is much lower. Clearing of land east of the forest for agriculture, and predation by the introduced Fox, have resulted in a number of species declining to the point where they are officially listed as "Rare" or "Specially Protected" under Western Australia's Wildlife Conservation Act (1950). Examples include mammals (e.g., the Chuditch [*Dasyurus geoffroii*]), birds (e.g., Baudin's Cockatoo [*Calyptorynchus baudinii*]), and reptiles (e.g., the Carpet python [*Python spilotes*]). Conservation of all native vertebrate species is now an important objective of forest management practices.

Alcoa's mining operations commenced in the 1960s and current operations result in the clearing and restoration of approximately 550 ha/year. Although over time this will total less than 4% of the forest area, the scale of operations means that there is the potential for significant local impacts on fauna if care is not taken to minimize clearing and impacts on unmined forest and establish a restored forest ecosystem that fulfills the habitat requirements of fauna species. Achieving this has necessitated extensive research into the processes of forest ecosystem establishment and the ecology of vertebrate fauna species.

Bauxite mine restoration techniques have evolved considerably since the first tree planting took place in the 1960s. From a fauna viewpoint, early restoration provided relatively poor habitat because it had low ground and understorey cover, low plant species richness, relatively low biomass, and did not include the dominant tree species—jarrah. The adoption of deep ripping, understorey seeding of a wide range of local species, direct topsoil return, and establishment of solely local eucalypt tree species significantly improved habitat value for a number of faunal groups such as birds (Armstrong & Nichols 2000; Nichols & Nichols 2003) and spiders (Simmonds et al. 1994). The current

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objective of restoration is to establish a self-sustaining jarrah forest ecosystem designed to enhance or maintain water, timber, recreation, conservation, and other nominated forest values. The specific conservation goal is to "encourage the development of floral, faunal and soil characteristics similar to those of the indigenous forest ecosystem" (Nichols & Nichols 2003).

Studies into the processes of vertebrate fauna colonization of Alcoa's restored bauxite mines began around 1975 soon after the commencement of restoration. There were two reasons for this. First, the key role of vertebrate fauna in jarrah forest ecosystem processes such as pollination, grazing, and predation were recognized and believed to be important in the development of a sustainable restored forest ecosystem. Second, some species were rare or uncommon, so priority was given to determining their status in unmined forest areas and promoting their return to restored forest areas following mining. Since then, detailed studies have taken place on reptiles, birds, and mammals both in unmined forest and in restored areas of varying ages and techniques. Limited studies have also been conducted on frogs and fish, but these are not discussed in the present article because apart from the occasional haul road stream crossing, mining operations take place in upslope and mid-slope areas of the forest and not in streams and stream zone areas where fish and frog populations occur.

This article summarizes the findings of 30 years of research conducted on mammals, birds, and reptiles and illustrates how this has provided considerable useful information on habitat restoration and management techniques beneficial to these fauna groups. Studies on invertebrates are discussed where relevant, with a detailed review of invertebrate recolonization given in Majer et al. (2007).

Mammals

Despite the fact that surveys on mammals in restored bauxite mines commenced in 1978, little has been published on this group. The main reason for this is because quantitative data has been difficult to obtain due to the low numbers of many species resulting from predation by the introduced Fox *Vulpes vulpes*. To clearly interpret patterns of mammal colonization to restored bauxite mined areas, it has been necessary to understand that, concurrently with species reinvasion following mining, changes have been taking place in jarrah forest mammal populations.

Many of the medium-sized mammal species, which occur in the jarrah forest, suffered significant declines in the years leading up to the mid-1990s. Some, such as the Chuditch (*Dasyurus geoffroii*), originally occurred over large areas of Australia (Morris et al. 2000) but have declined to small remnant populations in the southwest. For others, such as the Common Brushtail Possum (*Trichosurus vulpecula*) and Mardo (*Antechinus flavipes*), the decline has not been as extensive. Research demonstrated that the major reason for the significant decline in abundance of many species in the jarrah forest was Fox predation (Bailey 1996).

Research into the Fox predation problem led to the development of a dried meat bait containing sodium fluoroacetate, a naturally occurring chemical found in jarrah forest plant species. Indigenous fauna species have developed a high tolerance to this toxin, but introduced species such as the Fox are highly susceptible. Broadscale trials demonstrated that if large areas of the forest were aerially baited within 2–3 years numbers of mammal species such as the Chuditch increased (Morris et al. 1998). On the basis of these results, the decision was made to implement fox baiting over 700,000 ha of the northern jarrah forest to halt the decline in numbers of those mammal species known to be susceptible to Fox predation. Baiting in areas in which Alcoa's bauxite mining operations occur commenced in July 1994.

Following this baiting, Alcoa began a program of reporting all key fauna sightings by field staff. This showed that numbers of Fox sightings recorded at Huntly mine decreased from 15 in 1994 to 0 in 1999 and 2000.

Given the earlier decline in native mammal species described above, it is very important that the impact of mining operations on key mammal species in adjacent unmined forest is minimized and species are able to recolonize restored areas.

Mammal monitoring in relation to Alcoa's mining activities has focused on

- Broadscale surveys to obtain information on mammal populations in areas where future mining is planned.
- Surveys of unmined forest areas near current mining operations to detect trends in densities of key mammal species.
- Surveys of mammals in post-mining restoration to determine patterns of recovery against a background of changing densities of many species following Fox control.

Although all mammal species are monitored, the main focus of studies has been on local native species selected because of their susceptibility to Fox predation, rarity, and range of ecological roles. These are the Mardo (a small carnivore), Chuditch (large carnivore), Quenda (omnivore), and Common Brushtail Possum (folivore).

