

# Monitoring bird populations after logging in forests of south-west Western Australia: an update from two long-term experimental research case studies

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## ABSTRACT

We report the results of recent monitoring of the impacts of logging in karri (*Eucalyptus diversicolor*) and jarrah (*E. marginata*) forest. Avifaunal composition of logged and unlogged karri forest was the most similar so far, 21 years after logging took place, but species richness and total abundance remained higher in unlogged karri forest. In jarrah forest, species composition in four treatments (two logged, two unlogged) had not closely converged after 10 years. Graphs of the abundance of each bird species against time for each treatment in karri and jarrah forest are presented. We recommend that monitoring of these forests be continued, and plots relating to an earlier study in karri forest be re-activated. The data accrued so far provide an important baseline for assessing future impacts from changing climate, and any associated changes in fire regimes and infection by animal disease and *Phytophthora cinnamomi*, as well as for evaluating the ecologically sustainable basis of forest management.

Keywords: avifauna; disturbance; eucalypt; jarrah; longitudinal studies; karri

## INTRODUCTION

Thirty years ago the Forests Department of Western Australia (WA) anticipated impact, at least in the short term, on bird populations following the introduction of a clearfelling silvicultural system to log karri (*Eucalyptus diversicolor*) forest in 1967 and the opening in 1975 of a mill to chip non-sawlog wood (Forests Department nd, 1976). This expectation is of course self-evident, because the complete removal of trees (excepting a few seed trees) removes the habitat of birds. Foresters were confident, however, that they could regenerate a new forest. Following the progressive increase in height of this regrowth and self-thinning as trees increased in stem diameter, the resources required by each bird species would once again become available. Bird species were expected to recolonize the previously logged coupe, first to feed while continuing to nest in surrounding unlogged forest, and eventually to reside and breed in the regenerating forest. To examine these ideas, and provide empirical information, a longitudinal experiment was established in Gray forest block, 25 km south-west of Manjimup, in 1982.

Similarly, in 1993 the Department of Conservation and Land Management expected that a change of silvicultural method in jarrah (*E. marginata*) forest would cause impacts on some bird species (Burrows *et al.* 1993).

A longitudinal experiment was set up in three contiguous forest blocks (Kingston, Winneup and Warrup) 25 km north-east of Manjimup. This comprised two intensities of logging. Gap release involves logging to a residual basal area of c. 6 m<sup>2</sup>ha<sup>-1</sup> in a gap up to 10 ha in area, surrounded by an unlogged Coupe buffer no narrower than 100 m. Shelterwood involves logging to a residual basal area of c. 13 m<sup>2</sup>ha<sup>-1</sup> and is unconstrained in terms of the areal extent. It was expected that impacts of logging on bird populations would be short term, with recovery slower in gaps because of the greater intensity of logging.

The results of both experiments were reported by Williams *et al.* (2001) and Abbott *et al.* (2003). Clearfelling of karri forest had immediately reduced both total number of bird species (species richness) and total abundance of birds. In 1998, after 17 years, regrowth forest had not fully recovered in species richness and total abundance of birds. In jarrah forest, species richness and total abundance of birds in forest logged seven years previously differed little from forest that had not been logged for several decades.

Both studies showed that some species increased in numbers with disturbance, these being in the minority in karri forest but in the majority in jarrah forest. Multivariate comparisons of logged and unlogged or not recently logged forests showed considerable difference in species composition.

In order to assist in the development of improved ecologically sustainable management of karri and jarrah

forests, both experiments were converted into long term monitoring sites. Williams *et al.* (2001) had emphasized future monitoring with particular attention paid to 12 indicator bird species, whereas Abbott *et al.* (2003) recommended annual counts in spring for five years, after which recovery of all species would be reviewed.

Therefore, the objectives of this paper are to:

- monitor recovery of birds in karri forest since 1998, by including additional information collected in 2006–7
- monitor recovery of birds in jarrah forest since 2001, by including additional information for 2004–6
- provide for each species in karri forest and jarrah forest a graph showing abundance against time
- re-assess implications for forest policy and forest management practice relevant to ecological sustainability.

## METHODS

### Field methods

In the karri forest study (Williams *et al.* 2001), two matched sites were chosen on the basis of their similarity in landform and superficial vegetation structure, the lack of previous disturbance in the area, and for inclusion in planned timber harvesting operations. Birds were counted in 1982 and 1983 in order to provide a pre-treatment baseline. These sites were then managed differently. One remained unlogged and was left unburnt. The other was logged and burnt in 1984–5. Each site was censused during late spring/ early summer (late October to early December) and late summer/ early autumn (late January to early March). Birds were counted in spring and the following autumn in the period 1985–9 inclusive, 1996–8 inclusive, and in 2006 (for convenience, these spring/ autumn sample pairs are referred to by the year of the spring count). The new data presented here pertain to spring 2006 and autumn 2007.

At each site a 300 m x 300 m sampling grid was established. Each grid was > 1 000 m from the edge of previous timber harvesting areas, although some forest tracks traversed the area. Each grid was permanently marked by metal stakes at each corner. A variable circular-plot procedure was used to census birds five times in each census period at 18 regularly placed points within each grid. Six lines were established 60 m apart as walk trails, with three census points 120 m apart along each line. These were marked with wooden stakes and maintained throughout the study by hand slashing. Points were located at the edge of these lines to enable a line of sight for birds in the overstorey through the otherwise dense understorey. Points along adjacent lines were staggered, so each point was 85 m distant from the sampling points on adjacent lines. All birds detected within 30 m of the observer were tallied, resulting in a total censused area of 5.1 ha at each site. Density/distance functions based on the spring 1982 and summer 1983 data indicated that a distance of 30 m

from the observer adequately detected most birds (Wardell-Johnson 1984).

The transect and area search methods are the two most widely used procedures for censusing birds in Australia (Pyke and Recher 1984). The point-count is a variation on the transect count that is most useful in dense vegetation. The area count technique is difficult to apply in dense vegetation such as the study sites in this area of karri forest, but has been adopted as the Australian Bird Count.

Initially two teams each of two people carried out the census as a means of checking and minimizing variation between observers and to become familiar with the method. Subsequently one observer made each count and five counts were carried out in each grid during each census period. Observers alternated between sites to minimize the influence of personal bias on the total counts. Each bird seen or heard during a five minute interval at each point was counted and the horizontal distance to its location when first detected was estimated within one of six distance categories (0–5 m, 5–10 m, 10–20 m, 20–30 m, 30–60 m, over 60 m). All counts were carried out within four hours of sunrise and the time of detection recorded as minutes after sunrise.

In the jarrah forest study (Abbott *et al.* 2003), advantage was taken of more sophisticated experimental design (BACI, before/after control/impact). Each plot comprised 1 ha (100 m x 100 m), and was visited three times for 30 minutes. Birds present were recorded by sight or sound. There was a minimum period of 7 days between visits. Thirty plots were established in 1994, birds were counted in spring and autumn, and then 14 plots were logged and burnt in 1995–6. Birds were counted in autumn and spring of 1997, 1998, 1999, and spring 2000 and 2001. All counts commenced at sunrise and continued for 3 hours. The new data presented here relate to spring 2004, 2005, and 2006. In the analyses, only data from spring in all years were used.

### Statistical procedures

To investigate any differences in community structure between the main treatments, two complementary approaches were used. Firstly, non-metric multidimensional scaling ordination (nMDS, Kruskal 1964) was used to illustrate differences in community composition between the silvicultural treatments. Abundance data were  $\log(x+1)$  transformed to give the relative abundance values for each species. Using the transformed data, dissimilarity between sites was calculated by the Bray-Curtis metric to give a measure of 'distance' between sites (Faith *et al.* 1987), and represented as a two-dimensional plot using nMDS. The accuracy of the plot in representing the site dissimilarities was assessed using the 'stress' statistic, which indicates the level of distortion: values <0.1 indicate a good ordination; values <0.2 are useful but values close to 0.2 should be treated cautiously; and values <0.25 should be treated sceptically and considered in the light of other analyses (Kruskal, 1964; Clarke and Gorley 2006). The nMDS plot

emphasizes differences in community composition by weighting species equally irrespective of abundance.

Second, Canonical Analysis of Principal co-ordinates (CAP, Anderson and Robinson 2003; Anderson and Willis 2003) was used to test explicit *a priori* hypotheses of differences in community composition between the two matched sites (unlogged and not recently burnt) for before and after logging in karri forest and the four silvicultural treatments in jarrah forest. This method derives principal co-ordinates from the dissimilarity matrix derived above, then subjects the resulting ordinates to canonical discriminant analysis to 'search' for statistically significant differences between treatments and to identify those species causing the differences (Anderson and Robinson 2003). This technique is essentially precautionary, as it actively seeks to identify species that differ in relative abundance between treatments. The CAP analysis was also used to test for regional (or temporal) differences between the five sampling years.

Finally, overall treatment differences were tested using CAP. All nMDS was performed using PATN (Belbin 1995), and CAP analyses were performed using the CAP software package (Anderson 2004).

### Nomenclature

Latin binomials for species names follow those recommended by the Western Australian Museum (Johnstone 2001).

## RESULTS

Species richness and total abundance of birds in karri forest remained higher in the unlogged plot (Fig. 1). Both ordination methods showed that recovery of bird populations in the clearfelled forest was continuing. In 2006 the avifaunal composition of the logged and unlogged areas was the most similar in the 21 years since logging took place (Fig. 2).

Inspection of Table 1 and the recovery trajectories for each bird species in karri forest (Fig. 3) indicated that most species showed few or inconsistent differences between logged and unlogged plots in 2006 relative to before logging (1982–3). Three species, *Glossopsitta porphyrocephala*, *Pomatostomus superciliosus*, and *Myiagra inquieta*, showed a significant decrease in abundance. *Stagonopleura oculata* showed a significant increase in abundance.

Species richness and total abundance of birds in jarrah forest were each higher in Shelterwood and Gap release in 2004 relative to External reference grids, but this was reversed by 2006 (Fig. 4). The CAP analysis of abundance of each species by year for each treatment revealed considerable variation between years, even in the unlogged External reference and Coupe buffer treatments (Fig. 5). Species composition in the four treatments had not yet closely converged.

The abundance of each bird species in jarrah forest by treatment (Fig. 6) indicated significant differences between

the periods 2004–6 and 1994 for 10 of the 37 core species (Table 2). Only two of these species (*Acanthiza inornata*, *Daphoenositta chrysoptera*) showed a significant decrease in abundance.

## DISCUSSION

### Karri forest

It was initially envisaged that clearfelled coupes would be large (up to 200 ha), in order to ensure the destruction of all wastewood by intense fire and subsequent establishment of adequate regeneration (Forests Department nd; Senate Standing Committee 1978). The large coupe (125 ha) in Gray forest block was, however, not typical of the usual scale of logging in karri forest (c. 40–80 ha). The results of the Gray study are not representative of contemporary or later practice but are of great interest because of the unusual extent of the disturbance.

The logged stand now supports regenerated forest 21 years old, but trees are unlikely to have developed hollows utilizable by the nine bird species that require hollows for nesting: *Calyptorhynchus baudinii* and *carnabyi*, *Glossopsitta porphyrocephala*, *Platycercus zonarius*, *P. spurius*, *P. icterotis*, *Climacteris rufa*, *Pardalotus striatus* and *Hirundo nigricans*. Suitable hollows for the smallest species (*Climacteris rufa*, *Pardalotus striatus* and *Hirundo nigricans*) should develop before the larger hollows needed by the cockatoos and parrots (Abbott and Whitford 2002). The relationship between hollow entry diameter and bole diameter is unknown for karri. For jarrah, which is a slower growing species than karri, it has been established that all hollow-nesting bird species should find suitable hollows in trees 110–140 years old (Abbott and Whitford 2002).

The two non hollow-nesting species (*Pomatostomus superciliosus*, *Myiagra inquieta*) that have so far failed to occupy the logged site are unlikely to re-establish until a stand age of >50 years is attained (Tingay and Tingay 1984).

Although clearfelling in karri forest ceased in 2001 (Conservation Commission of Western Australia 2004) and much of this forest has since been reserved as national park (in which logging is prohibited), it is important that monitoring should continue but at a lower frequency. We suggest every 15 years, with the next due in 2021. It is important that both sites are managed identically in terms of application of fire. Future burning should be no different from the usual regional practice, though it should take place at least 8 years before monitoring so that fire impacts will have moderated and will not confound the impact of the logging.

### Jarrah forest

The small area of the intensely logged gaps, together with the retention of large numbers of hollow-bearing trees, has moderated the impact of logging and associated burning on the avifauna. This is not surprising, as the centre of a 10 ha circular gap is <200 m from the



surrounding unlogged Coupe buffer. Maps of logged forest in relation to unlogged forest and reserves, presented in Abbott *et al.* (2003) and Whitford and Stoneman (2004), reinforce this concept of an intricate admixture of recently logged, not recently logged, and never logged forests.

We recommend that birds should be counted in spring every five years, with the next count due in 2011, 15 years after regeneration. It is important that the fire management of grids is integrated with that of the surrounding forest, and is co-ordinated so that fire impacts do not confound interpretation of the return of bird species in respect of regeneration after logging.

### **Statistical power**

Studies such as those reported here are limited in their ability to detect significant changes in the abundance of individual species by three factors. First, species that are infrequently encountered ('rare') or difficult to detect ('cryptic') typically have insufficient data with which to determine changes (MacKenzie *et al.* 2003; MacKenzie 2005). Second, changes in the abundance of species with high intrinsic variability are difficult to quantify accurately. Both of these shortcomings, which are common to forest monitoring studies, can be potentially overcome by increasing the third factor, the level of sampling intensity; i.e., by increasing statistical power (Osenberg *et al.* 1994; MacNally 1997; Foster 2001). However, it is common for sampling levels to be influenced by logistic and resource constraints, so that power will almost always be inadequate for some species. For many species in these studies power was low, as evidenced by large changes in relative abundance that were not statistically significant. In these studies we emphasize the changes in community structure, rather than individual species, with the objective of determining if (or when) the logged sites attain 'bioequivalence' with the reference areas (McDonald and Erickson 1994). Methods to examine impacts on particular species of conservation concern are discussed in the references cited above.

### **Implications for forest policy and forest management practice**

The ordinations presented showed that even without logging the composition and abundance of bird assemblages varied between years, presumably reflecting annual differences in rainfall, temperature, insect abundance and nectar flows. If these assemblages were static and constrained by limited flexibility of the constituent species, this variation should have been less. These ordinations are consistent with a perspective that the jarrah and karri avifauna is resilient to the period of 'summer stress' that characterizes the Mediterranean climate of south-west WA (Gentilli 1989). All of the bird species have had to acquire the capability of tracking to some degree changes in the supply of resources, with some species restricted to local scales of movement and others involved in movements at landscape and regional scale

(Abbott 1999). Not unexpectedly, the logged treatments match the unlogged treatments in the extent of annual variation in composition and abundance of the avifauna.

What then are the implications from the monitoring data reported here for conservation of bird populations in jarrah and karri populations? How should forest managers refine practices? We suggest that few changes are required, for the following reasons:

- Revegetation of all logged sites is progressing as expected, based on information presented by Stoneman *et al.* (1989).
- Recovery of the avifauna is consistent with the expected succession trajectory following disturbance in these forests (Abbott and Whitford 2002; Abbott *et al.* MS; Armstrong and Nichols 2000; Tingay and Tingay 1984).
- Logged stands are well-buffered by extensive areas of unlogged forest and old regrowth (Conservation Commission of Western Australia 2004; Whitford and Stoneman 2004; Fig. 7) in which all bird species are well represented (Abbott 1999).
- No bird species is endemic to these forests, with all found in suitable vegetation to the west, north, south and east of the forest belt (Abbott 1999), although several are declining outside the forest.
- Forest management practices are not implicated in the conservation status of any listed bird species (Abbott 1999; Calver and Dell 1998a, 1998b; Government Gazette 2008a).
- Current forest management builds on a long tradition of applying a prudential and conservative approach (Lee and Abbott 2004).

However, decision-makers could improve the extent of monitoring in karri forest to match that underway in jarrah forest (Abbott *et al.* 2003; Abbott *et al.* MS). We suggest that the eight plots (four logged, four unlogged) established and sampled in 1981–2 by Tingay and Tingay (1984) be relocated, permanently marked and re-sampled as soon as possible. The regeneration on these logged plots is now 26, 32, 39 and 77 years old, so that this series neatly dovetails with the Gray block study reported here (regeneration 21 years old). This dataset will enable a more informed evaluation of how similar the bird fauna present in older regeneration is to that of mature karri forest (120–250 years).

Rare, nocturnal, large or highly mobile bird species will typically be absent, or in low numbers, when counts are made in plots. These species need to be studied separately (Wardell-Johnson and Williams 2000), either by survey (Abbott 2002–7; Liddel *et al.* 2002) or by detailed demographic research (Luck 2001; Wardell-Johnson *et al.* 2004). The latter includes marking individual birds and measuring breeding success, microhabitat usage, and selection of nest sites. *Pomatorhinus superciliosus* and *Myiagra inquieta* populations in karri forest and nature reserves of the wheatbelt should be contrasted and compared in this way. Until this is done, consideration of the mechanism(s) responsible is speculative and thus inappropriate.

However, population studies are difficult, time-consuming and expensive, and for these reasons are often best addressed by doctoral candidates. The Department of Environment and Conservation is obliged to take a balanced view of competing priorities. For example, 209 animal species are listed for Western Australia as rare or likely to become extinct (Government Gazette 2008a), and 42 of these are listed by the Department as Critically Endangered. No forest bird species is ranked as Critically Endangered, and none of the bird species are listed because of a supposed threat related to logging of forests. In addition, 388 plant taxa in WA are listed as rare flora (Government Gazette 2008b), of which 133 taxa are Critically Endangered. Sufficient resources to conduct detailed demographic studies of all Critically Endangered fauna and flora have not been provided to the Department of Environment and Conservation by the Government of WA.

Hollow-nesting bird species are well catered for by the ongoing provision of hollows in live trees (Abbott and Whitford 2002). The major threat to these species is not reduction in the supply of hollows through logging but the usurpation of hollows by swarms of feral bees *Apis mellifera* (Johnstone and Kirkby 2007). The appropriate management intervention is not to reserve more forest from logging but to control feral bees.

Other approaches such as predictive modelling and population viability analysis may also be applicable (Wardell-Johnson *et al.* 2004) but need to be used intelligently, cautiously and sensitively if misleading conclusions are not to be drawn (Abbott and Christensen 1996; Brook and Kikkawa 1998; Lindenmayer *et al.* 2003; Margules and Austin 1995; Wintle *et al.* 2005).

Abbott (1999) discussed in detail threats to forest birds in south-west WA. Some of these factors (conversion of native forest to farmland or pine plantation, damming of rivers) have now ceased, one factor (urbanization) continues unabated, and another factor (wildfire) is more or less minimized. New threats are emerging. Climate change is resulting in increased temperatures (Rosenzweig *et al.* 2008) and reduced rainfall (IOCI 2005), and may exacerbate the risk of wildfire, thereby converting mature karri forest to the establishment phase over large areas. Declining rainfall should alter jarrah and wandoo (*E. wandoo*) forest to woodland, eliminate understorey (Havel 1975), and convert parts of karri forest to more open forest. All of these changes will entail altered habitat structure for many bird species. Increased frequency of summer rainfall is likely to amplify the impact of the plant disease *Phytophthora cinnamomi* in the northern jarrah forest and synergize with warmer soils in the southern jarrah forest to result in significant mortality of jarrah (Shearer and Tippett 1989). Finally, animal diseases are likely to be introduced to WA by means of illegal landings of fishing vessels on the north-west coast (cf. Abbott 2006).

The monitoring plots already in place (the basis of this paper), the FORESTCHECK monitoring program (Abbott *et al.* MS), and reactivation of monitoring in previously established plots in karri forest should provide

adequate baseline data for assessing the impact of these threats on the forest avifauna, as well as evaluating the ecologically sustainable basis of forest management. However, for some bird species more detailed population studies are warranted.