Broadscale survey sites were situated in areas typical of those mined, but located outside planned mining areas, so that they could be resurveyed in the future to assess longer term impacts. Trapping generally involved establishing two trap lines similar to those described in Nichols and Nichols (2003), using wire cage traps, large and medium aluminum box traps, and pit traps. All mammals caught were weighed, sexed, earmarked (to avoid counting recaptures), and pouches were checked for young prior to their release.

Percentage trap success results for key species such as Chuditch, Quenda, and Possum in broadscale trapping conducted between 1980 and 1999 all showed evidence of

an increase in the abundance of these species in the forest following fox baiting (Fig. 1). Trapping success of both Chuditch and Possums in 2005 was much higher than in any of the previous years. For Quenda, trapping success was much higher in 1999 than in previous years; however, by 2005, numbers of Quenda had declined. This result has been confirmed elsewhere (see later) and is thought to be due to a severe drought in early 2001.

Numerous surveys of restored mines have also been carried out since 1978. These have included the Alcoa Long Term Fauna Monitoring Program (LTFMP; Nichols & Nichols 2003) as well as reported sightings by field staff. Together, they indicate that all mammal species recolonize mined areas within 10 years of restoration (Table 1). Some, such as the Grey Kangaroo, Mardo, and Chuditch, recolonize very rapidly, whereas others, such as the Brushtail Possum and Brush-tailed Phascogale, take longer. The difference is probably at least partly due to their feeding requirements. Kangaroos graze on newly established plants, whereas Mardos and Chuditch venture into young restored mines in search of prey such as invertebrates and feral mice. By contrast, Brushtail Possums probably require trees of a certain age in which to feed, and Brush-tailed Phascogales are arboreal predators who also require mature trees in which to forage.

Breeding details indicate that for most species, females have been recorded carrying young in restored areas (Table 1). For example, the Grey Kangaroo breeds in restored mines as does the Western Pygmy Possum, which uses nest boxes placed in older sites for monitoring purposes. The Mardo and Brush-tailed Phascogale also use nest boxes and possibly breed in them. The presence of Brushtail Possum females with young probably only means that they are foraging in restored mines and nesting in hollow trees in unmined forest. Chuditch, which have also been recorded in restored mines with young, usually nest in a den constructed in a large log or stump, probably in unmined forest, although fauna log habitats are now routinely constructed in restored mines. Quenda construct a nest among dense vegetation and may breed in areas of suitable restoration, although no such nest has been located.

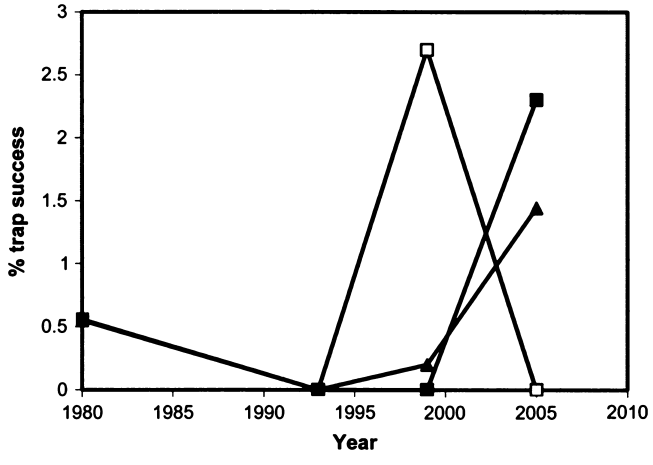

Figure 1. Percentage trapping success for key mammal species recorded in surveys of unmined upland forest between 1980 and 2005 (▲, Chuditch; □, Quenda; and ■, Brushtail Possum).

Trends in the recolonization of restoration by key mammal species are revealed by LTFMP data. Although the abundance of Mardos showed a slight increase in restored mines, it remained lower than that recorded in unmined forest (Fig. 2). Other studies have shown that the abundance of invertebrate groups such as spiders (Simmonds et al. 1994), ants (Majer & Nichols 1998), and collembola (Greenslade & Majer 1993) are comparable in bauxite mine restoration and in unmined sites. The availability of food is therefore probably not a reason for the Mardos lower abundance in mining restoration. Competition with feral mice is also unlikely as the two species have different dietary requirements and the large decline in mice numbers did not reflect a corresponding increase in Mardos. The most likely reason is a lack of shelter in the form of small hollows and crevices in mature trees, logs, and stumps; these are largely absent from young restoration.

Large increases in Quenda abundance were recorded (Fig. 2). The increase in restored mines mirrored that in unmined forest sites, and trap success rate for the species was even higher than that recorded in the separate survey of unmined forest (Fig. 1). It can be concluded that from these results that in response to Fox control, Quenda are able to recolonize restored mines in densities comparable to those recorded in unmined forest. The subsequent decline in Quenda numbers in both mined and unmined sites is likely to be due to the 2001 drought, as noted earlier.

Brushtail Possums tend to colonize older restored mines when trees have grown large enough to provide their feeding requirements. By 2001, their trap success rate of 2% in restored mines (Fig. 2) was comparable to that recorded in the unmined control sites and also in the Huntly unmined forest sites (Fig. 1).