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## REFERENCES

- Abbott, I. (1999) The avifauna of the forests of southwest Western Australia: Changes in species composition, distribution and abundance following anthropogenic disturbance. *CALMScience* Supplement No. 5: 1–175. Corrigenda. *Conservation Science Western Australia* **5**, 136 (2004).
- Abbott I (2002–7) Karrak-watch: A summary of information about the Forest red-tailed black cockatoo (FRTBC) of south-west Western Australia. <http://www.naturebase.net/content/view/2384/482>
- Abbott I (2006) Mammalian faunal collapse in Western Australia, 1875–1925: the hypothesised role of epizootic disease and a conceptual model of its origin, introduction, transmission, and spread. *Australian Zoologist* **33**: 530–561.
- Abbott I., Christensen P (1996) Objective knowledge, ideology and the forests of Western Australia. *Australian Forestry* **59**, 206–212.
- Abbott I, Liddelow G, Vellios C, Mellican A, Williams M (MS) Monitoring of the response of birds to silvicultural methods currently applied in open eucalypt forest in Mediterranean south-west Western Australia.
- Abbott I, Mellican A, Craig MD, Williams M, Liddelow G, Wheeler, I (2003) Short-term logging and burning impacts on species richness, abundance and community structure of bird species in open eucalypt forest in Western Australia. *Wildlife Research* **30**, 321–329.
- Abbott I, Whitford K (2002) Conservation of vertebrate fauna using hollows in forests of south-west Western Australia: strategic risk assessment in relation to ecology, policy, planning, and operations management. *Pacific Conservation Biology* **7**, 240–255.
- Anderson M (2004) CAP: a FORTRAN computer program for canonical analysis of principal coordinated. Department of Statistics, University of Auckland, New Zealand.
- Anderson MJ, Robinson J (2003) Generalized discriminant analysis based on distances. *Australian & New Zealand Journal of Statistics* **45**, 301–318.
- Anderson MJ, Willis TJ (2003) Canonical analysis of principal coordinates: A useful method of constrained ordination for ecology. *Ecology* **84**, 511–525.

- Armstrong KN, Nichols OG (2000) Long-term trends in avifaunal recolonisation of rehabilitated bauxite mines in the jarrah forest of south-western Australia. *Forest Ecology and Management* **126**, 213–225.
- Belbin L (1995) PATN: Pattern analysis package (Technical Reference and Users Guide). Division of Wildlife and Ecology, CSIRO, Australia.
- Brook BW, Kikkawa J (1998) Examining threats faced by island birds: A population viability analysis on the Capricorn silveryeye using long-term data *Journal of Applied Ecology* **35**, 491–503.
- Burrows N, Friend G, Morris K, Stoneman G, Wardell-Johnson G, Williams M (1993) A proposed integrated study of the effects of timber harvesting on the jarrah forest ecosystem. Science and Information Division, Department of Conservation and Land Management.
- Calver MC, Dell J (1998a) Conservation status of mammals and birds in southwestern Australian forests. I. Is there evidence of direct links between forestry practices and species decline and extinction? *Pacific Conservation Biology* **4**, 296–314.
- Calver MC, Dell J (1998b) Conservation status of mammals and birds in southwestern Australian forests. II. Is there unstudied, indirect or long-term links between forestry practices and species decline and extinction? *Pacific Conservation Biology* **4**, 315–325.
- Clarke KR, Gorley RN (2006) *PRIMER v6: User Manual/Tutorial*. Primer-E Ltd, Plymouth, UK.
- Conservation Commission of Western Australia (2004) Forest Management Plan 2004–2013. Crawley, Western Australia.
- Faith D, Minchin P, Belbin L (1987) Compositional dissimilarity as a robust measure of ecological distance: A theoretical model and computer simulations. *Vegetatio* **69**, 57–68.
- Forests Department (nd = ?1973) Environmental impact statement on the wood chipping industry agreement proposals for Western Australia. Perth.
- Forests Department (1976) Review of fauna monitoring and research associated with the Manjimup woodchip project. Western Australian Wildlife Authority file 650/67 vol. 5. Department of Environment and Conservation, Kensington WA.
- Foster JR (2001) Statistical power in forest monitoring. *Forest Ecology and Management* **151**, 211–22.
- Gentili J (1989) Climate of the jarrah forest. In *The Jarrah Forest [.] A Complex Mediterranean Ecosystem* (ed. B Dell, JJ Havel, N Malajczuk), pp. 23–40. Kluwer, Dordrecht, The Netherlands.
- Government Gazette (2008a) Wildlife conservation (Specially protected fauna) Notice 2008. 22 January, pp. 177–185.
- Government Gazette (2008b) Wildlife conservation (Rare flora) Notice 2008. 22 January, pp. 185–191.
- Havel JJ (1975) Site-vegetation mapping in the northern jarrah forest (Darling Range). 2. Location and mapping of site-vegetation types. Forests Department of Western Australia Bulletin No. 87.
- IOCI (2005) Climate notes Numbers 1–11. Indian Ocean Climate Initiative, Perth. <http://www.ioci.org.au/publications/pdf/IOCIclimatenotes.pdf>
- Johnstone RE (2001) Checklist of the birds of Western Australia. *Records of the Western Australian Museum Supplement* No. 63, 75–90.
- Johnstone RE, Kirkby T (2007) Feral European honey bees: A major threat to cockatoos and other tree hollow users. *Western Australian Naturalist* **25**, 252–254.
- Kruskal JB (1964) Nonmetric multidimensional scaling: a numerical method. *Psychometrika* **29**, 115–129.
- Lee K, Abbott I (2004) Precautionary forest management: a case study from Western Australian legislation, policies, management plans, codes of practice and manuals for the period 1919–1999. *Australian Forestry* **67**, 114–121.
- Liddelow GL, Wheeler IB, Kavanagh RP (2002) Owls in the southwest forests of Western Australia. In *Ecology and Conservation of Owls* (ed. I Newton, R Kavanagh, J Olsen, I Taylor), pp. 233–241. CSIRO Publishing, Collingwood, Victoria.
- Lindenmayer DB, Possingham HP, Lacy RC, McCarthy MA, Pope ML (2003) How accurate are population models? Lessons from landscape-scale tests in a fragmented system. *Ecology Letters* **6**, 41–47.
- Luck GW (2001) The demography and cooperative breeding behaviour of the rufous treecreeper, *Climacteris rufa*. *Australian Journal of Zoology* **49**, 515–537.
- MacKenzie DL (2005) Was it there? Dealing with imperfect detection for species presence/absence data. *Australian & New Zealand Journal of Statistics* **47**, 65–74.
- MacKenzie DL, Nichols JD, Hines JE, Knutson MG, Franklin AD (2003) Estimating site occupancy, colonization and local extinction probabilities when a species is not detected with certainty. *Ecology* **84**, 2200–7.
- MacNally R (1997) Monitoring forest bird communities for impact assessment: the influence of sampling intensity and spatial scale. *Biological Conservation* **82**, 355–67.
- Margules CR, Austin MP (1995) Biological models for monitoring species decline: The construction and use of data bases. In *Extinction Rates* (ed. JH Lawton, RM May), pp. 183–196. Oxford University Press, Oxford.
- McDonald LL, Werickson WP (1994) Testing for bioequivalence in field studies: Has a disturbed site been adequately reclaimed? In *Statistics in Ecology and Environmental Monitoring* (eds DJ Fletcher, BFJ

- Manly), pp. 183–197. University of Otago Press, Dunedin New Zealand.
- Osenberg CW, Schmitt RJ, Holbrook SJ, Abu-Saba KE, Flegal AR (1994) Detection of environmental impacts: natural variability, effect size, and power analysis. *Ecological Applications* **4**, 16–30.
- Pyke GH, Recher HF (1984) Censusing Australian birds: A summary of procedures and a scheme for standardization of data presentation and storage. *Department of Conservation and Environment of Western Australia Bulletin* No. 153, 55–63.
- Rosenzweig C, Karoly D, Vicarelli M *et al.* (2008) Attributing physical and biological impacts to anthropogenic climate change. *Nature* **453**, 353–357.
- Senate Standing Committee on Science and the Environment (1978) *Woodchips and the environment. Supplementary report*. Australian Government Publishing Service, Canberra.
- Shearer BL, Tippett JT (1989) Jarrah dieback: The dynamics and management of *Phytophthora cinnamomi* in the jarrah (*Eucalyptus marginata*) forest of south-western Australia. Department of Conservation and Land Management Research Bulletin No. 3.
- Stoneman GL, Borg H, Rose, PW (1989) Recovery of vegetation cover following logging and regeneration in the southern forest of Western Australia and the short term hydrologic implications. *Australian Forestry* **52**, 4–9.
- Tingay A, Tingay SR (1984) Bird communities in the karri forest of Western Australia. Australian Conservation Foundation, Melbourne.
- Wardell-Johnson G (1984) The effectiveness of a variable circular-plot census procedure for estimating bird density in the Karri *Eucalyptus diversicolor* F.V. [sic] Muell. forest of South-Western Australia. *Department of Conservation and Environment of Western Australia Bulletin* No. 153, 25–33.
- Wardell-Johnson G, Williams M (2000) Edges and gaps in mature karri forest, south-western Australia: Logging effects on bird species distribution and diversity. *Forest Ecology and Management* **131**, 1–21.
- Wardell-Johnson G, Calver M, Saunders D, Conroy S, Jones B (2004) Why the integration of demographic and site-based studies of distribution is essential for the conservation of jarrah forest fauna. In *Conservation of Australia's Forest Fauna* (ed. D Lunney), pp. 394–417. Royal Zoological Society of New South Wales, Mosman NSW.
- Whitford K, Stoneman G (2004) Management of tree hollows in the jarrah *Eucalyptus marginata* forest of Western Australia. In *Conservation of Australia's Forest Fauna* (ed. D Lunney), pp. 807–829. Royal Zoological Society of New South Wales, Mosman NSW.
- Williams MR, Abbott I, Liddelow GL, Vellios C, Wheeler IB, Mellican A (2001) Response of bird populations after clearfelling of tall open eucalypt forest in Western Australia. *Journal of Applied Ecology* **38**, 910–920.
- Wintle BA, Elith J, Potts JM (2005) Fauna habitat modelling and mapping: A review and case study in the Lower Hunter Central Coast region of NSW. *Austral Ecology* **30**, 719–738.



Table 1

Bird species detected in karri forest, showing the percentage change in abundance from 1982–3 to after 2006, and its statistical significance.

Species	Number of detections	P-value (test from before (1982–83) to after 2006)	% change* from before (1982–83) to after 2006
<b>Core species</b>			
<i>Accipiter fasciatus</i>	34	0.7175	.
<i>Phaps elegans</i>	20	0.1112	.
<i>Calyptorhynchus baudinii/latirostris</i>	282	0.5316	.
<i>Glossopsitta porphyrocephala</i>	3329	0.0272	-100
<i>Platycercus zonarius</i>	375	0.1465	-81
<i>Platycercus spurius</i>	113	0.8352	.
<i>Platycercus icterotis</i>	1264	0.2026	-48
<i>Cacomantis flabelliformis</i>	244	0.1773	70
<i>Chrysococcyx lucidus</i>	37	0.3798	.
<i>Climacteris rufa</i>	397	0.0760	-72
<i>Malurus elegans</i>	1307	0.4472	-25
<i>Pardalotus punctatus</i>	2055	0.4417	-41
<i>Pardalotus striatus</i>	2059	0.9479	-37
<i>Sericornis frontalis</i>	1535	0.5211	36
<i>Gerygone fusca</i>	837	0.1147	170
<i>Acanthiza apicalis</i>	2014	0.4380	33
<i>Melithreptus chloropsis</i>	4363	0.4516	-26
<i>Phylidonyris novaehollandiae</i>	3648	0.1822	-69
<i>Acanthorhynchus superciliosus</i>	29	0.6936	.
<i>Anthochaera chrysoptera</i>	838	0.4979	.
<i>Anthochaera carunculata</i>	1306	0.2254	-85
<i>Petroica multicolor</i>	35	1.0000	.
<i>Eopsaltria georgiana</i>	1857	0.3025	-39
<i>Pomatostomus superciliosus</i>	371	0.0002	-100
<i>Pachycephala pectoralis</i>	1744	0.9784	-10
<i>Colluricincla harmonica</i>	303	0.2309	-82
<i>Myiagra inquieta</i>	48	0.0043	-100
<i>Rhipidura fuliginosa</i>	2141	0.9319	6
<i>Coracina novaehollandiae</i>	184	0.2431	-53
<i>Artamus cyanopterus</i>	208	0.7272	.
<i>Corvus coronoides</i>	29	0.3579	.
<i>Stagonopleura oculata</i>	158	0.0069	.
<i>Hirundo nigricans</i>	712	0.0646	-100
<i>Zosterops lateralis</i>	1243	0.8003	60
<b>Non-core species</b>			
<i>Dacelo novaeguineae</i>	97	0.0999	-56
<i>Malurus splendens</i>	42	0.8913	.
<i>Lichmera indistincta</i>	42	1.0000	.
<i>Anthus novaeseelandiae</i>	59	1.0000	.
Total abundance	35359	0.0510	-68
Species richness	38	0.0624	-11

\* % change calculated as  $[(la/ca) * (cb/lb)] - 1$ .

where la = Logged area (after logging)

ca = Unlogged area (after logging)

cb = Unlogged area (before logging)

lb = Logged area (before logging).

If "ca" or "lb" is zero, % change cannot be calculated.



Table 2

Bird species detected in jarrah forest, showing the percentage change in abundance from 1994 to 2004–6, and its statistical significance.

Species	Number of detections	P-value (test from before (1994) to after (2004–6))	% change* from before (1994) to after (2004–6)
<b>Core species</b>			
<i>Phaps elegans</i>	15	0.2288	.
<i>Calyptorhynchus banksii</i>	69	0.3051	.
<i>Calyptorhynchus baudinii/latirostris</i>	27	0.6135	.
<i>Glossopsitta porphyrocephala</i>	11	0.7488	.
<i>Platycercus zonarius</i>	213	0.7322	144
<i>Platycercus spurius</i>	116	0.7564	84
<i>Platycercus icterotis</i>	128	0.2779	.
<i>Cacomantis flabelliformis</i>	43	0.7087	294
<i>Chrysococcyx basalis</i>	17	0.4013	.
<i>Chrysococcyx lucidus</i>	71	0.6511	1753
<i>Climacteris rufa</i>	100	0.2474	-100
<i>Malurus splendens</i>	241	0.0167	.
<i>Malurus elegans</i>	114	0.0679	-1
<i>Pardalotus punctatus</i>	140	0.0007	565
<i>Pardalotus striatus</i>	695	0.0011	-17
<i>Sericornis frontalis</i>	272	0.0085	44
<i>Gerygone fusca</i>	535	0.1021	-54
<i>Acanthiza apicalis</i>	867	0.0007	24
<i>Acanthiza inornata</i>	240	0.0015	-86
<i>Acanthiza chrysorrhoa</i>	7	1.0000	.
<i>Melithreptus chloropsis</i>	235	0.0781	470
<i>Acanthorhynchus superciliosus</i>	1	0.0071	.
<i>Anthochaera carunculata</i>	35	0.1995	.
<i>Petroica multicolor</i>	252	0.5793	-80
<i>Eopsaltria australis</i>	191	0.2173	213
<i>Eopsaltria georgiana</i>	39	0.3279	.
<i>Daphoenositta chrysoptera</i>	99	0.0385	-33
<i>Pachycephala pectoralis</i>	358	0.5518	106
<i>Colluricincla harmonica</i>	129	0.4107	-45
<i>Rhipidura fuliginosa</i>	392	0.0489	73
<i>Coracina novaehollandiae</i>	49	0.0069	.
<i>Artamus cyanopterus</i>	52	0.8934	.
<i>Cracticus tibicen</i>	12	1.0000	.
<i>Strepera versicolor</i>	19	0.9350	-6
<i>Corvus coronoides</i>	16	0.7605	.
<i>Hirundo nigricans</i>	122	0.6109	166
<i>Zosterops lateralis</i>	124	<0.0001	.
<b>Non-core species</b>			
<i>Neophema elegans</i>	8	0.7722	.
<i>Dacelo novaeguineae</i>	34	0.1734	.
Total abundance	6136	0.7748	44
Species richness	56	0.1317	26

\* % change calculated as  $[(la/ca) * (cb/lb)] - 1$ .

where la = Logged area (after logging)

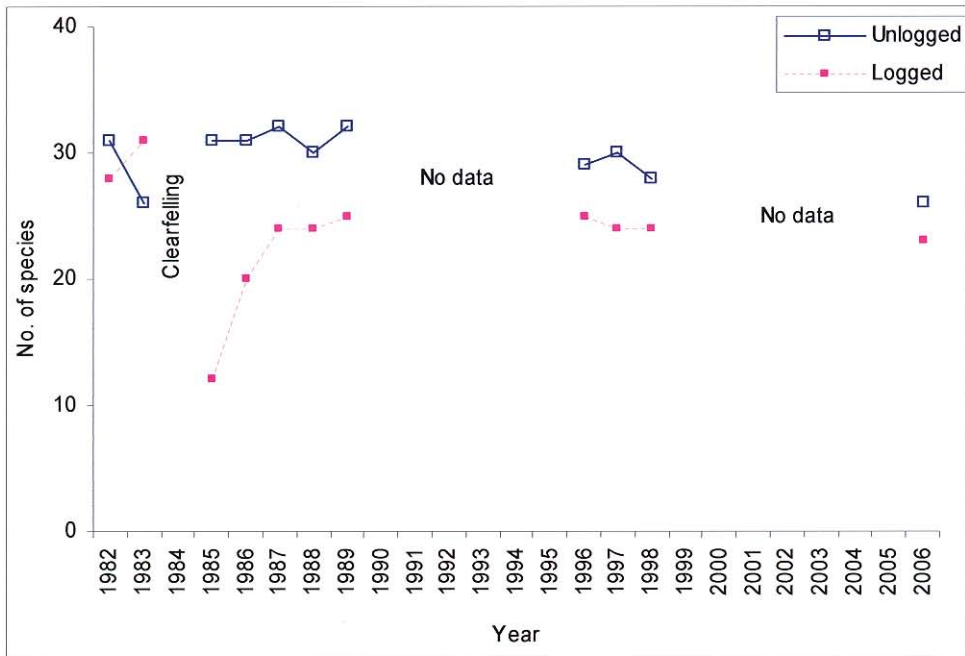
ca = Unlogged area (after logging)

cb = Unlogged area (before logging)

lb = Logged area (before logging).

If "ca" or "lb" is zero, % change cannot be calculated.

(a)



(b)

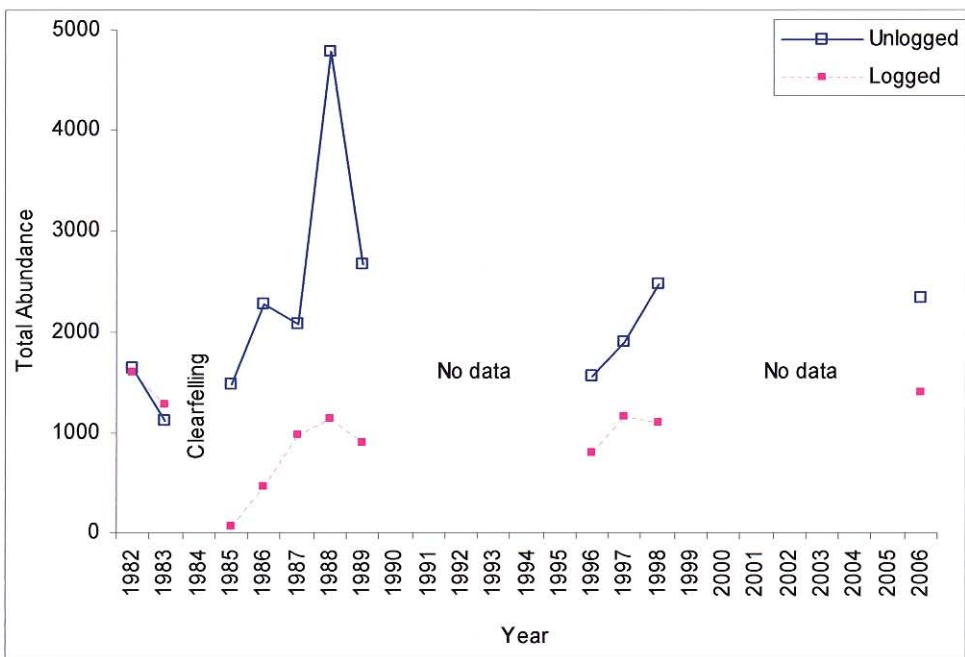
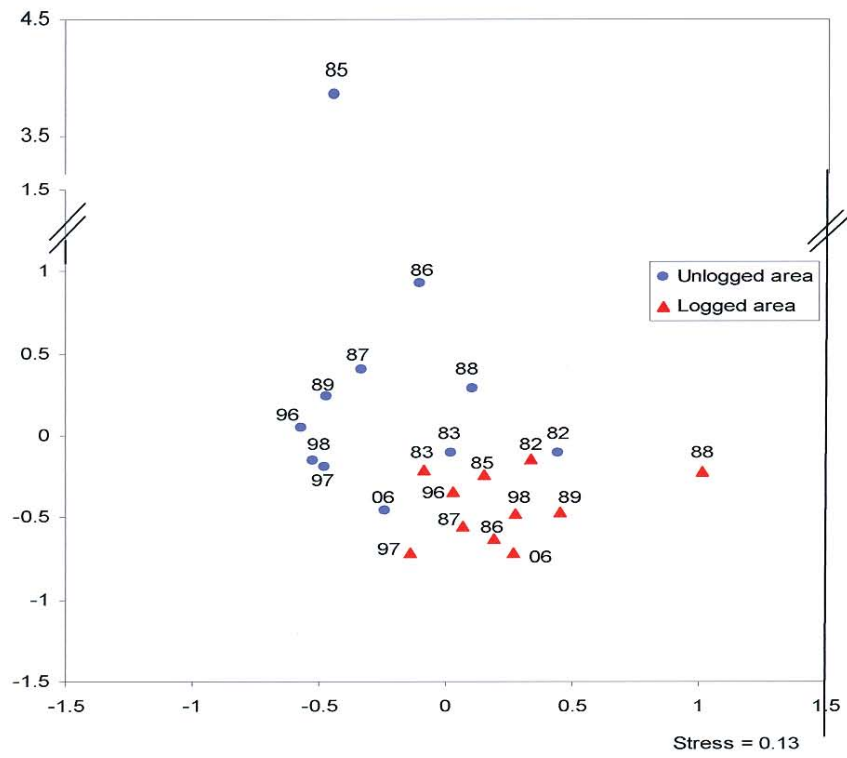


Figure 1. Number of core bird species (a) and their total number (b) recorded each year in unlogged and logged karri forest.