No Chuditch were trapped in restored mines during the LTFMP. However, other surveys have recorded the species in restoration. For example, a survey of burnt and unburnt nine-year-old restored mines at Jarrahdale in July 1998 recorded Chuditch at a trapping success rate of 1.6%—similar to that in the Huntly survey (Fig. 1) (Alcoa, unpublished data). One capture included a female with young in restored mines burnt only one year previously (see Table 1). The trap success rate in that survey was higher than the rate recorded in the May 1999 Jarrahdale survey of unmined sites and comparable to the rate recorded in the 1998 broadscale forest surveys. The patchiness of the species recovery in unmined forest following Fox control may partly explain why it is recorded in some restored areas and not in others. However, the lack of suitable shelter in the form of hollow logs and stumps in older restored mines would also probably limit the extent to which these sites fulfill Chuditch habitat requirements.

Table 1. Native mammal species recorded in upland forest and restoration trapping programs, with information on age first recorded and breeding details where available.*

Species	*Age First Recorded (yr)*	*Comments*
Echidna (*Tachyglossus aculeateus*)	8	Increase in sightings follow fox baiting, occasional sightings in a range of restoration types
Dunnart (*Sminthopsis dolichura*)	4	Uncommon everywhere
Mardo (*Antechinus flavipes*)	2	Two females with 8 and 10 young in burnt restoration, 2 years after fire in 16-year-old restoration
Brush-tailed Phascogae (*Phascogale tapoatafa*)	10	Nests observed in nest boxes
Chuditch (*Dasyurus geoffroii*)	2	4 YIP in burnt restoration 1 year after fire in a 9-year-old site
Quenda (*Isoodon obesulus*)	2	3 YIP in burnt restoration 3 years after fire in 11-year-old site. Also 3 YIP in 8-year-old restoration
Common Brushtail Possum (*Trichosurus vulpecula*)	8	1 YIP 1 year after fire in 9-year-old site
Western Pygmy Possum (*Cercartetus concinnus*)	5	Breeds in nest boxes in approximately 8- to 10-year-old restoration
Brush Wallaby (*Macropus irma*)	4	Breeding not known
Western Grey Kangaroo (*M. Fuliginosa*)	0	YIP commonly observed in a range of restoration ages

Species not recorded in upland forest (e.g., Quokka [*Setonix brachyurus*]) and species reintroduced as part of recovery plans are not included. YIP, young in pouch.
*Note that the presence of females with young does not necessarily mean that the nest or den site is located in restoration; for example, for Chuditch, the den is likely to be in a large log or stump in unmined forest; Possums would nest in tree hollows in unmined forest.

Some feral species are indicative of the restored sites' disturbance. For example, the abundance of feral mice was much higher in two-year-old restored mines than in unmined forest (Fig. 2), then declined rapidly, and from 1998 onward, they remained similar to those recorded in unmined forest. Previous studies have shown that the species colonizes forest areas following disturbance. For example, fauna surveys of sand-mined areas in woodlands of eastern Australia (Fox 1996) have also shown that numbers of mice are initially high following restoration, then decline. Christensen and Kimber (1979) found that in Karri (*Eucalyptus diversicolor*) forest, mice colonized a burnt area within five months after the fire, numbers peaked within one year, and the species was not recorded 28 months after the fire. Rapid colonization of disturbed sites is enhanced by the species' rapid reproductive rate, generalist habitat and food requirements, and mobility. Possible reasons for the subsequent decline include a decrease in seed availability as acacias mature and senesce, and a gradual change in vegetation structure as sites become more open; this may reduce shelter availability for mice.

Some monitoring of mammal response to fire has been conducted in the same sites used for bird monitoring. For Quenda, this has shown no clear difference in the extent to which the species uses forest and restored sites after fire (Alcoa, unpublished data). Possums have been recorded in recently burnt restoration on several occasions in similar numbers to those in unburnt restoration and presumably feed on the new epicormic growth. Mardos were not present one year after a burn but returned after three years. Feral Mice, an indicator of disturbance, recolonize dense restoration in large numbers in the first year after a burn and by six years are still present although in lower numbers.

Overall, mammal survey results indicate that, although all species use restoration to some extent, there are differences between them in the rate and extent to which they recolonize. These differences appear to be due to different food and shelter requirements and possibly their abundance in the surrounding forest.

Birds

Monitoring of birds commenced in the mid-1970s with general inventory surveys of restored and unmined forest. The first detailed monitoring commenced in 1981 (Nichols & Watkins 1984). Despite the fact that the restoration was established using methods now considered outdated, the results showed that sites as young as 4–5 years can support similar bird species numbers, densities, and diversities as unmined forest. The same sites were resurveyed in 1987, 1993, and 1999. The number of bird species in the direct seeded restored site was very similar to that in the healthy unmined forest site in all years (Fig. 3). Bird numbers in the restored site that received direct return topsoil were initially similar to the healthy forest site but from 1993 onward were lower, as some understorey plant species senesced and the site became more open. At that stage, the number of bird species in the direct return site became more similar to those in the die-back site, which had a sparse tree cover and low understorey density, and in all years supported fewer bird species than the healthy forest site and the direct seeded restored site.