(a)



(b)

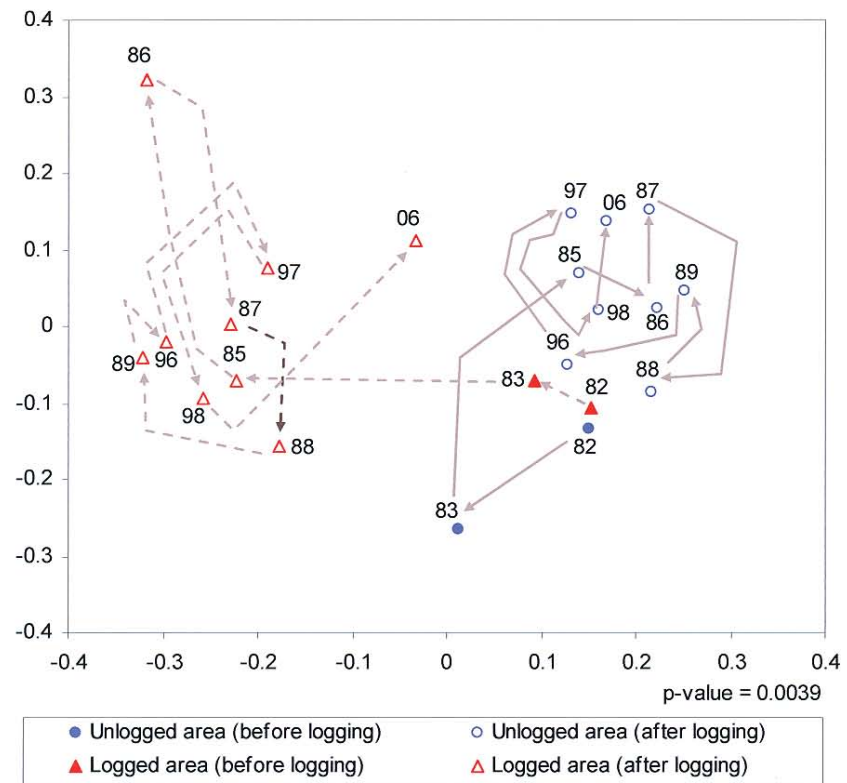


Figure 2. Temporal changes in bird community structure in karri forest, based on the pattern of species abundances, revealed by non-metric multidimensional scaling (a) and canonical analysis of principal co-ordinates (b).

Core species

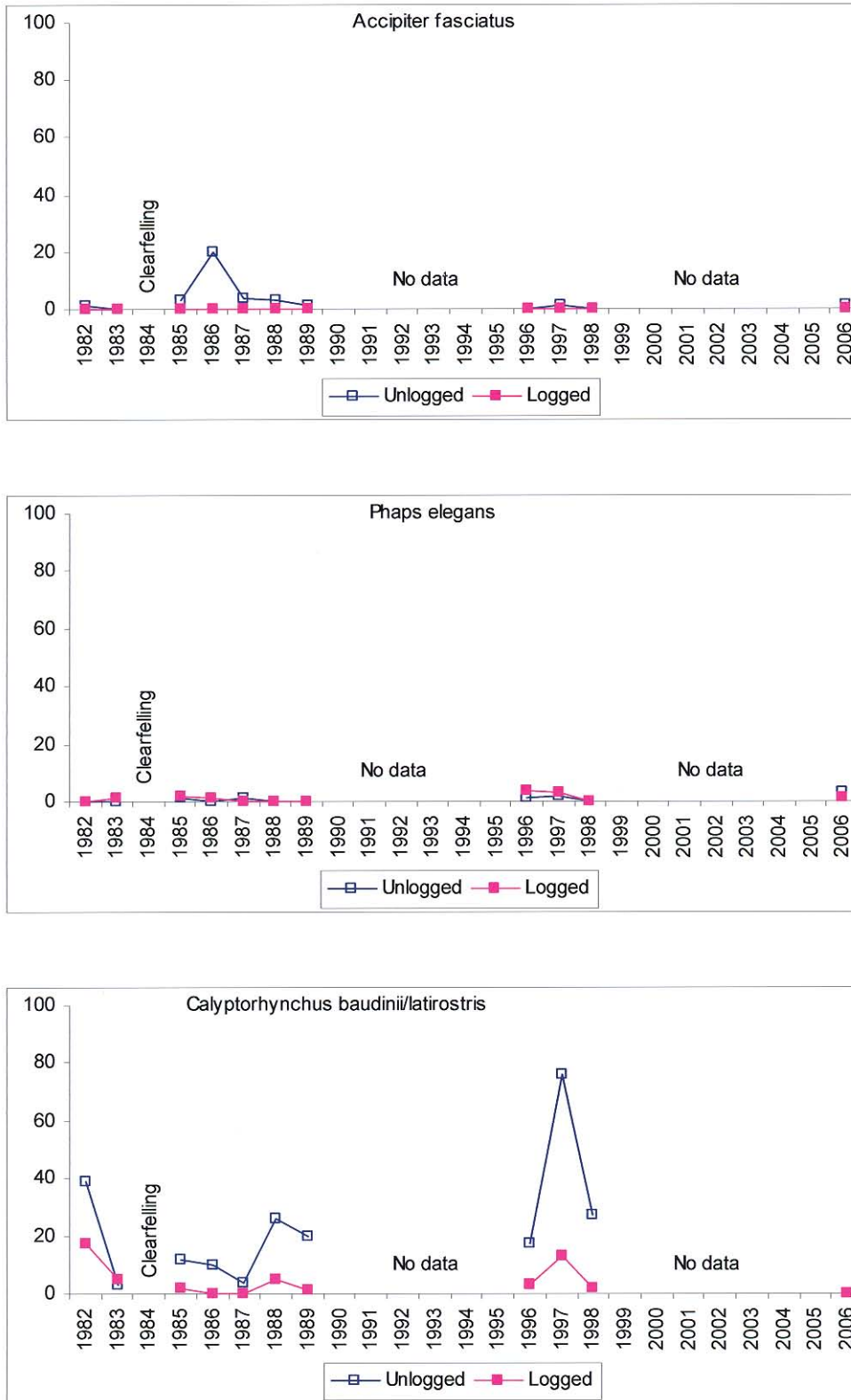


Figure 3. Abundance of each bird species in logged and unlogged karri forest, 1982–2006. Note variation in scale of Y-axis.



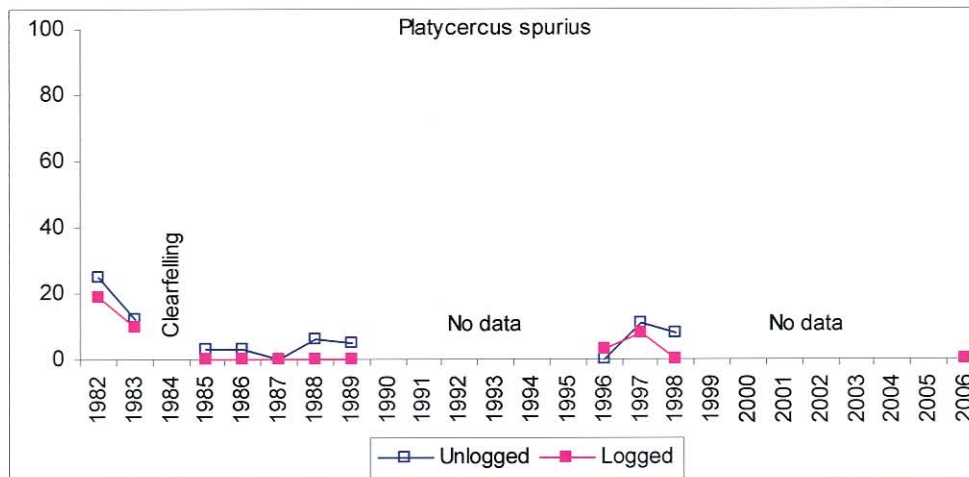
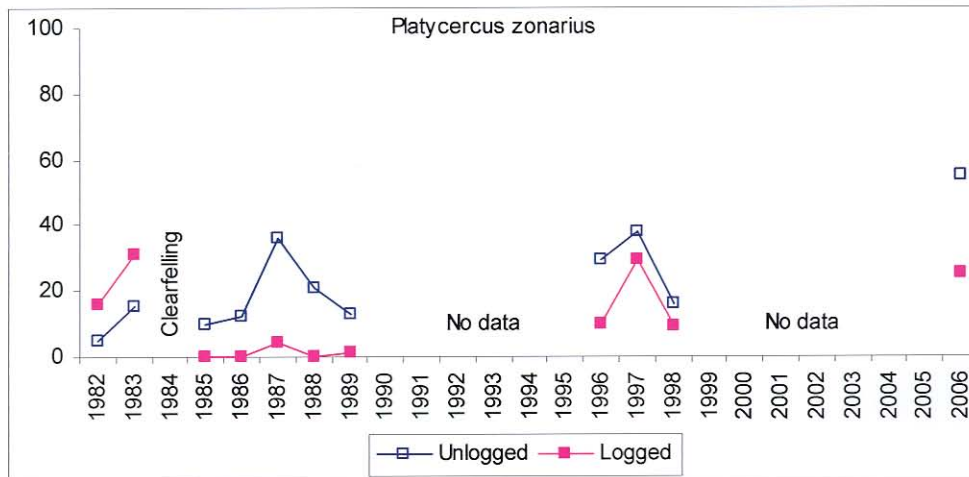
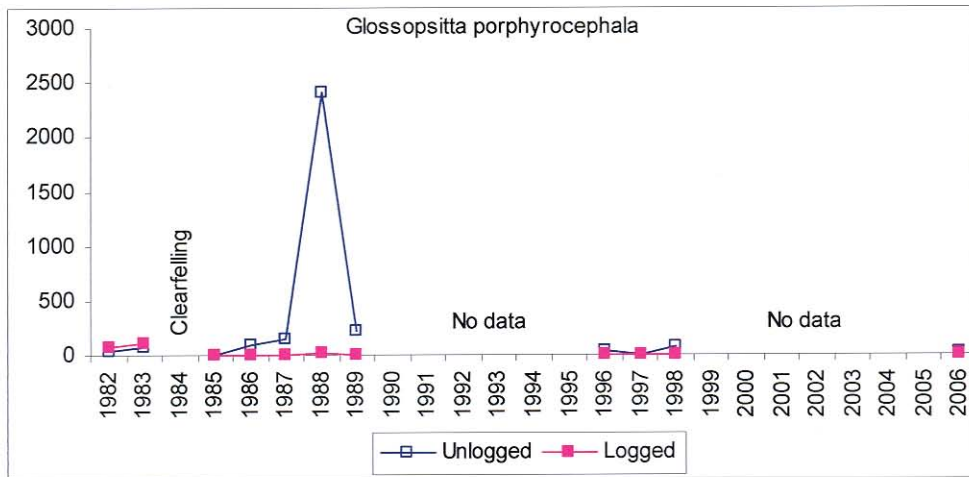


Figure 3. (cont.)

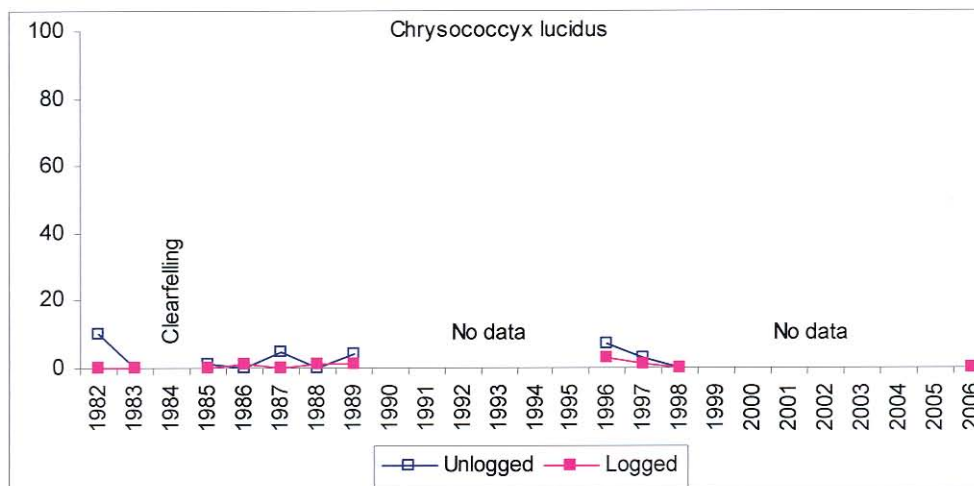
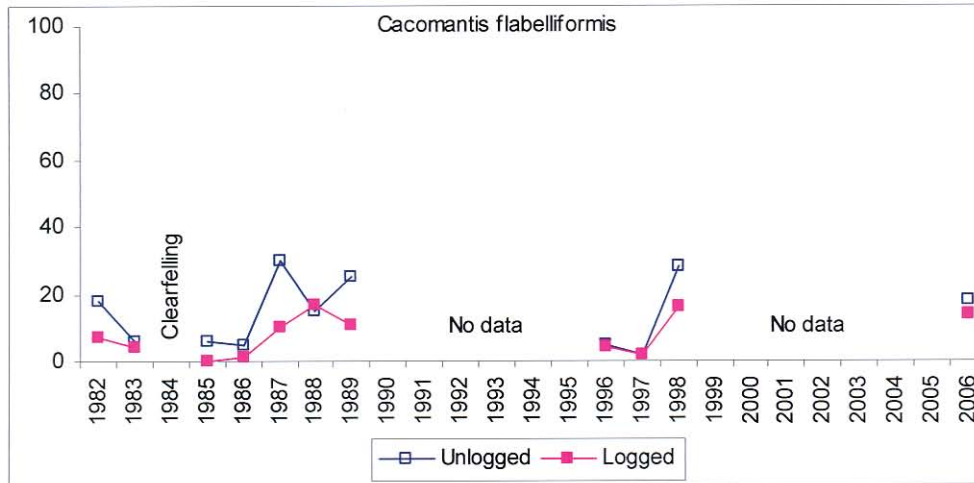
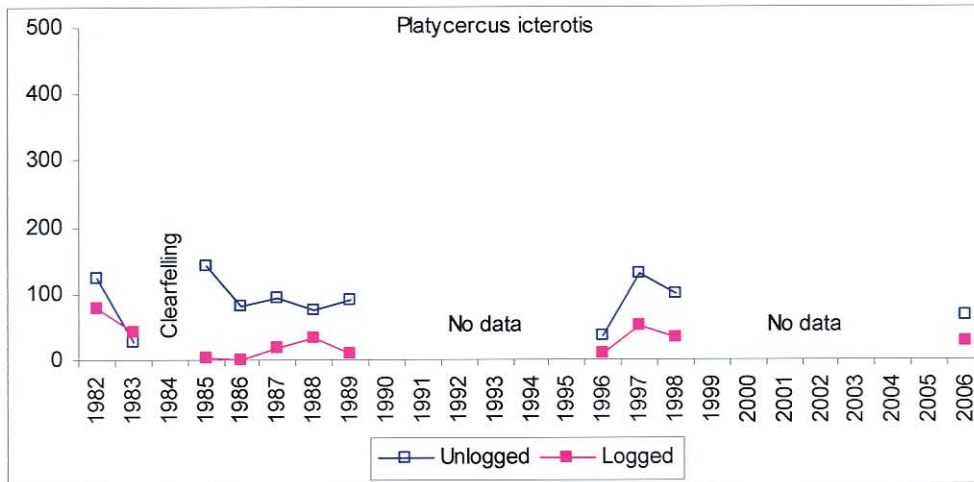


Figure 3. (cont.)

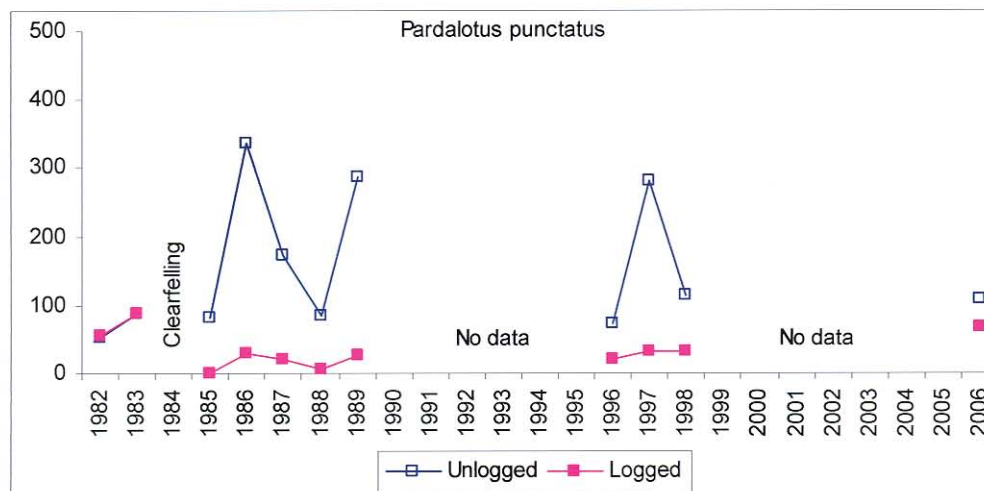
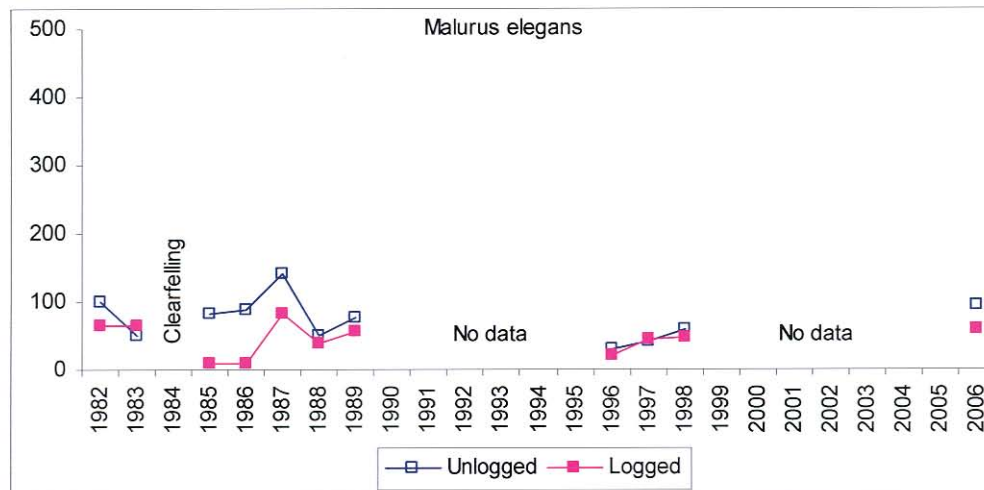
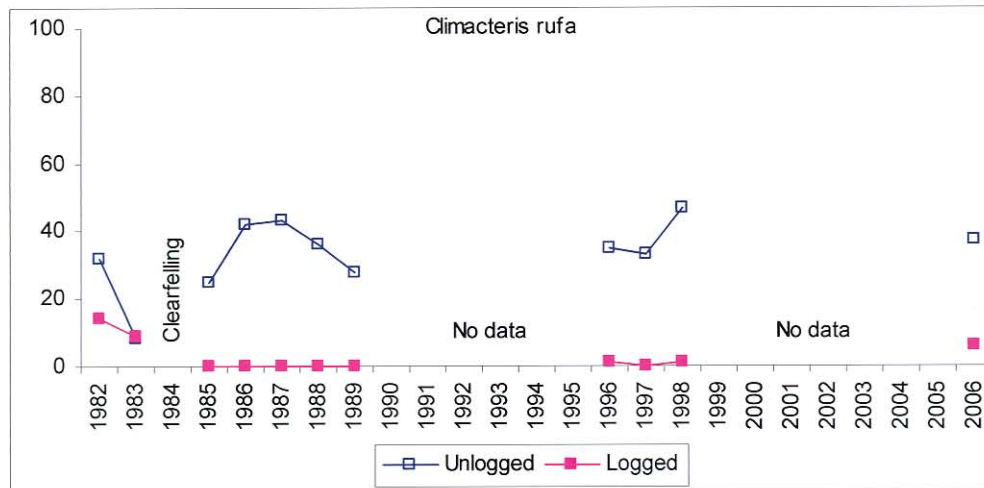


Figure 3. (cont.)