A separate study conducted in 1981 and 1982 showed similar results (Collins et al. 1985). It demonstrated that bird communities in 6- to 7-year-old vegetation resulting from advanced (for those times) restoration techniques

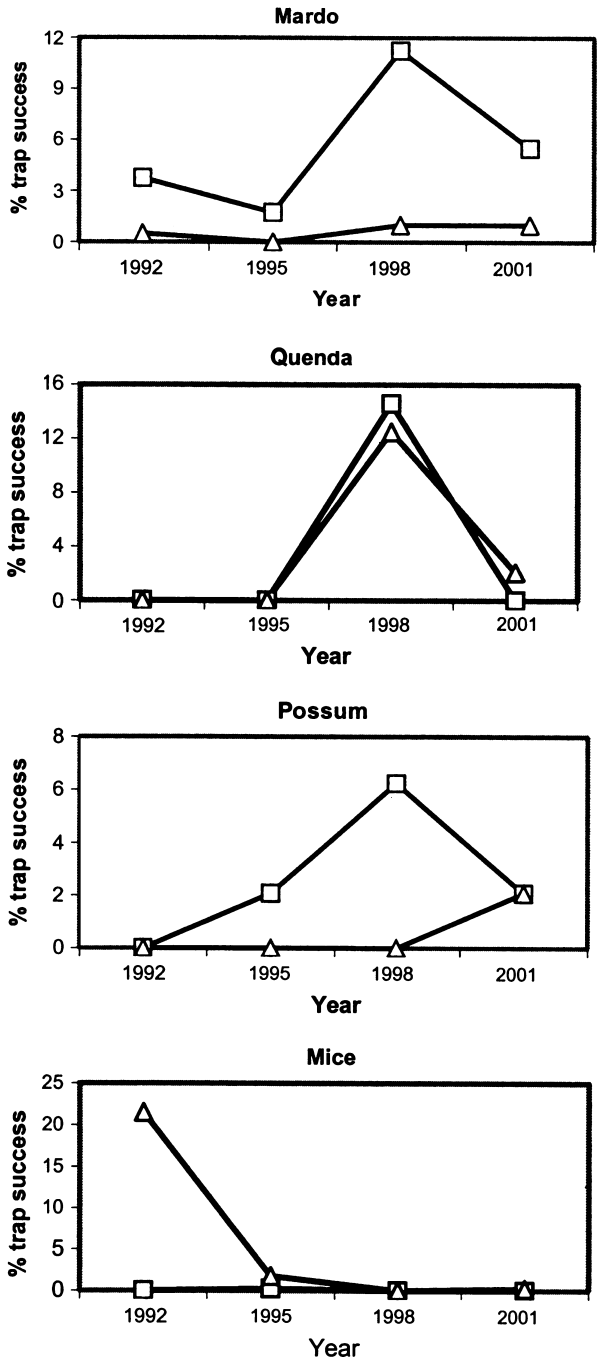

Figure 2. Total numbers of Mardos, Quenda, Brushtail Possums, and Feral Mice recorded in 1990 restoration (△) and in healthy unmined forest (□) during the Alcoa LTFMP.

have densities and total numbers of species similar to those of healthy forest communities.

In 1991, Alcoa designed the LTFMP. The first monitoring commenced in 1992, when the restored sites surveyed were two years old. Details of the program are described in Nichols and Nichols (2003). LTFMP bird data from sites restored using techniques more representative of current practices show that by eight years, total species numbers in restored mines are comparable to those in unmined sites (Fig. 4). Diversity, which measures the relative abundance of species, also attains similar values to those in unmined areas by the same age (Fig. 4).

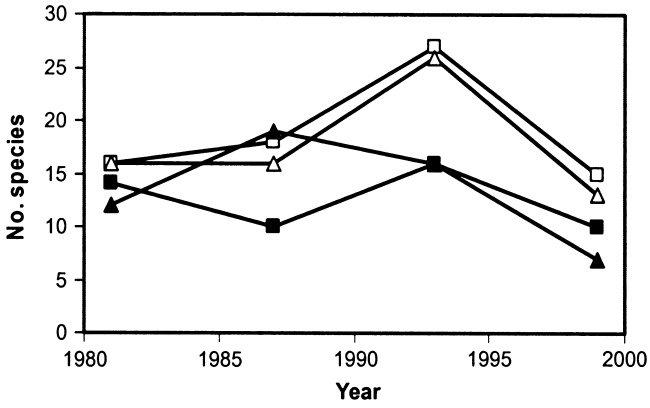

Figure 3. Total bird species recorded between 1981 and 1999 in two sites restored in 1976 (△, direct seeded and ▲, direct return), one healthy forest (□) and one dieback–affected site (■).

The LTFMP results were examined in more detail to see whether the composition of the avifaunal community in restored mines differed from that in healthy unmined forest. Classification analysis conducted using Sorenson's similarity index (Nichols & Nichols 2003) showed that, on the basis of species composition, five-year-old restored sites grouped separately from unmined forest sites. By eight years, the separation between forest and restored sites was not as apparent and the dissimilarity value separating the unmined and restored sites had declined.

Analysis of 2001 monitoring data, conducted with stream zone monitoring sites included showed that, based on species' presence/absence, the composition of the 11-year-old restoration avifaunal community was indistinguishable from that of unmined forest occurring in stream zones, which also contain tall, dense understorey. With time, acacias and some other understorey species will senesce in the restored sites, resulting in a more open habitat and the composition of the avifaunal community becoming more like that of upland forest.

All bird studies combined have shown that, to date, 95% of the 70 bird species that inhabit upland jarrah forest adjacent to mining have been recorded in restored mined areas (Nichols 1998). The most notable species not yet present is the Rufous Treecreeper (*Climacteris rufa*), which forages for insects on the trunks of tall eucalypts and among log piles. The remainder are uncommon species that may have returned but have not yet been observed.