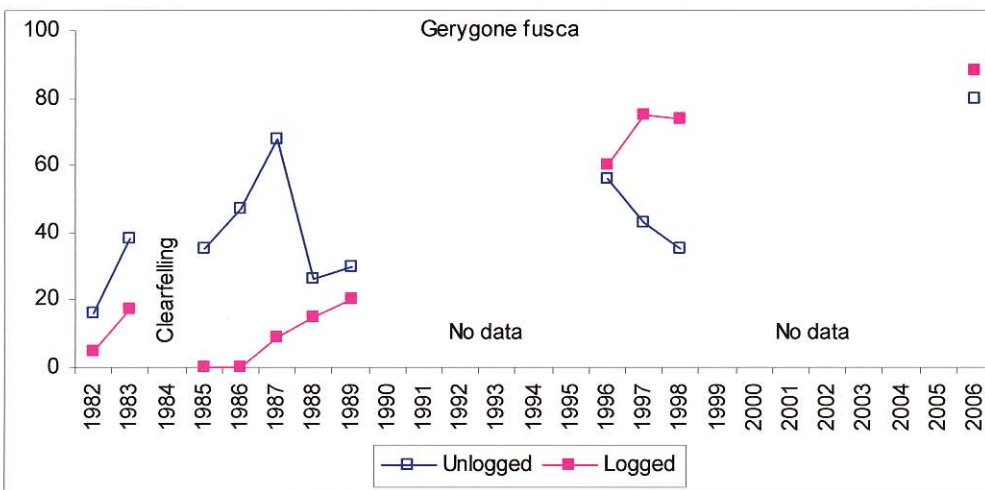
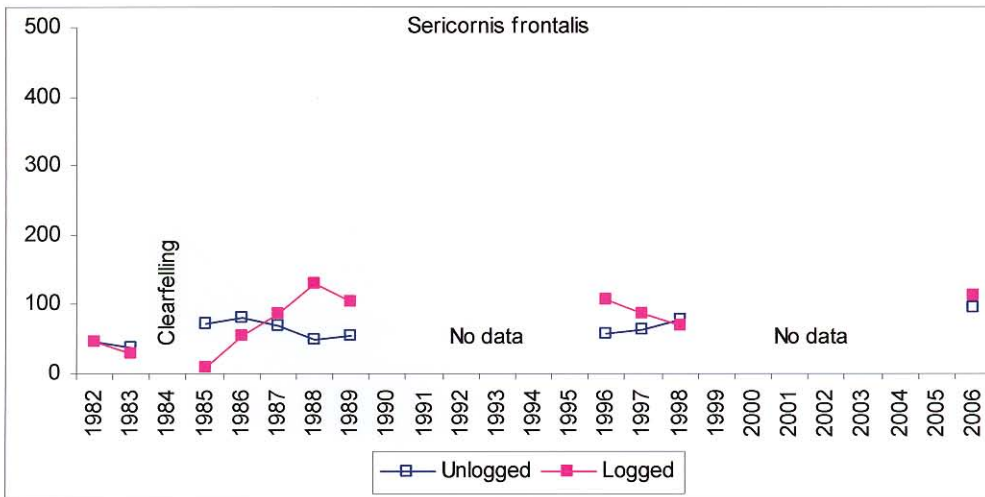
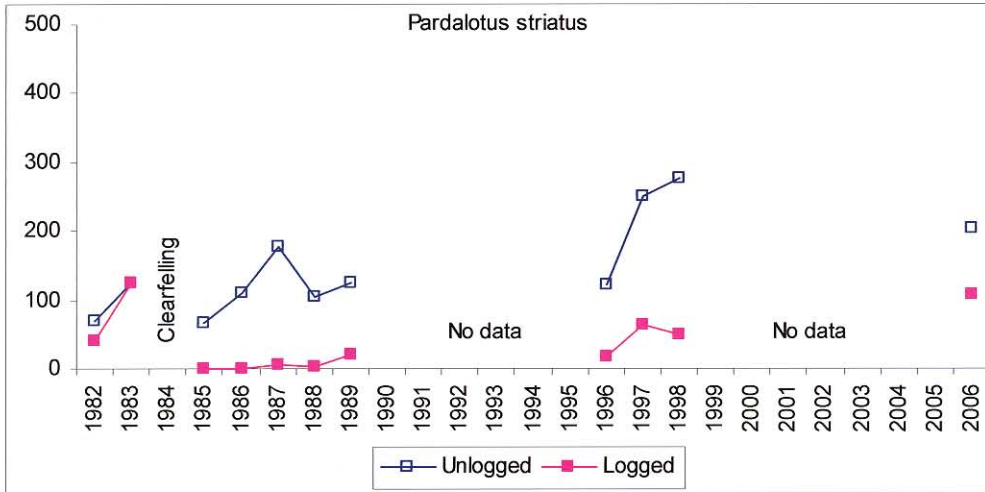


Figure 3. (cont.)



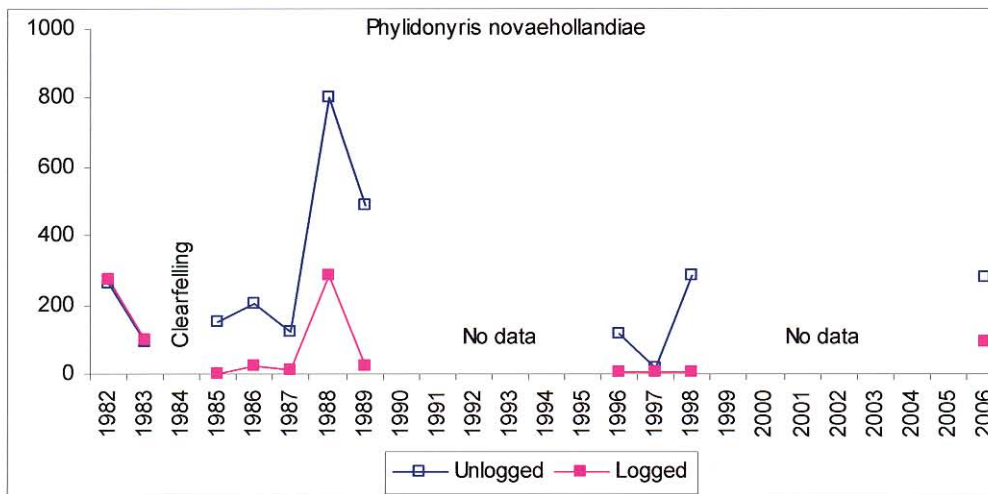
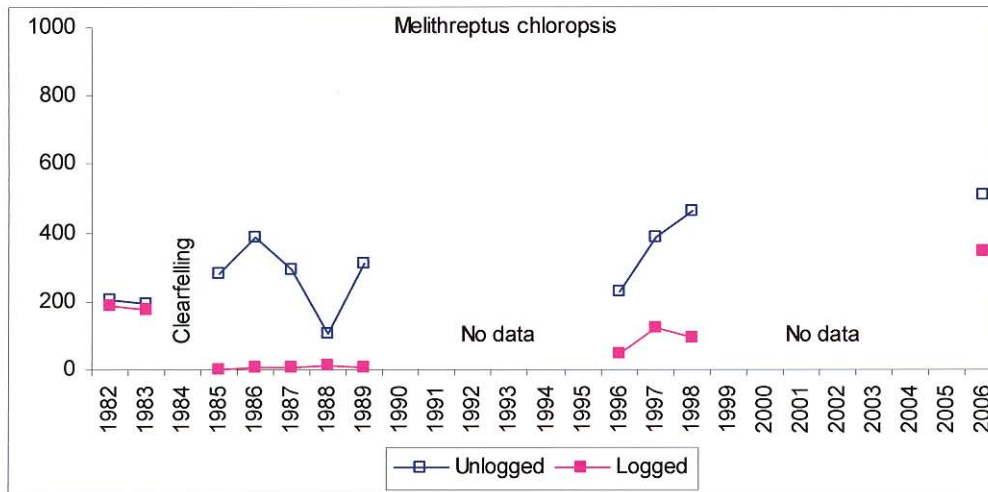
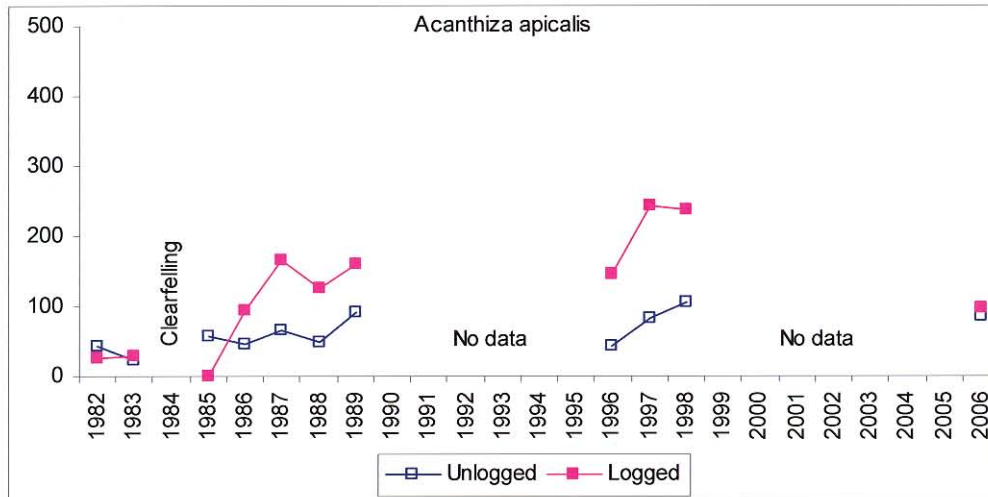


Figure 3. (cont.)

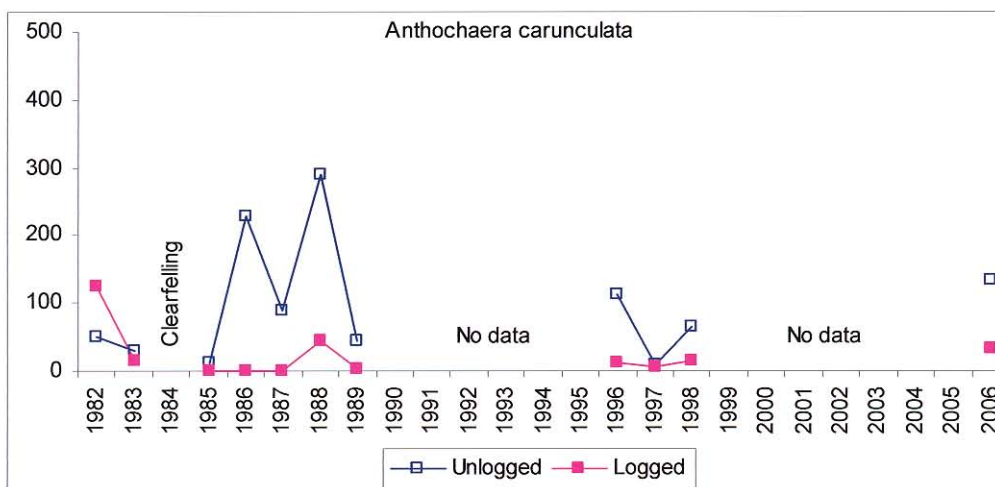
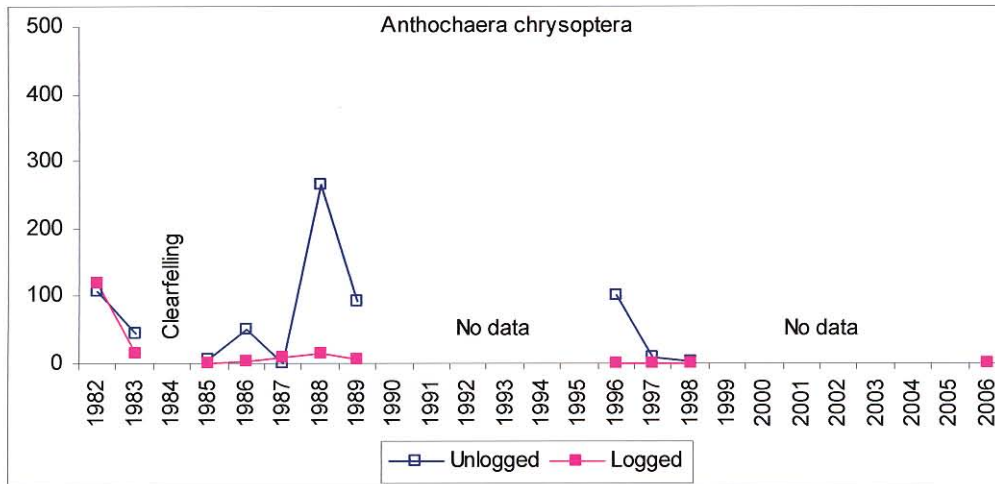
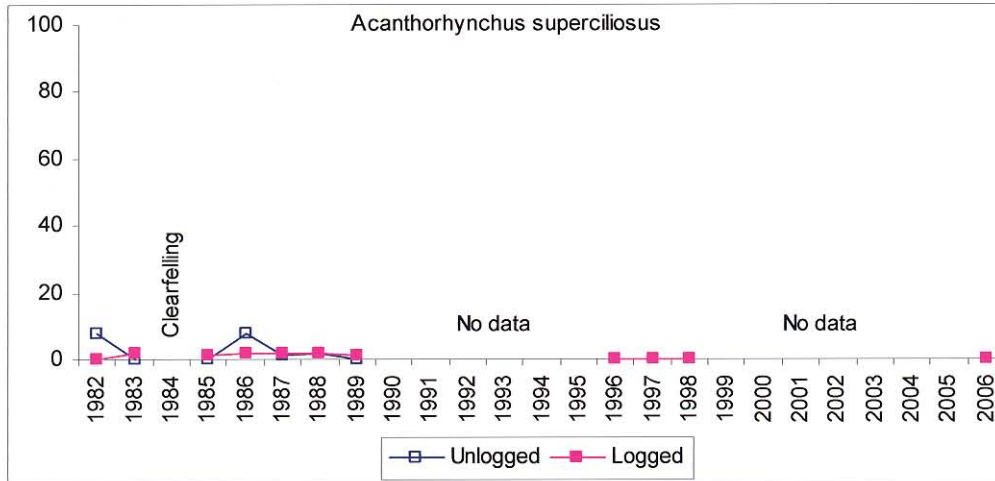


Figure 3. (cont.)

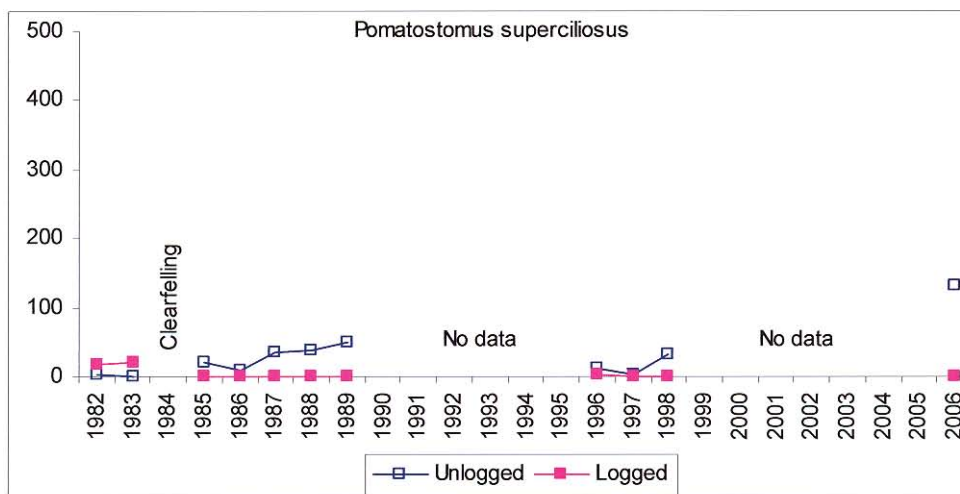
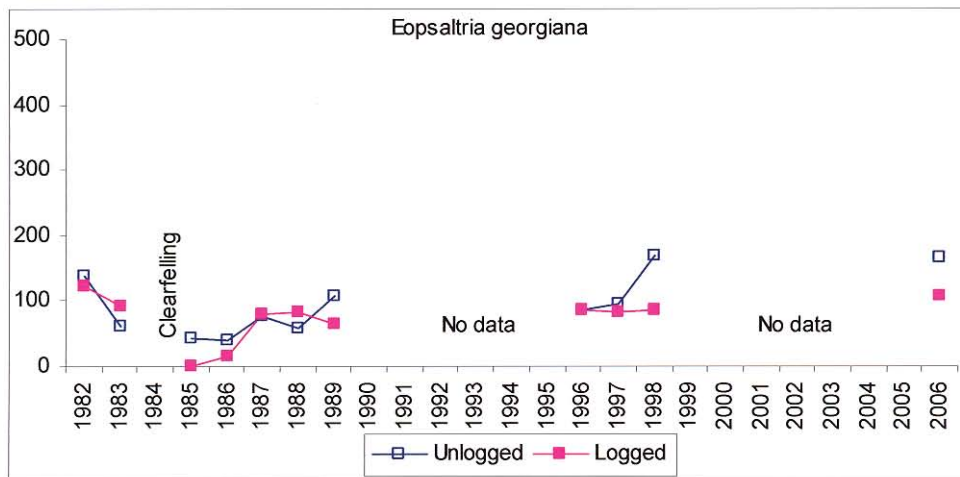
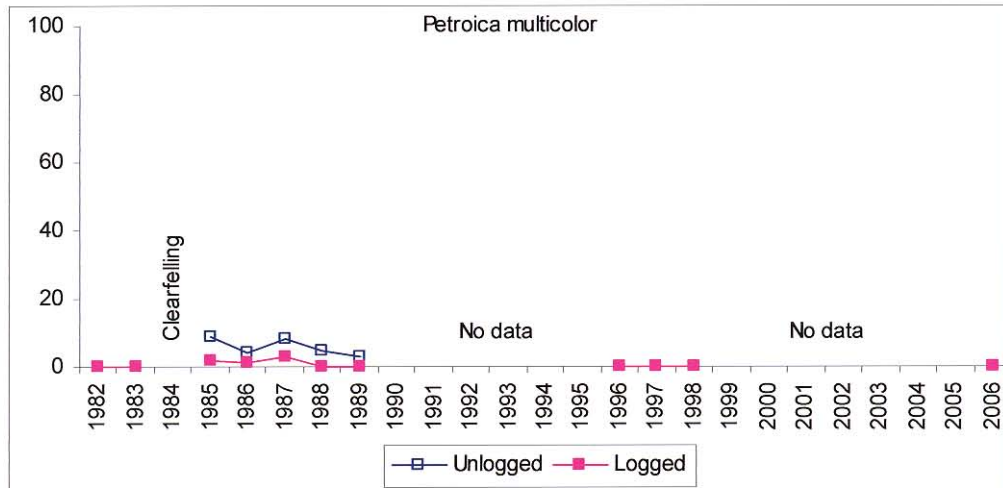


Figure 3. (cont.)

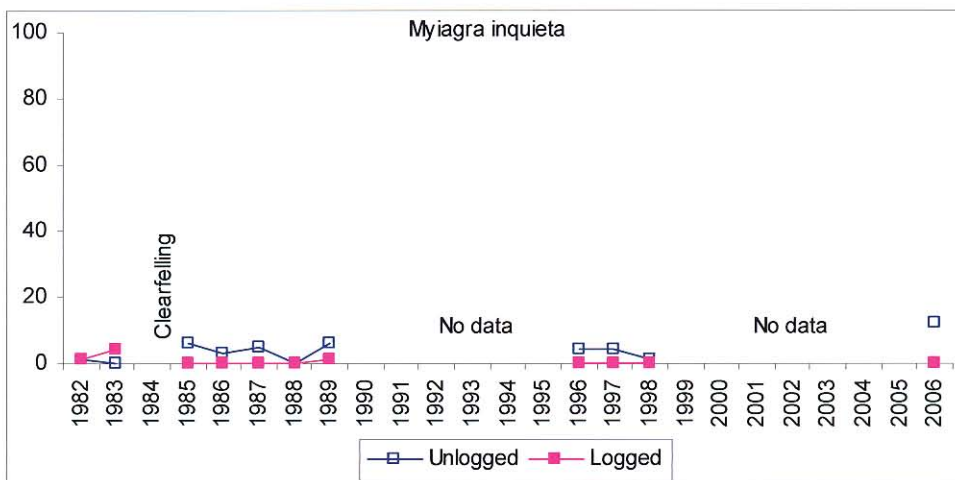
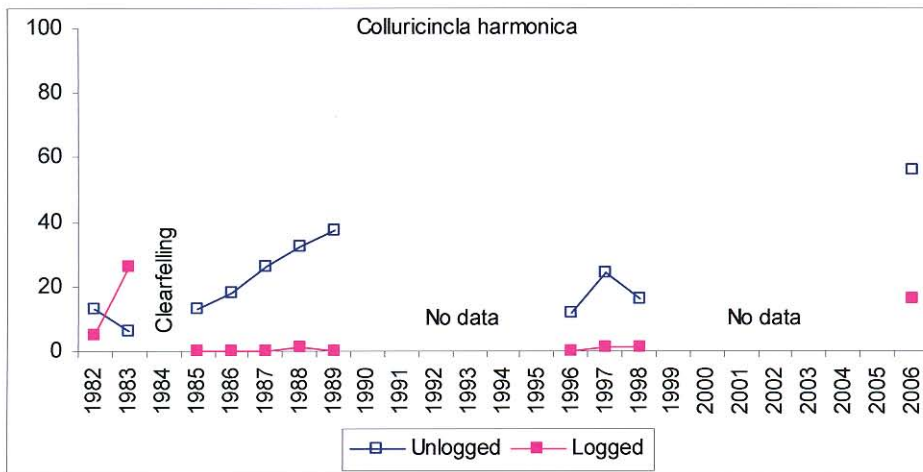
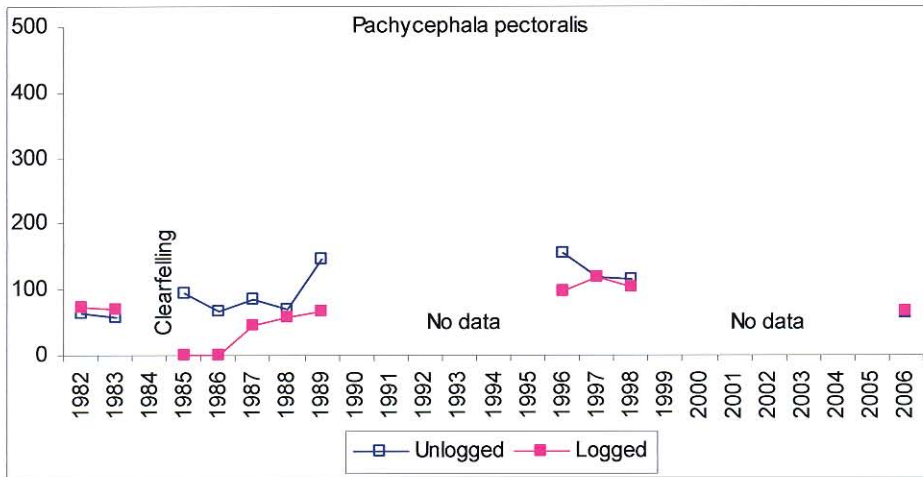


Figure 3. (cont.)



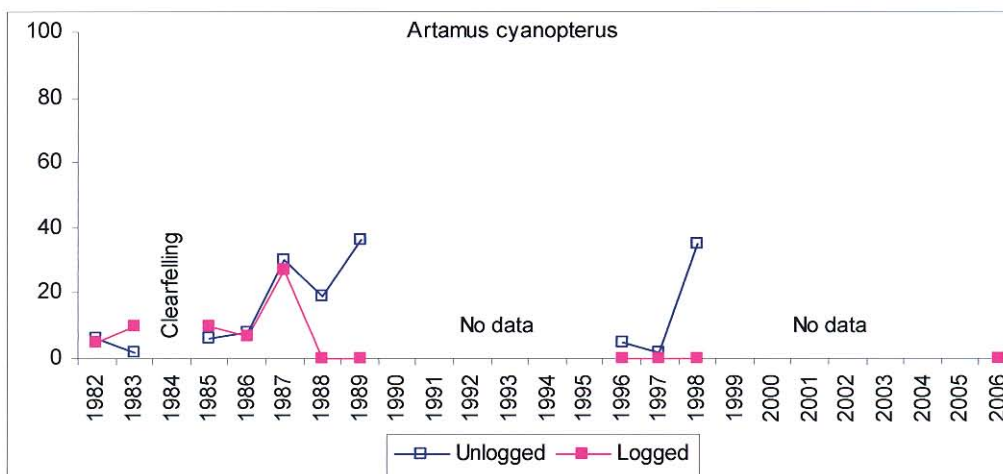
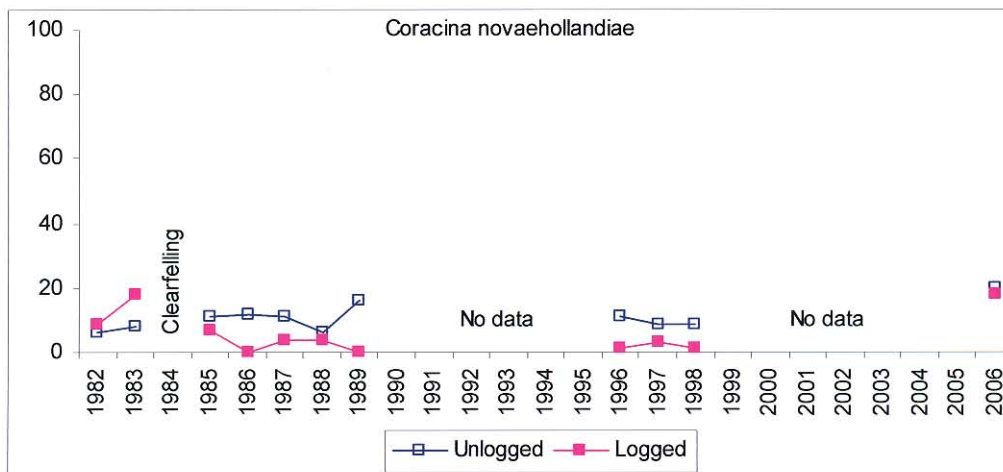
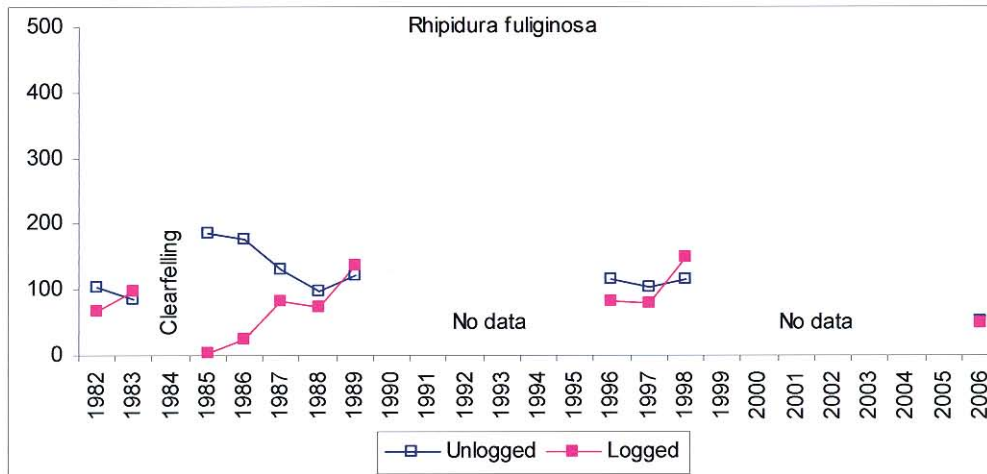


Figure 3. (cont.)

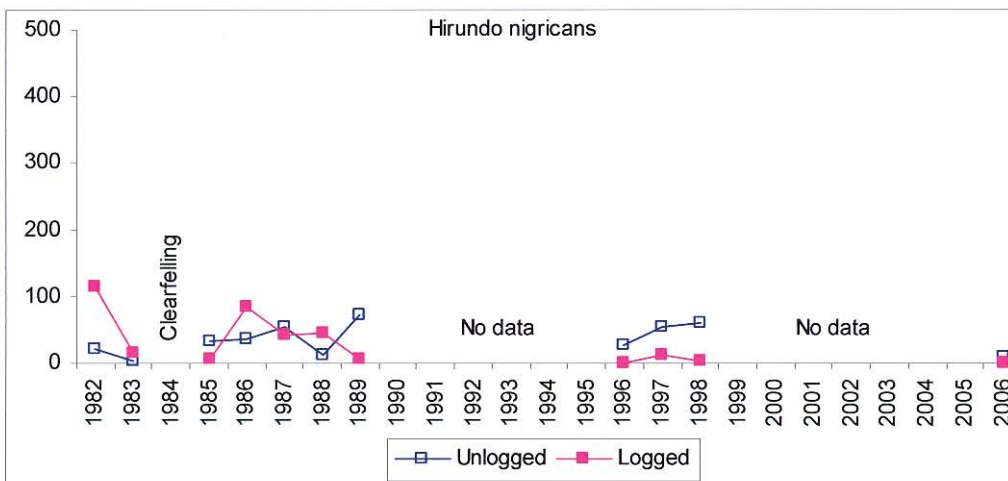
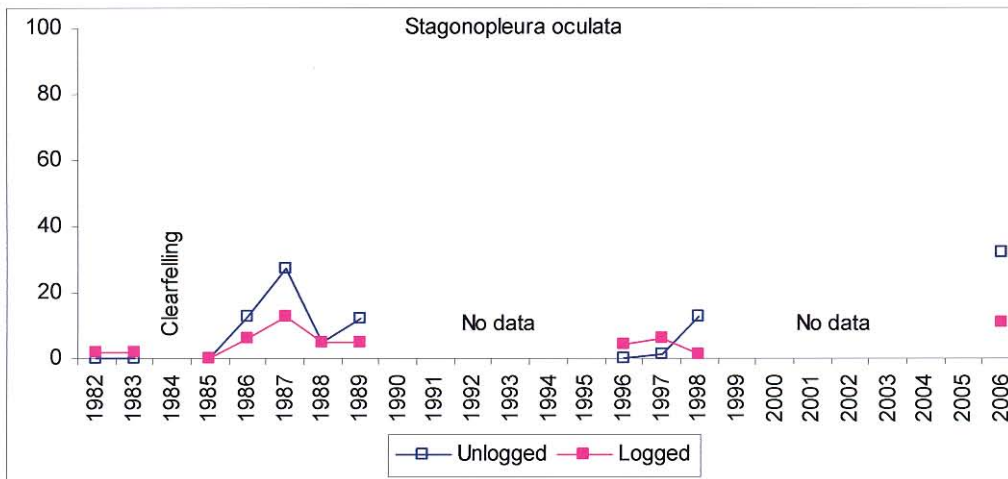
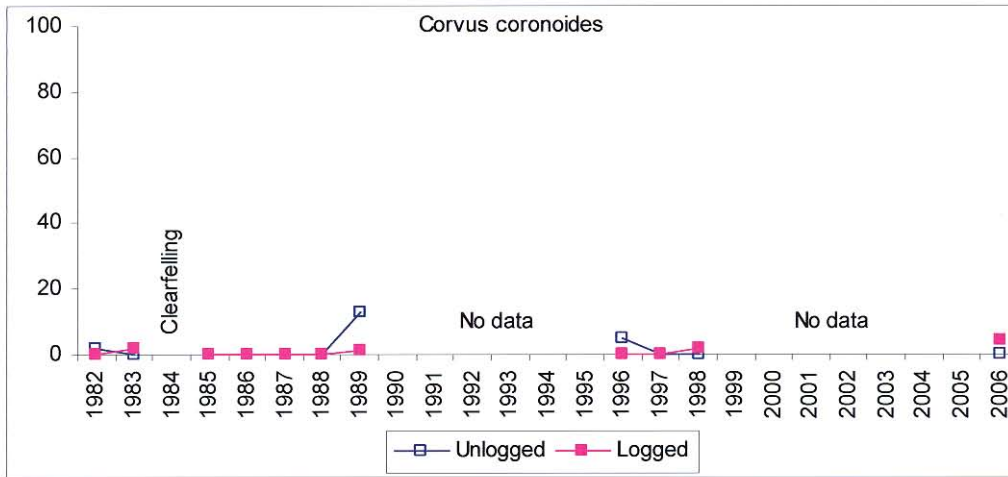
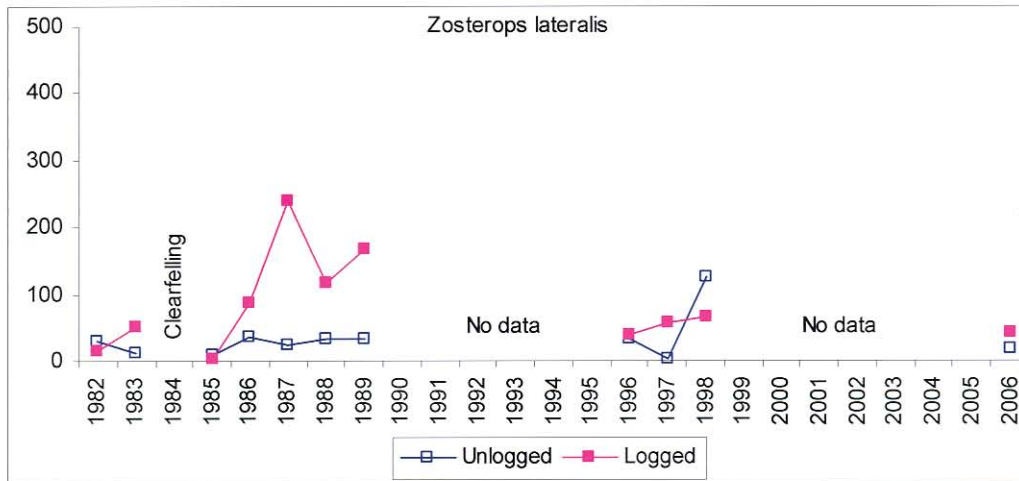


Figure 3. (cont.)



Non-core species

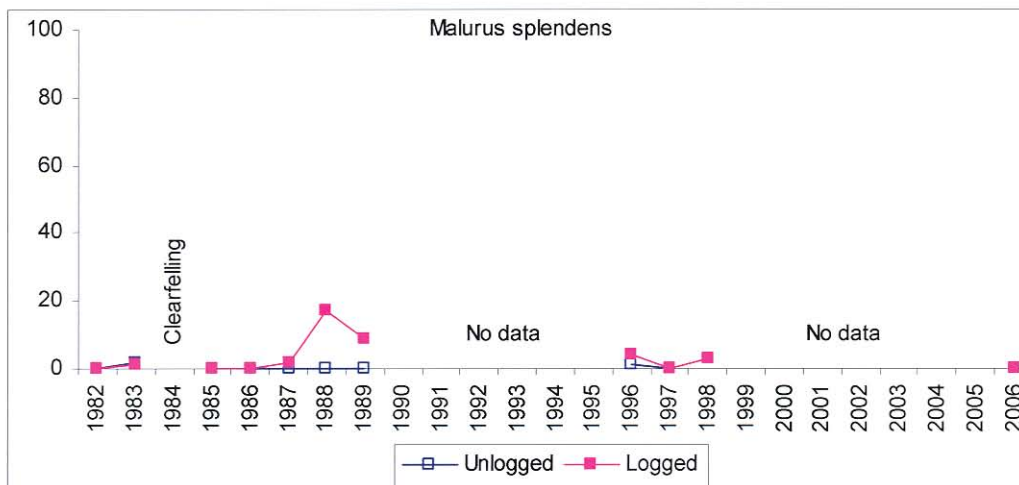
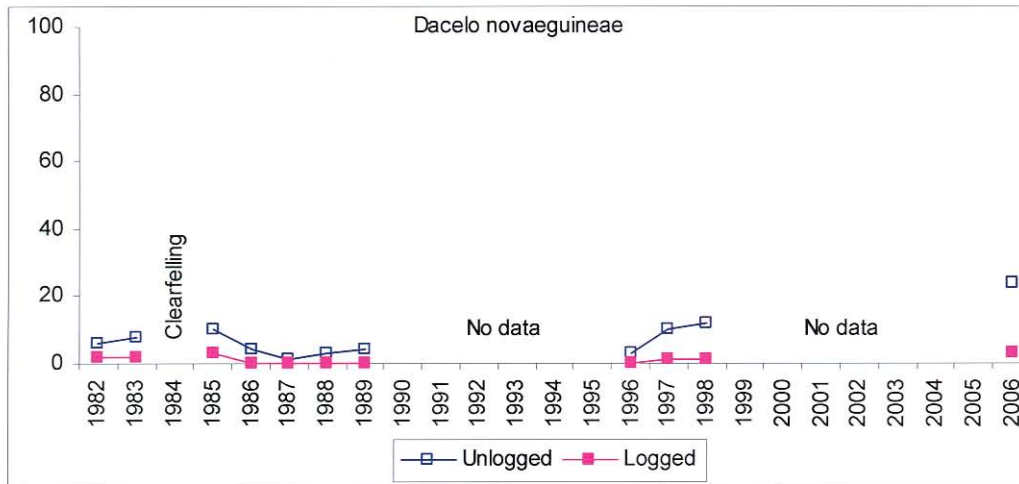


Figure 3. (cont.)