The presence of bird species alone does not necessarily imply that a restored site is fulfilling all the habitat requirements for a particular species. Separate studies (e.g., Curry & Nichols 1985) have shown that bird species which build nests in a variety of sites breed successfully in restored mines. However, those that nest in hollow trees

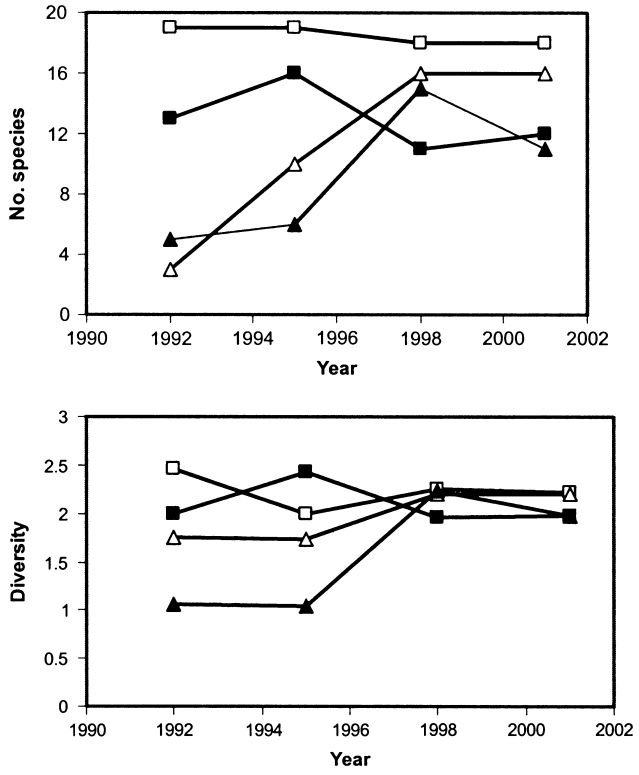

Figure 4. Total numbers of bird species and bird diversity (Shannon-Weiner) recorded in summer at Jarrahdale mine in 1990 restoration (△, restoration 1 and ▲, restoration 2) and in healthy unmined forest (□, forest 1 and ■, forest 2) sites during the Alcoa LTFMP. Surveys at each site were conducted along two 250 m transects on three occasions, recording all birds within 20 m of the transect.

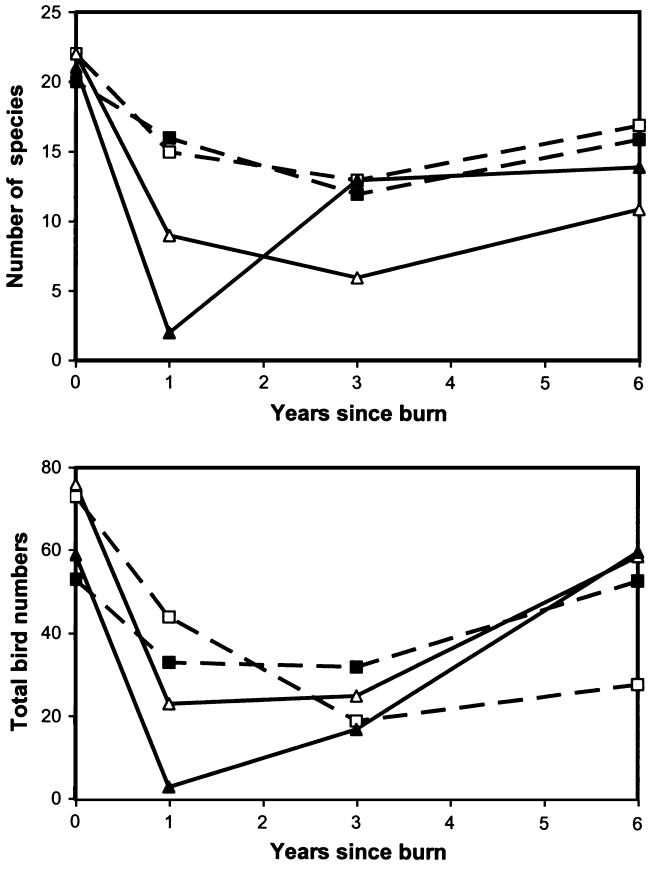

Figure 5. Bird species numbers and total bird numbers before and after sites were burnt (□, unburnt forest; ■, burnt forest; △, unburnt dense restoration; and ▲, burnt dense restoration). Sites were restored in 1989 and first monitored in 1997.

will not do so for many years but will use the restored mines for foraging purposes.

Fire is an integral and recurring component of the forest ecosystem. Some indication of how the avifaunal community might be affected by vegetation changes resulting from burning of restored mines was obtained through a research project that commenced in 1997. In that year, birds were surveyed in two unmined forest and four restored bauxite mine pits. The restored areas included two dense and two sparse areas. In November 1997, one forest, one dense, and one sparse restored area were burnt. Postburn monitoring was conducted one (1998), three (2000), and six (2003) years after the fire, using identical methods to those used in the preburn survey.

The most notable postburn change in the avifaunal community following fire was the temporary decline in bird species numbers and total bird numbers in the dense restored site immediately following the burn (Fig. 5). Three and six years after the burn, this effect was no longer apparent. Bird species numbers in the unburnt dense restored site also declined following the burn (although not as much); however, three and six years after the fire, it remained lower than at the other sites, probably due to ongoing senescence of the tall acacias. Six years after the burn, classification showed no separate grouping of burnt and unburnt sites (Alcoa, unpublished data). These results suggest that, at most, fire has only a temporary effect on the total numbers of birds using both mined and unmined sites. Data analysis for small insectivores and honeyeaters showed that honeyeaters were the group largely responsible for the temporary difference in total bird numbers in the dense restored site after the burn.

Overall, the results for birds indicate that the forest avifaunal community recolonizes mined areas the most rapidly and completely of all vertebrates and recovers from fire-induced vegetation changes within a relatively short period of time.

Reptiles

Reptile studies commenced in the mid-1970s as part of general vertebrate surveys of restored areas and unmined jarrah forest. The first detailed comparison of reptile populations in restored mines and unmined forest were undertaken in 1981 (Nichols & Bamford 1985). The study showed that older style restored areas (e.g., those established using

only trees) were unsuitable for most reptile species, whereas those established using more advanced techniques such as direct topsoil return supported more species and much greater abundance of reptiles. The same plots were surveyed again in 1987, 1993, and 1999. The total number of reptile species recorded in the healthy forest site was greater than that in both restored sites in all years apart from 1999, when the site had been burnt just over 12 months previously and was still recovering from fire (Fig. 6, from Price 1999). With the exception of 1981, numbers of reptile species recorded in the dieback–affected site were also greater than those in the restored sites. Of the two restored sites, in most years, the least species were recorded in the direct seeded site.

The above study was carried out in sites restored using techniques, which, by the early 1990s, no longer reflected standard operational practices. Monitoring of more current restoration in LTFMP sites has shown that total numbers of reptile species were consistently higher in unmined forest, although by 2001, the difference between the LTFMP mined and the unmined sites was only two species (Fig. 7).

Combined reptile studies have shown that, of the 24 species that have been recorded in upland jarrah forest typical of that normally mined, 21 or 87% have been recorded in restored sites (Nichols 1998). They include species from all upland reptile families, viz geckos, legless lizards, dragon lizards, skinks, blind snakes, goannas, pythons, and elapid (front fanged) snakes. This diversity of taxonomic groups indicates that, at least to some extent, bauxite mine restoration caters for the habitat requirements of a wide range of reptile species.

For those species that have returned, a clear pattern of succession appears to exist. As described in Nichols and Gardner (1998) and Nichols and Nichols (2003), general foragers such as the skink (*Tiliqua rugosa*) and active predators such as the Dugite snake (*Pseudonaja affinis*), which feed on feral mice (an early postdisturbance colonizer), return within 2–3 years. They are followed by small, mobile, insect-eating skinks including *Menetia greyi*, which can inhabit sites with variable ground cover and shallow leaf litter. Species requiring particular habitats, which take longer to develop, such as exfoliating bark (e.g., for the gecko [*Phyllodactylus marmoratus*]) and deep leaf litter (e.g., for the blind snake [*Ramphotyphlops australis*]), colonize later. In monitoring conducted to 2001, neither had been recorded in any of the LTFMP restored sites; the only records of both are from restored sites greater than 12 years old (O. Nichols, ACMER, 2006, personal observation).

The three species that have not yet been recorded in restored mines are the legless lizard *Lialis burtonis* and the snakes *Rhinoplocephalus gouldii* and *R. nigriceps* (Nichols & Gardner 1998). All three feed on small vertebrates, including skinks, so low densities of small reptiles (see later) may explain their absence. Another factor may be the scarcity of shelter in the form of logs, old stumps, and coarse woody debris. However, all three species are rarely encountered in unmined forest, so it is possible that they may have recolonized following mining but not yet been recorded.

The abundance of some reptiles tends to be greater in unmined forest compared with restored areas. For example, captures of skinks were greater in unmined than in mined areas, although by 2001, numbers in restored mines were increasing (Fig. 7). Numbers of the Southwestern Cool Skink (*Acritoscincus trilineatum*) increased with restoration age, and by eight years, they exceeded those

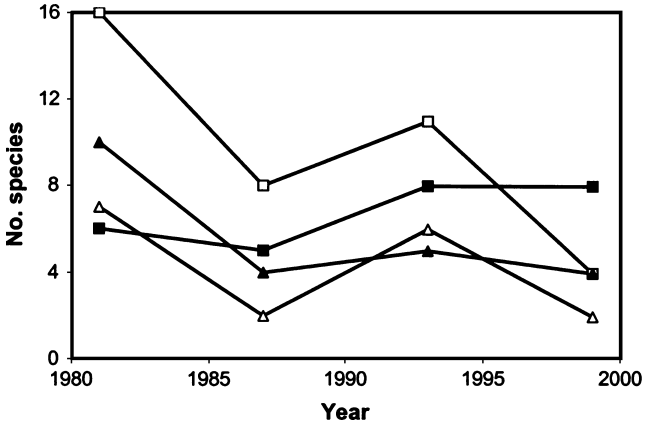

Figure 6. Total reptile species recorded between 1981 and 1999 in two sites restored in 1976 (△, direct seeded and ▲, direct return), one healthy forest (□) and one dieback–affected site (■).