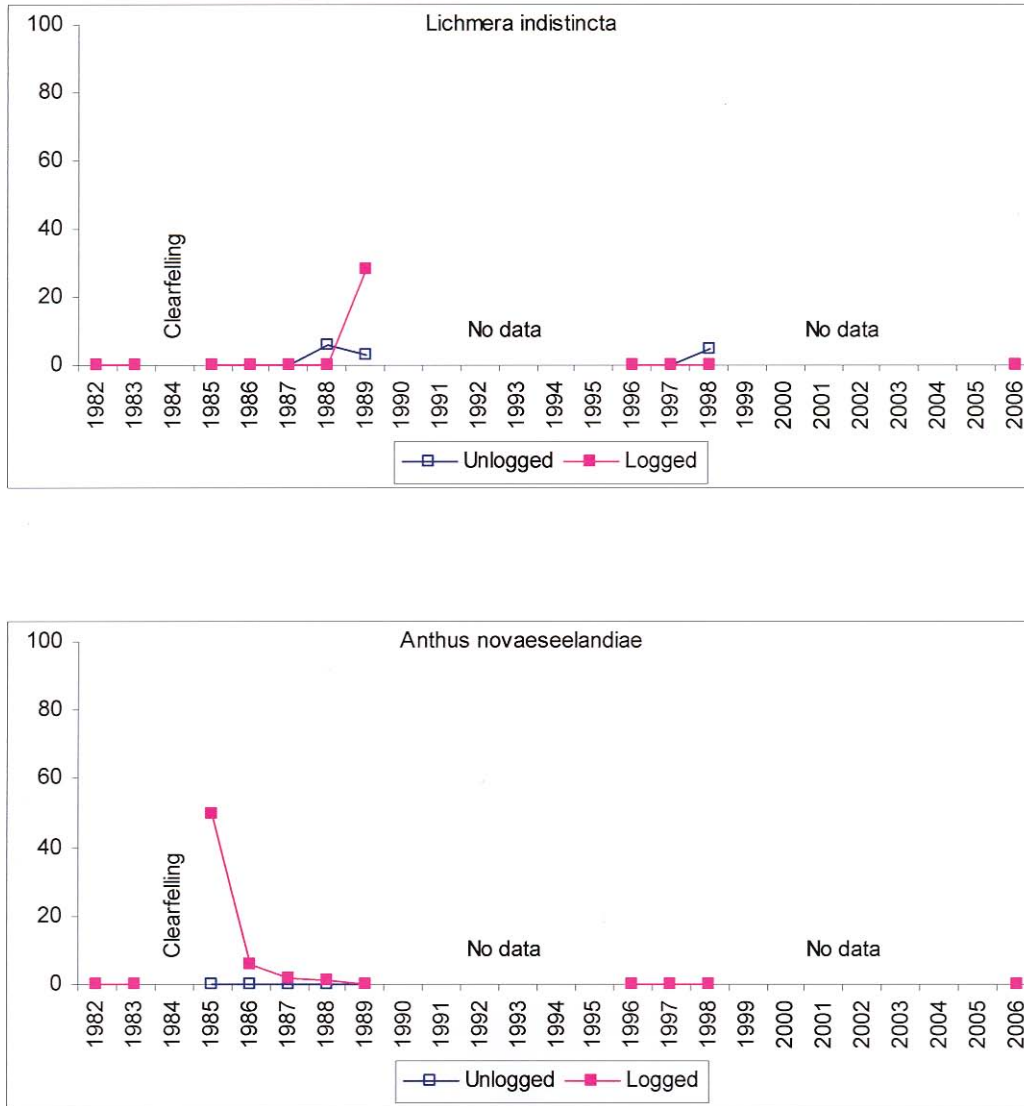
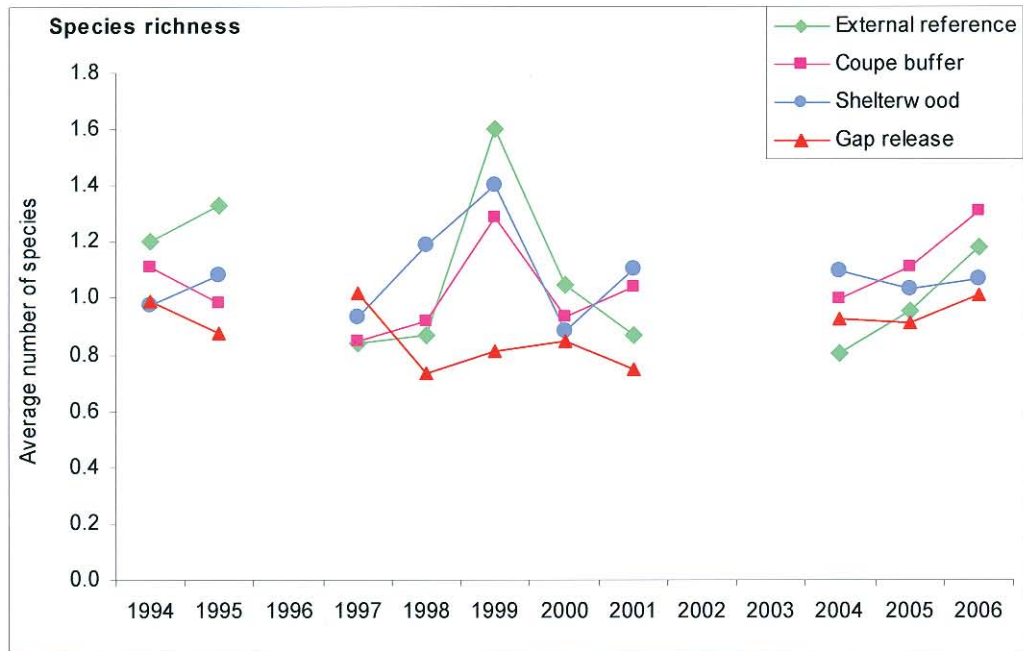


Figure 3. (cont.)



(a)



(b)

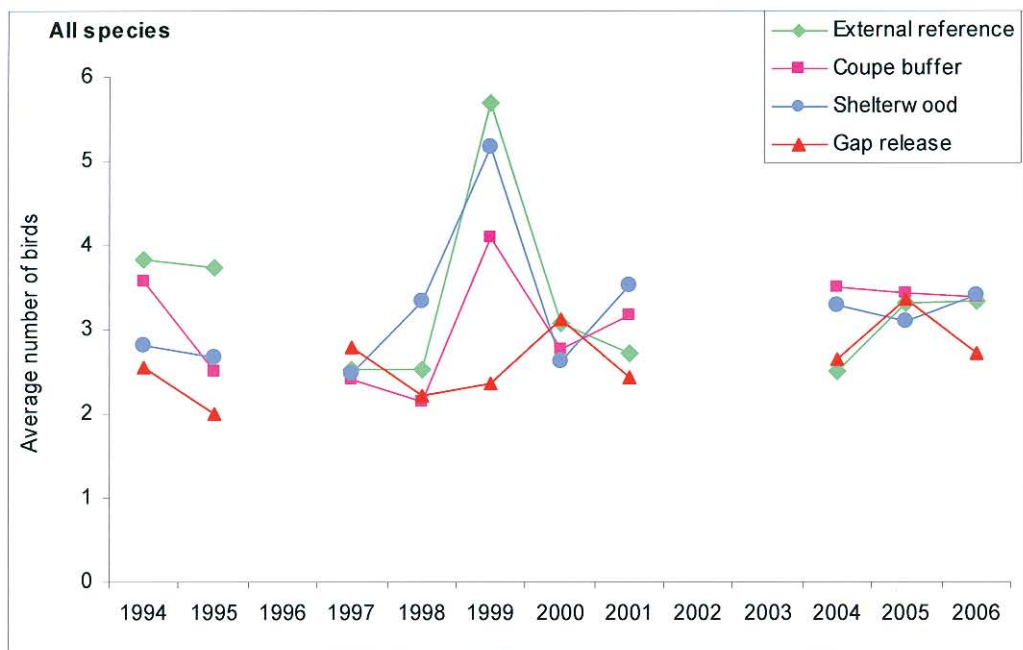


Figure 4. Average number of bird species (a) and the average number (all species) recorded each year for the four treatment categories in jarrah forest.

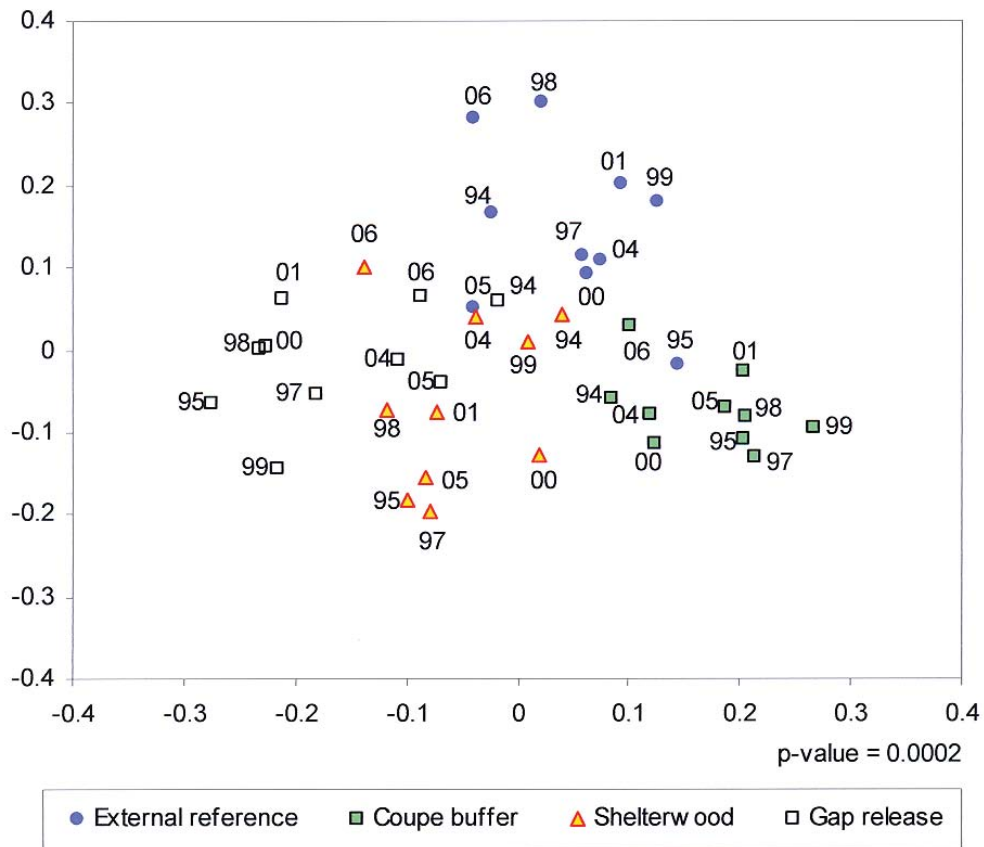


Figure 5. Temporal changes in bird community structure in jarrah forest, based on the pattern of species abundances, revealed by canonical analysis of principal co-ordinates.

Core species

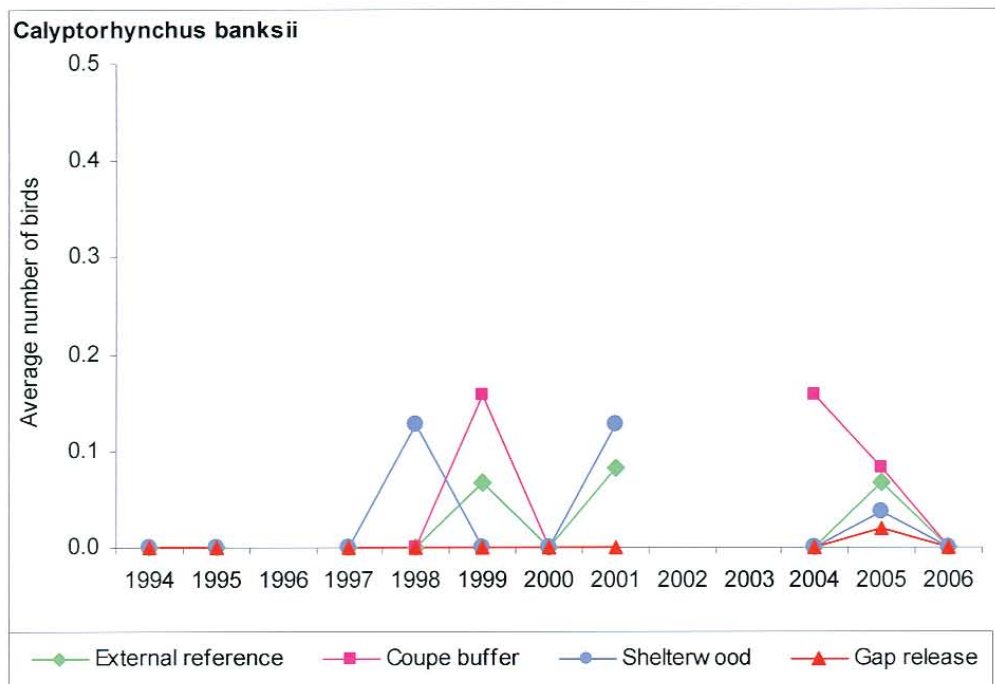
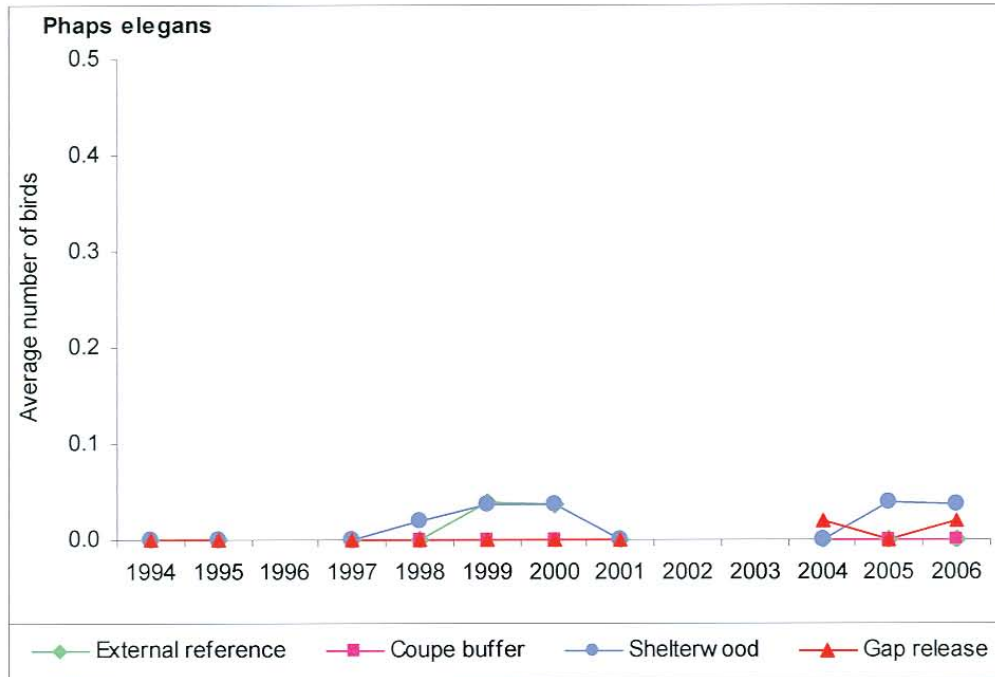


Figure 6. Average abundance of each bird species in logged and unlogged treatments in jarrah forest, 1994–2006. Note variation in scale of Y-axis.

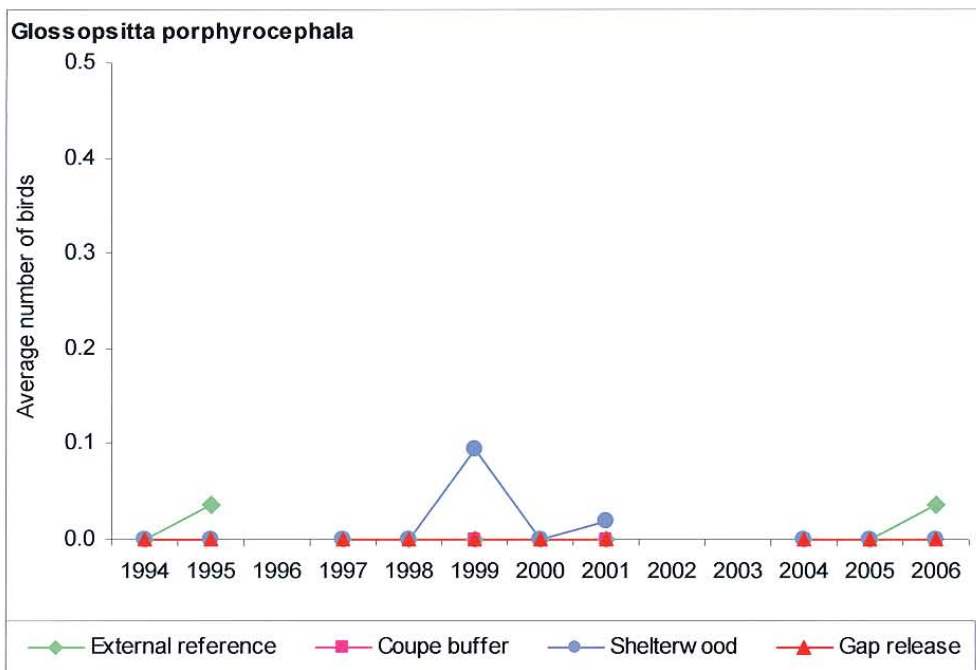
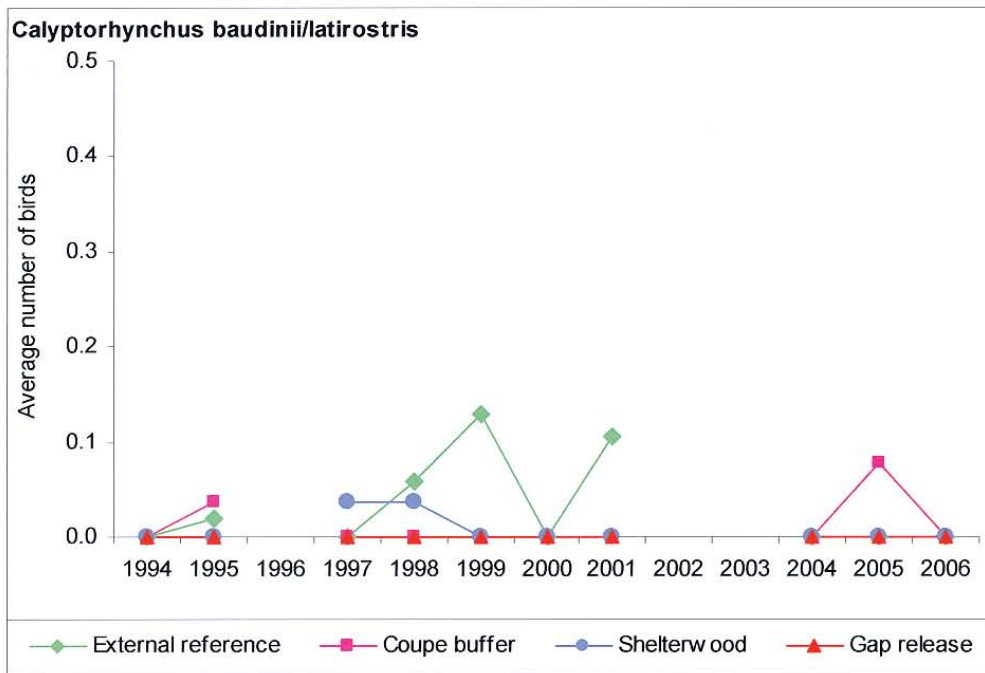


Figure 6. (cont.)

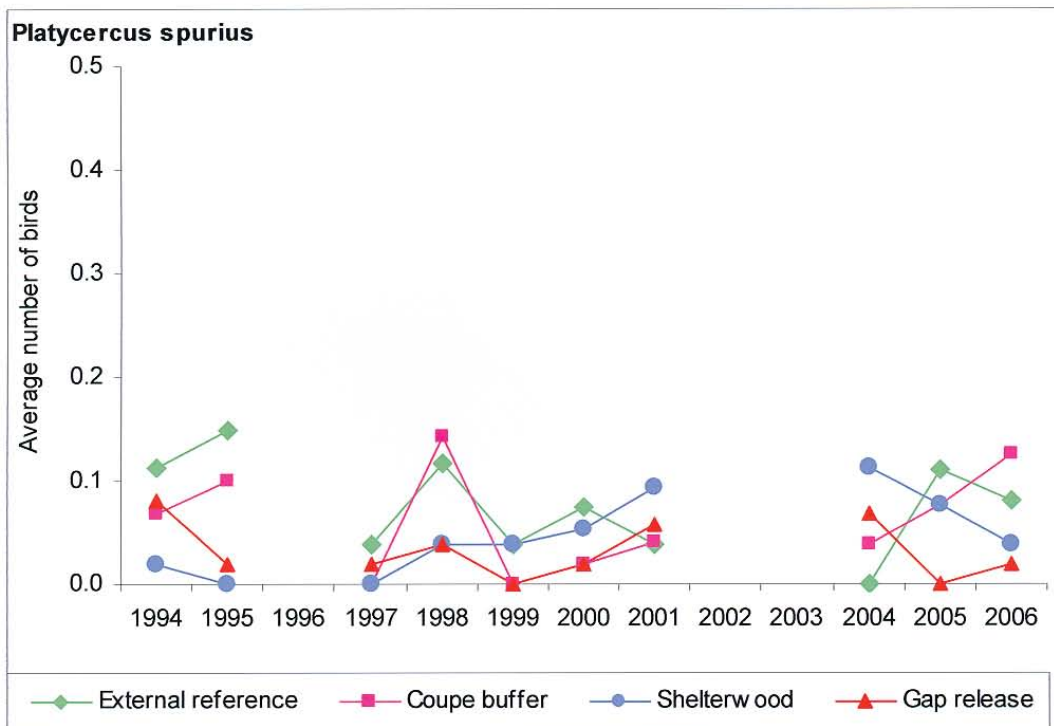
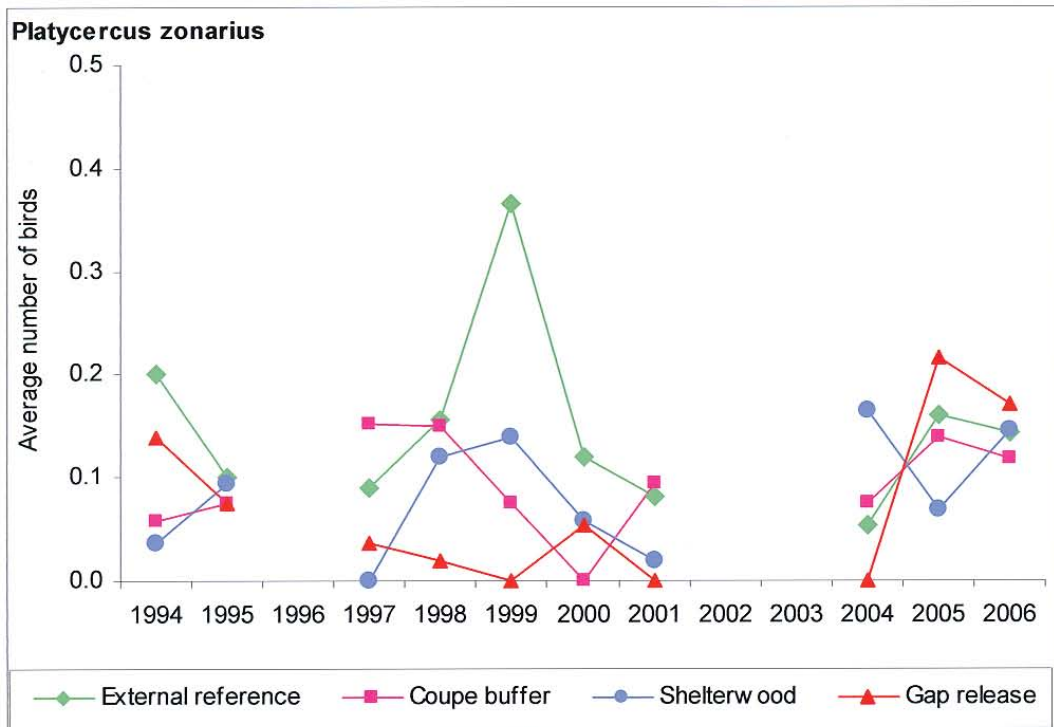


Figure 6. (cont.)



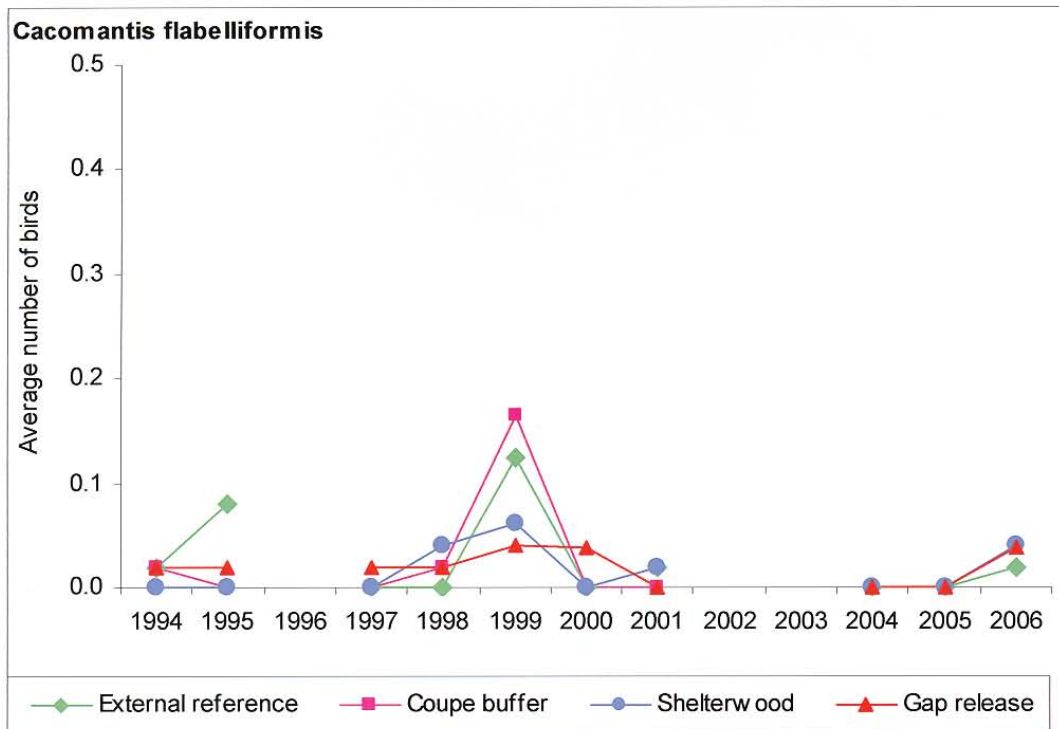
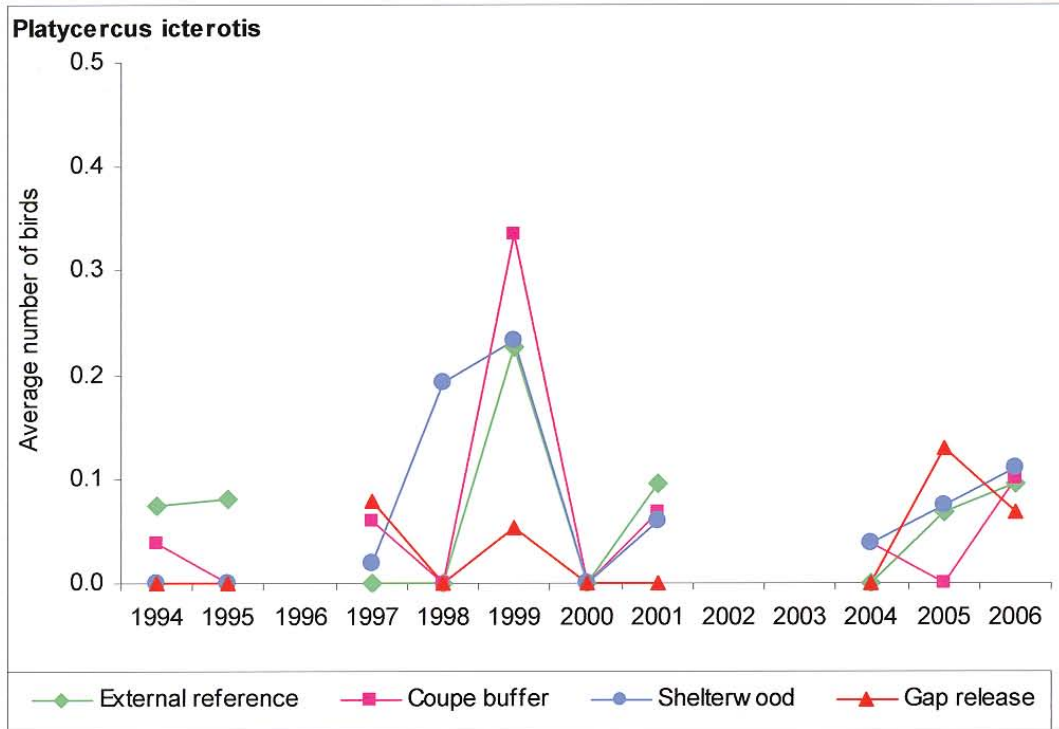


Figure 6. (cont.)

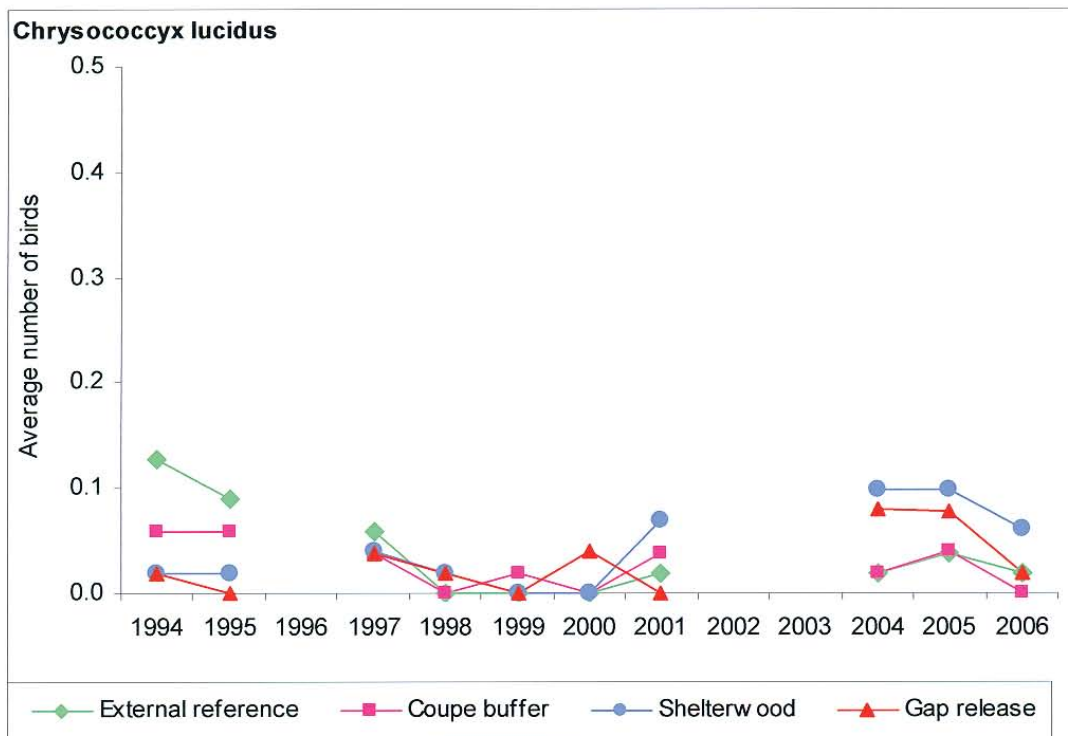
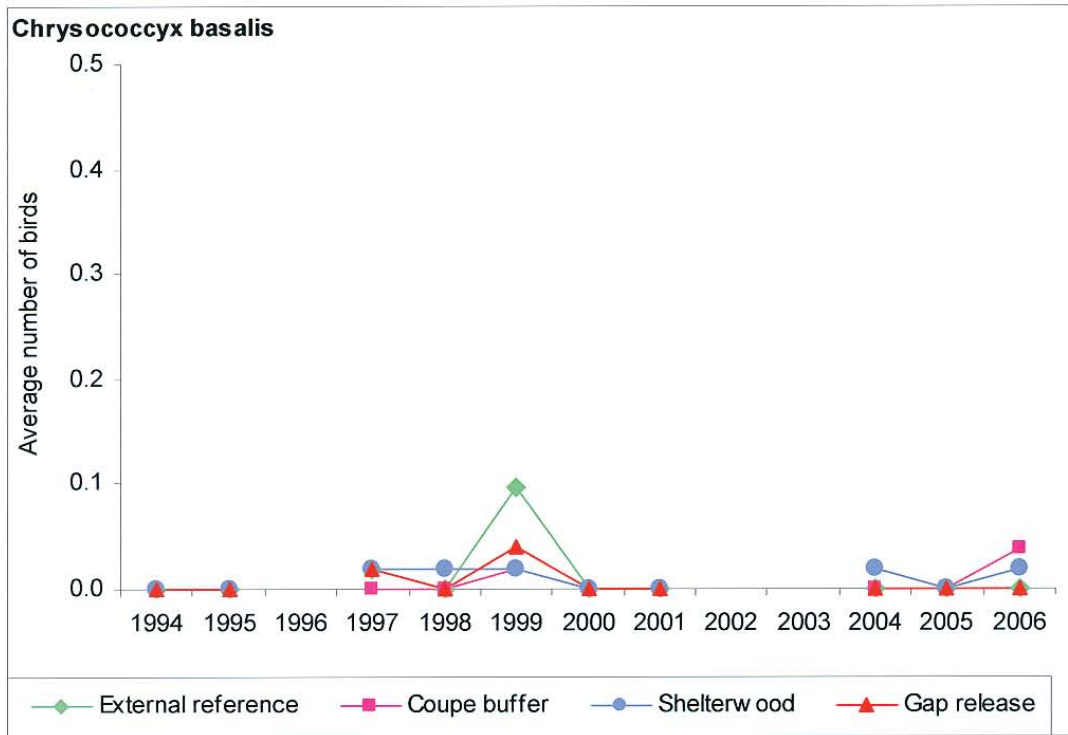


Figure 6. (cont.)

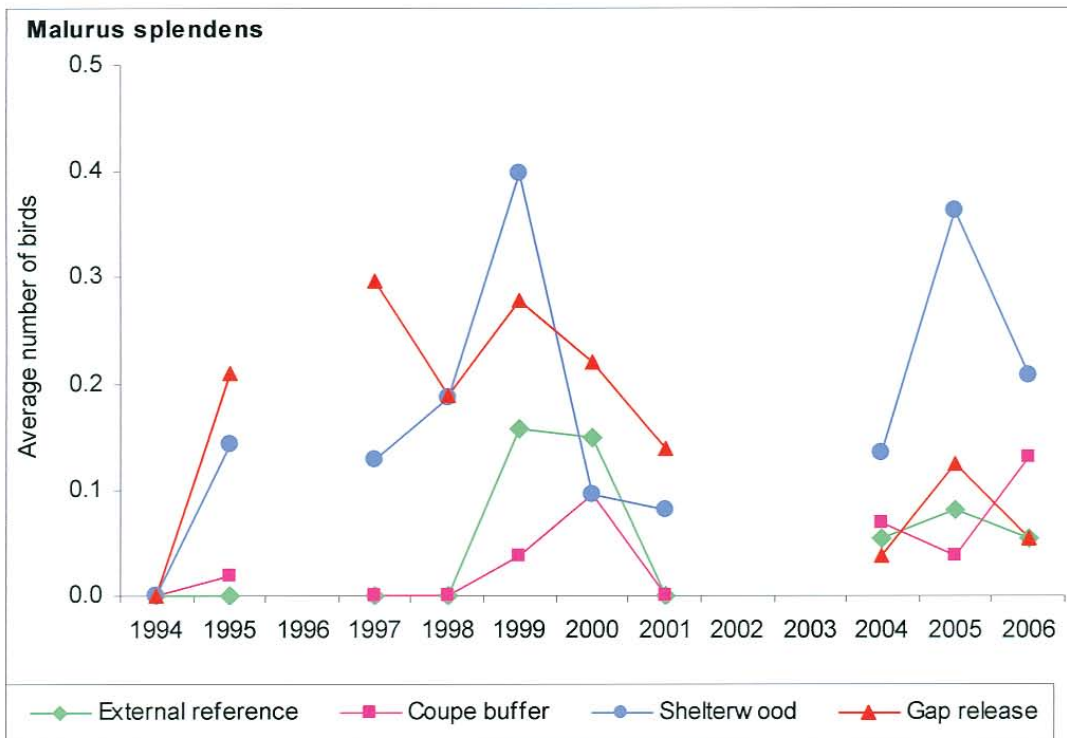
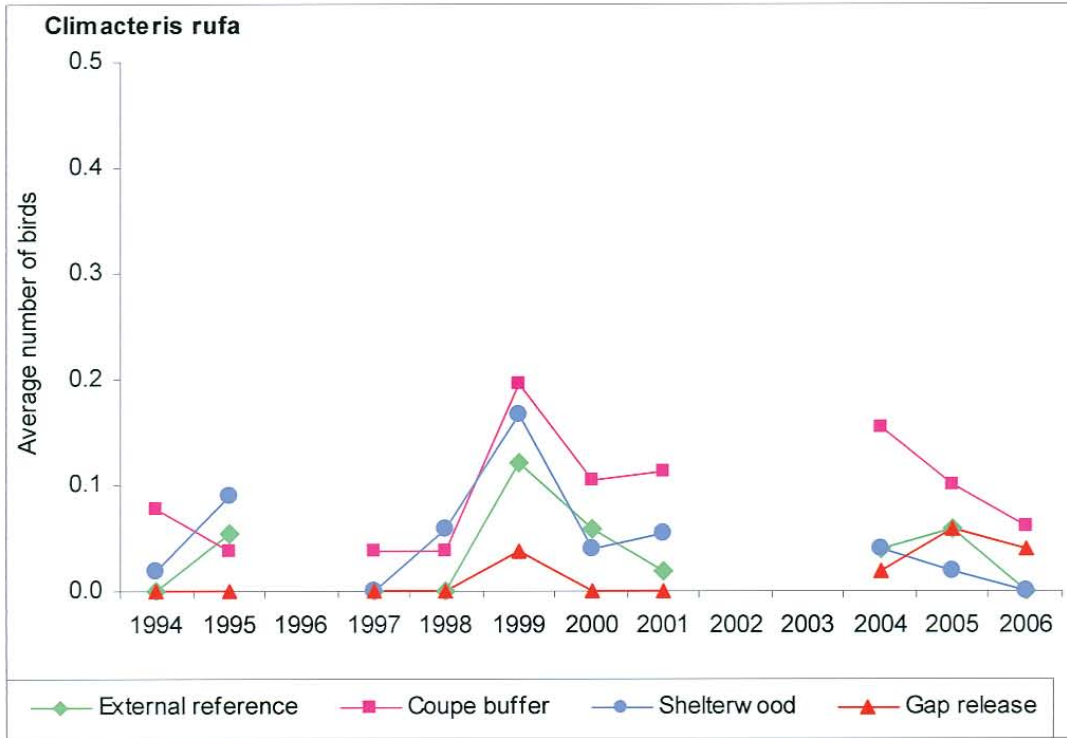


Figure 6. (cont.)

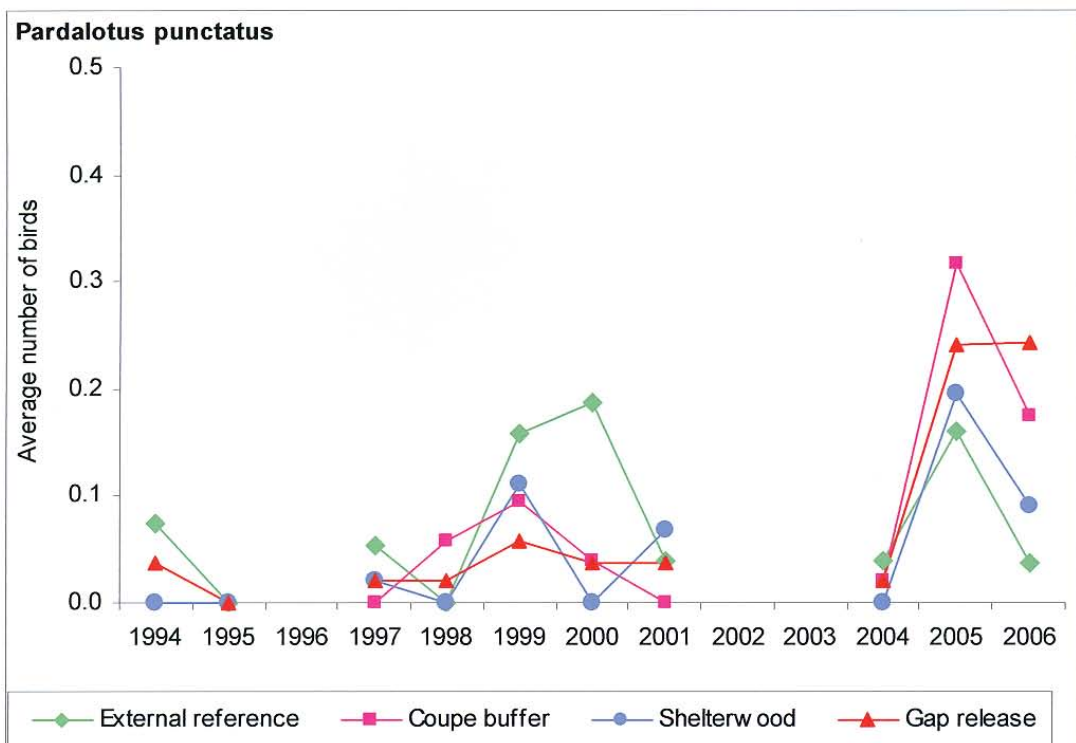
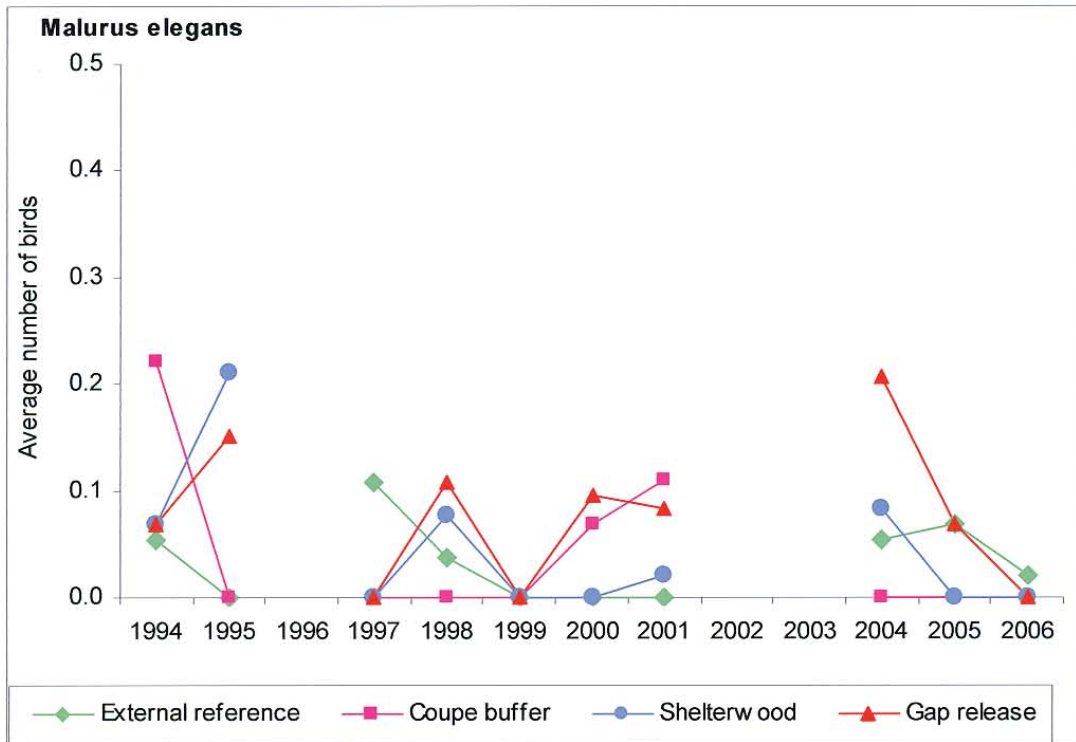


Figure 6. (cont.)