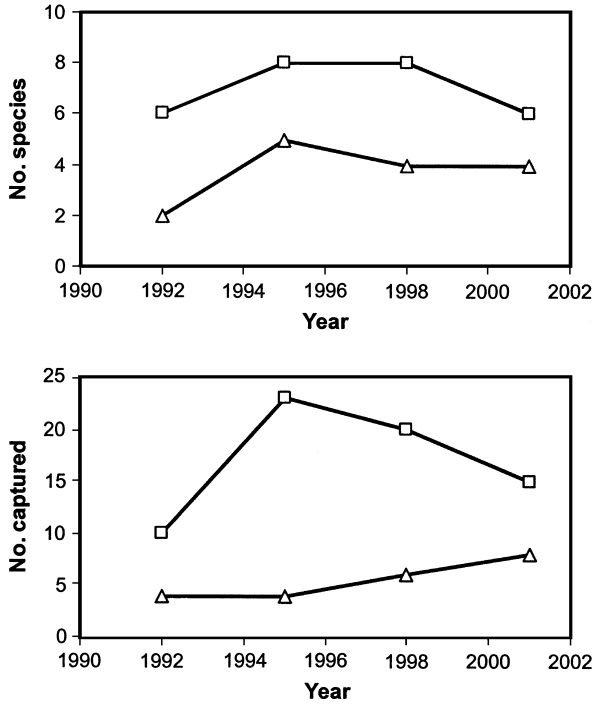

Figure 7. Total numbers of reptile species recorded, and total skinks captured, in 1990 restoration (△) and in healthy unmined forest (□).

captured in unmined forest (Fig. 8). However, this species tends to be more common in dense, stream zone vegetation, and sites where soil moisture is high (Nichols & Bamford 1985). Dense restored sites resemble this more than upland forest, and this is probably the reason why this skink species is more common in restored mines than in unmined areas. The remaining skink species, in most years, were captured in lower numbers in restored mines than in unmined forest, with several not trapped in restoration at all (Fig. 8). Variation between the species suggests that different factors may determine the extent to which they recolonize mined areas. Studies by Nichols and Bamford (1985) suggested that limited food abundance (small invertebrates) is unlikely to be a problem. At this stage, the most likely contributing factor is thought to be the availability of suitable shelter. Skink species such as the Southwestern Crevice Skink (*Egernia napoleonis*) and the Red-legged Skink (*Ctenotus labillardieri*) both live in crevices in logs and stumps and the availability of this is much lower in restored mines than in unmined forest. Most of the other species occasionally shelter in crevices or under logs.

Current research is directed toward gaining a better understanding of the habitat requirements of species not returning to restored areas and developing practical ways of managing restoration to increase the numbers recolonizing. Log habitats are now placed in restoration as standard practice, and operational thinning and burning trials have been carried out for a number of years. A number of research projects have just commenced and are designed to assess the effect of these management practices on reptile recolonization through better understanding and provision of species habitat requirements.

Discussion and Conclusions

Overall, the vertebrate fauna monitoring and research have provided useful information on how the bauxite

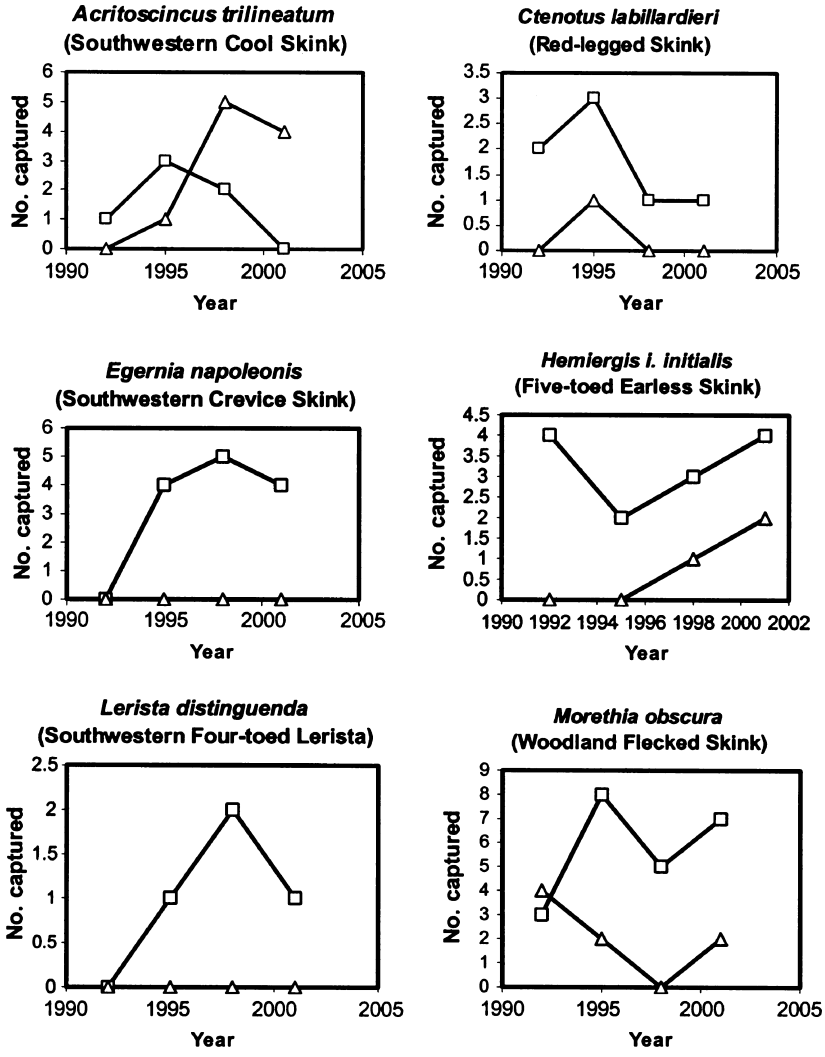

Figure 8. Numbers of particular skink species trapped in 1990 restoration (△) and in healthy unmined forest (□).

mine restoration is developing, how it could be improved, and the net impacts of mining and restoration on the conservation status of particular species. All of this is critical given the recent trend in the mining industry toward a whole-of-mine-life focus on biodiversity conservation, specifically through minimizing direct and indirect impacts of mining operations on biodiversity, and maximizing the extent to which biodiversity values are replaced following mining (ICMM 2005).

Mammal trapping programs conducted have confirmed the findings of other studies, which show recovery of medium-sized native mammal species following Fox control. This recovery has enabled more detailed quantitative studies of mammals to be undertaken. All upland mammal species recolonize mined areas, although the recolonization patterns vary between species. The densities of some, such as the Quenda and Possum, approach that in unmined sites. Mardo numbers are generally lower than in unmined sites. In some studies, Chuditch trap success matched that in unmined sites, but numbers are generally too low to draw conclusions regarding the species' comparative abundances in the two habitats.

The jarrah forest avifauna appears to reestablish in mined areas the most rapidly of all vertebrate fauna groups. More than 95% of species have recolonized, and a number of surveys have shown that bird species numbers, densities, and diversities in mined areas have attained the values recorded in unmined sites less than eight years after restoration. Some differences in composition remain with classification indicating that the community of 11-year-old restored areas more closely resembles that of stream zones than unmined upland forest. Studies in other ecosystems have showed that the rates of bird recolonization vary, with more rapid rates recorded in more mesic, forested areas. For example, Passell (2000) showed that bird species richness, abundance, and Shannon-Wiener diversity all showed a significant increase three years after restoration of tin-mined areas in Indonesia. By contrast, Parmenter et al. (1985) showed that in semiarid shrub-steppe areas of western Wyoming, no apparent relationship existed between the number of bird species recorded and time since revegetation.

Studies on reptiles have demonstrated that although most species and all families recolonize restored mines, compared with birds and some mammals, reptile species numbers and total reptile numbers tend to be lower in restoration than in unmined forest. Species that have not yet recolonized feed on small vertebrates, such as skinks, so food availability may be a factor in their absence. A number of other skink species are present in lower numbers than in unmined sites, and information on their habitat requirements in unmined forest suggests that this may be due to a scarcity of shelter in the form of logs, stumps, trunks with crevices and exfoliating bark. Introduction of habitat log piles and corridors is likely to go some way toward addressing this need, but more information is needed on the specific requirements of particular species. Other studies have also demonstrated that reptile species have variable habitat requirements. For example, Litt et al. (2001), in a study of reptile recolonization in disturbed longleaf pine sandhills in northwest Florida, showed that the degree of habitat heterogeneity influences herpetofaunal community composition. Twigg and Fox (1991) surveyed reptile recolonization of rehabilitated sand-mined areas in eucalypt woodlands of eastern Australia. They found that rehabilitation age, patchy vegetation in the 0–1 m layer, live shrub cover, and the proportion of plant species endemic to the forest were all found to influence abundance of one or more species. Together, these indicate the importance of studies that focus on developing a clearer understanding of reptile species habitat requirements.

Responses of vertebrate faunal communities to burning are only relatively well understood for birds. Research has shown that three years after a burn, any differences in bird species or total bird numbers between burnt and unburnt restoration have disappeared, and by six years, classification showed no separate grouping of burnt and unburnt sites. Further studies are needed to clarify the likely impacts of burning and thinning operations on the reptile and mammal populations of restored areas.

On the basis of the results obtained, a number of steps have been taken to promote faunal conservation in areas close to mining operations and in mine restoration. These include

- The continuation of fox baiting.
- The construction of fauna "habitats" and corridors. During premining clearing, hollow logs, stumps, and other material are usually burnt. Alcoa has now developed procedures for using them to construct habitats and corridors extending across narrow sections of pits. These provide mammals and reptiles with shelter for breeding purposes and protection from predators. The procedures are now routinely implemented at all mines, and Quenda, Mardo, and Chuditch have already been recorded using them (Mutzig 1998).
- In 1993/1994, nest boxes were placed in a range of unmined and restored sites at Jarrahdale and in restored mines at Huntly. Most of the boxes were used by mammal species including the Brushtail Phascogale, Western Pygmy Possum, and Mardo. Although it would be impractical to install the boxes in all restored sites, the technique could be considered in sensitive areas, for example, where mining takes place near conservation reserves or in good quality forest.

Overall, the results of 30 years of vertebrate fauna monitoring indicate that it is possible to establish restoration which caters for the habitat requirements of most species. However, for some species, further work is needed to understand how restoration practices might be improved to further promote their return. Research is currently being undertaken on the effects of long-term forest management practices on some vertebrate fauna species, particularly reptiles and mammals.

The findings of existing and ongoing fauna studies will prove useful to Alcoa and other government and nongovernment stakeholders in the further development of completion criteria. The process used in the development of the current completion criteria includes a requirement that the criteria be publicly reviewed every five years to take into account advances in knowledge and restoration techniques (Nichols et al. 2005). The information from both vertebrate and invertebrate fauna studies will help in the refinement of criteria relating to the establishment of fauna habitat, ecosystem sustainability, and reestablishment of forest land uses and management practices.

Implications for Practitioners

- The variable habitat requirements of different vertebrate species need to be understood and, where possible, met in a cost-effective manner to ensure their successful recolonization following restoration.
- Almost all vertebrate fauna species recolonize in time. However, different fauna groups recolonize at different rates, with birds generally returning the most rapidly, whereas some mammal and reptile species take much longer.
- Recolonization of fauna such as mammals needs to be assessed in the context of trends concurrently occurring in unmined sites, which are the sources of recruitment animals.
- The effects of forest management practices such as burning need to be taken into account. Bird communities of restored jarrah forest areas recover within six years of burning, whereas further studies are needed to determine the impacts of fire on mammal and reptile communities.

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