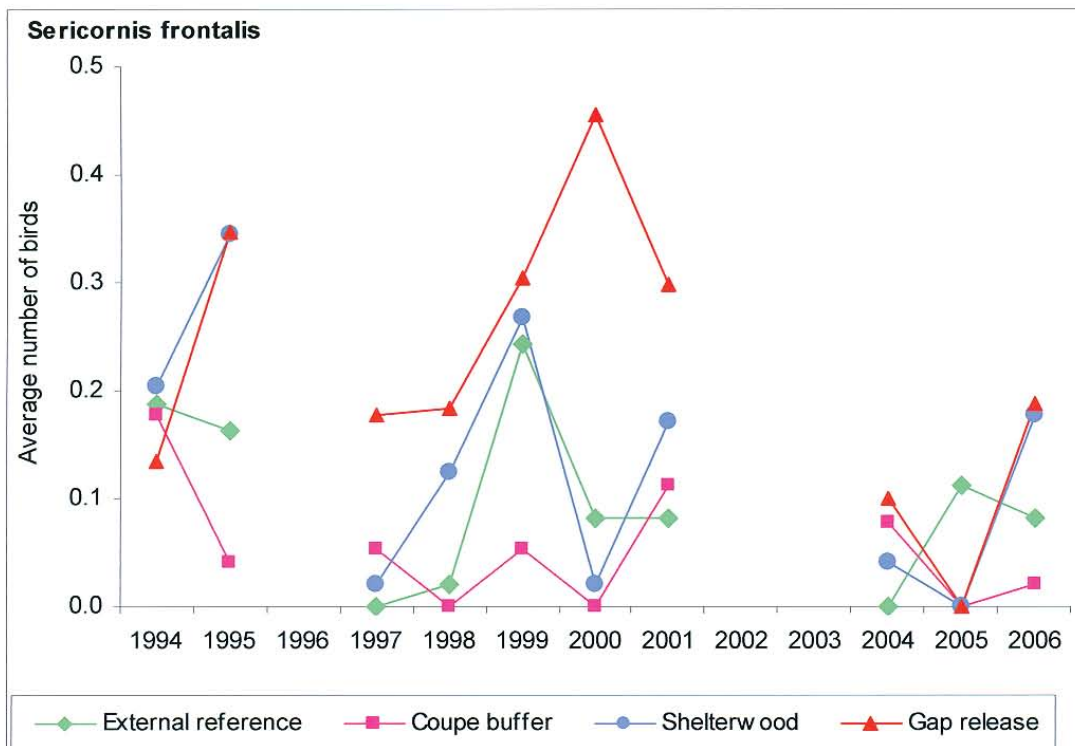
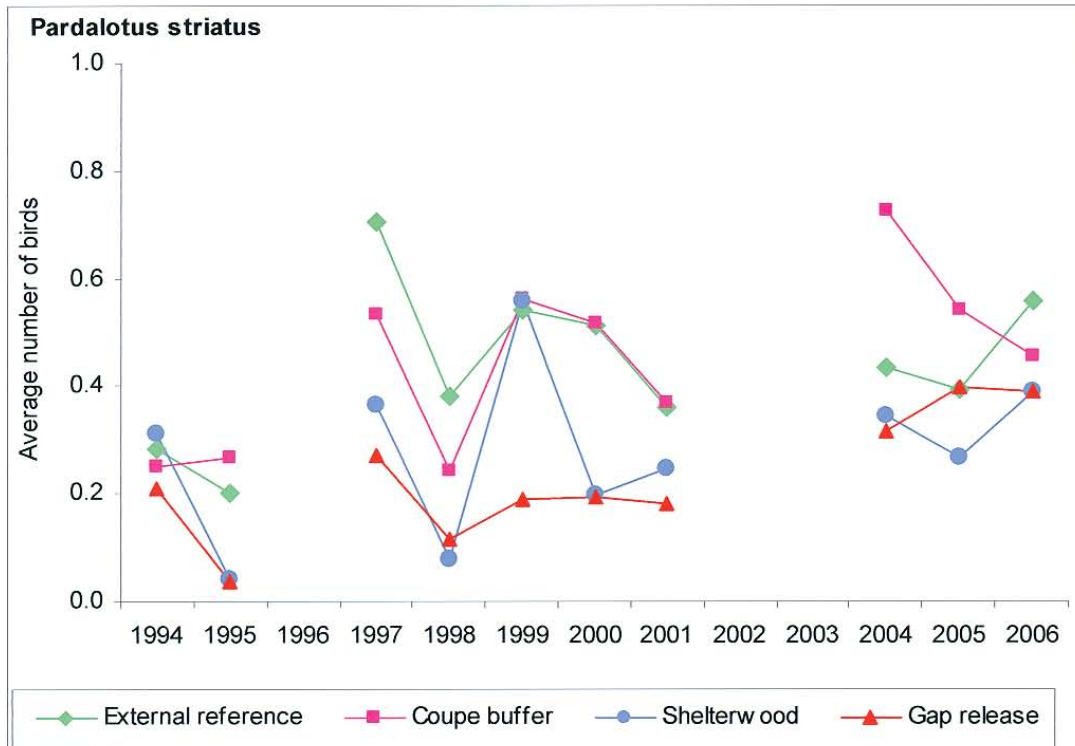


Figure 6. (cont.)



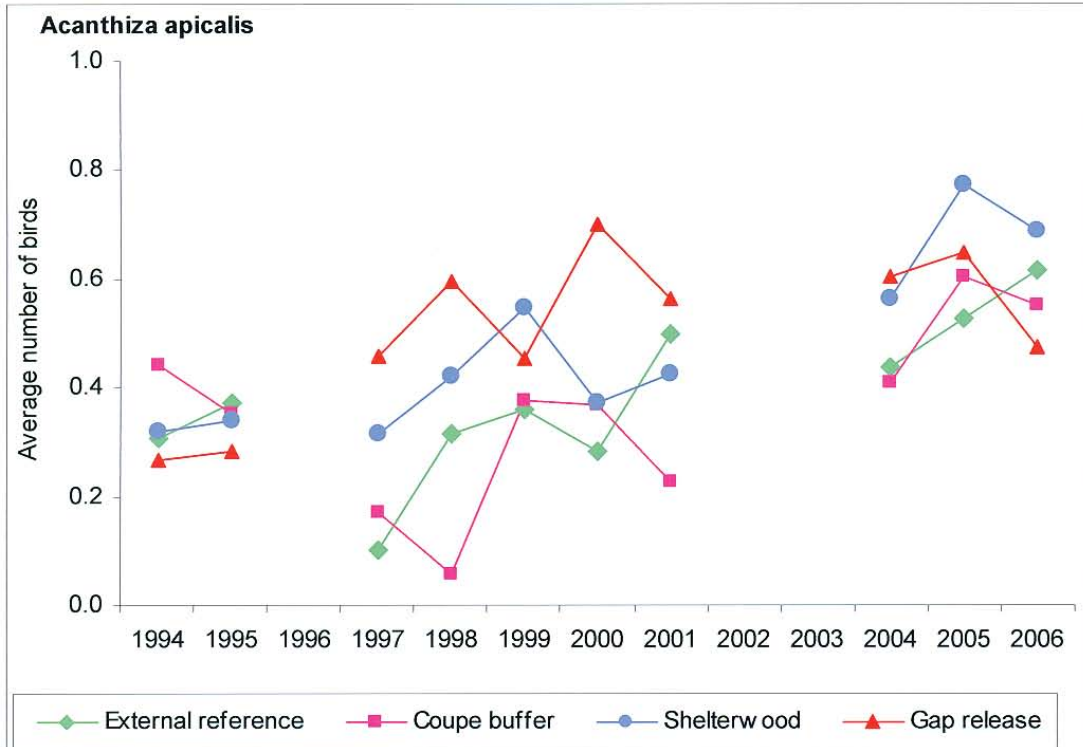
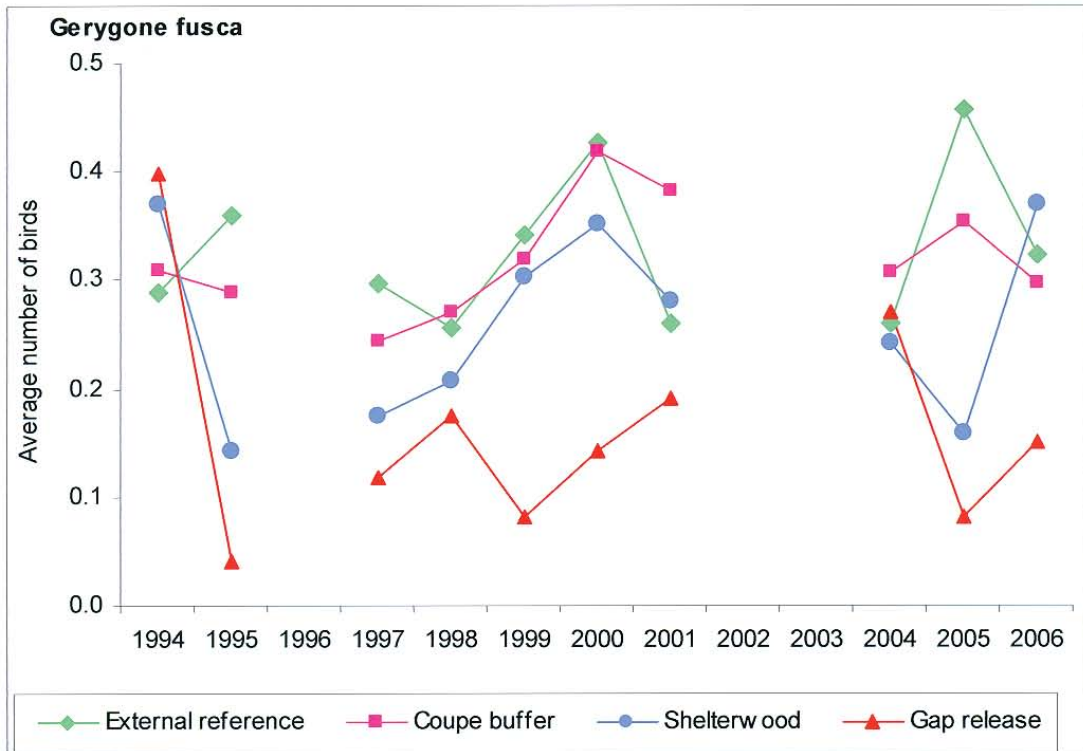


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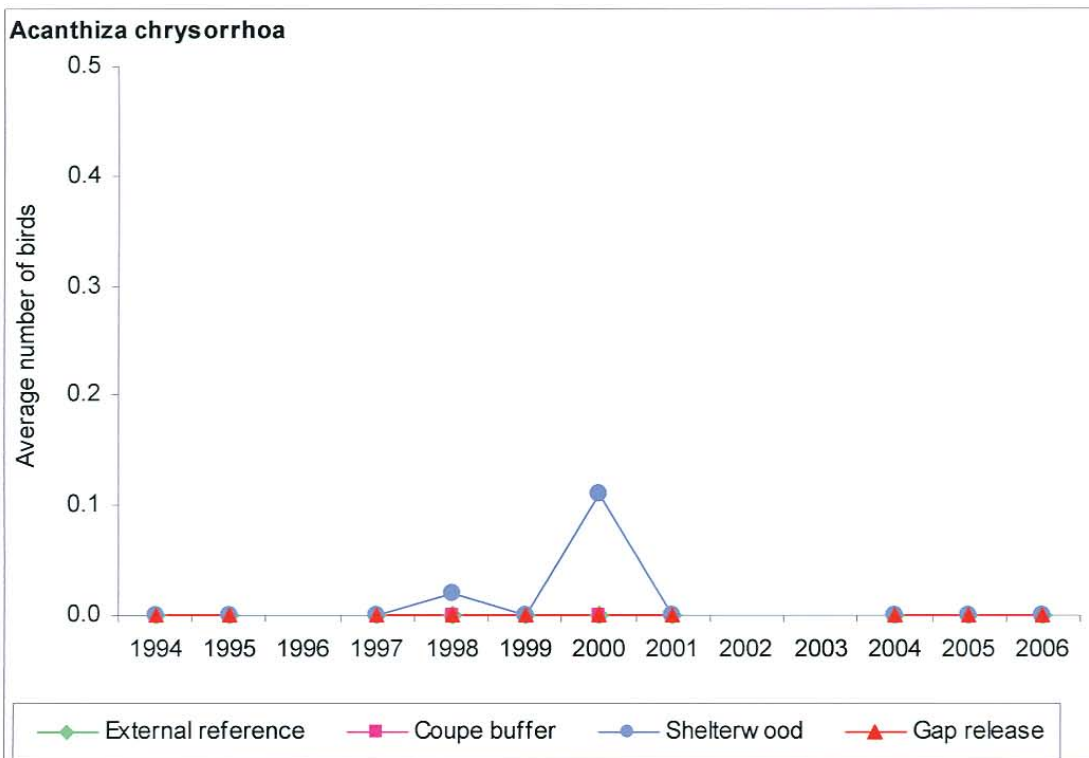
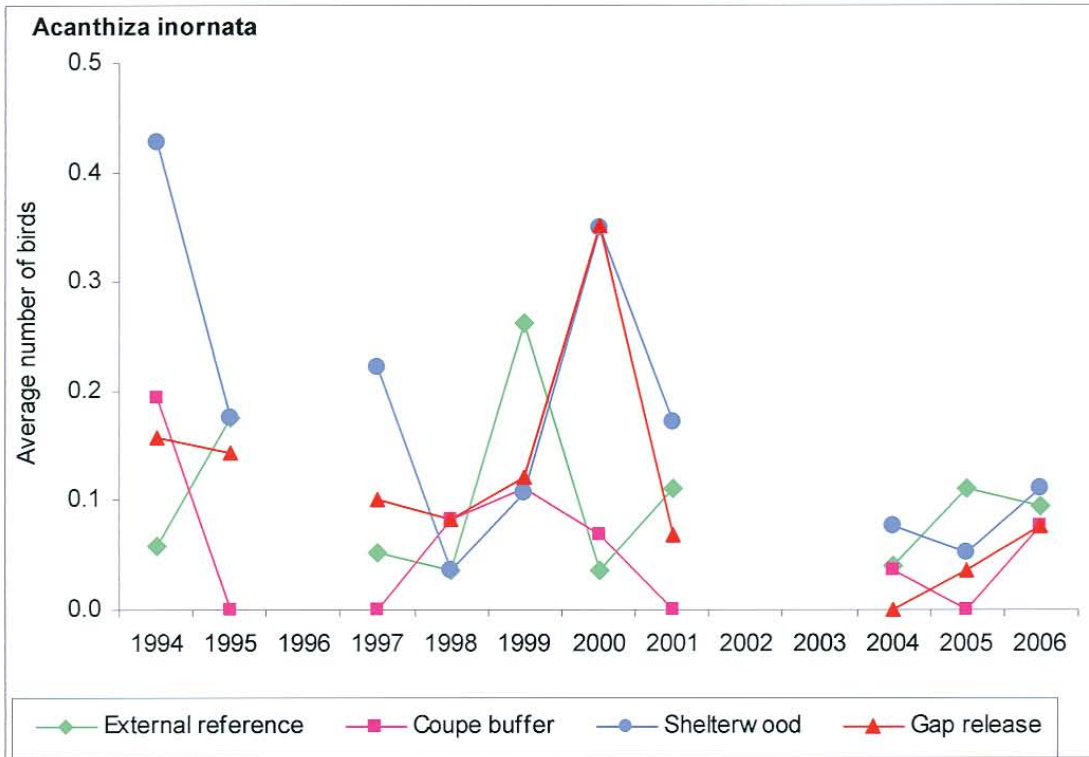


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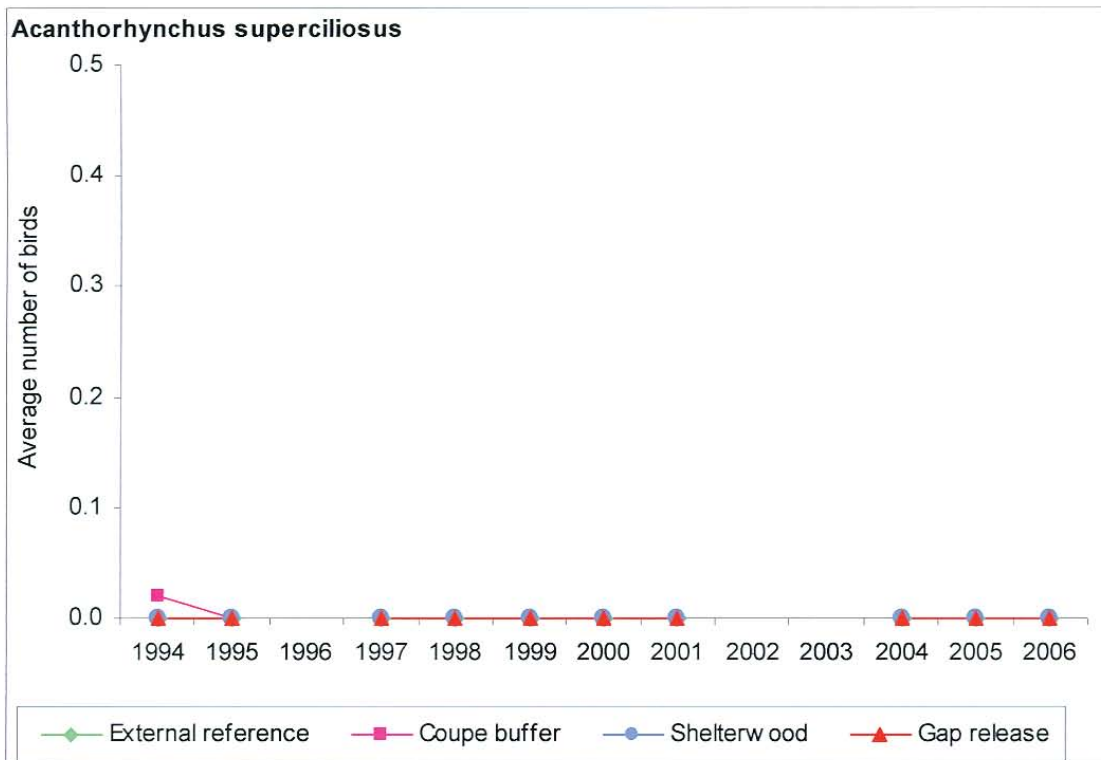
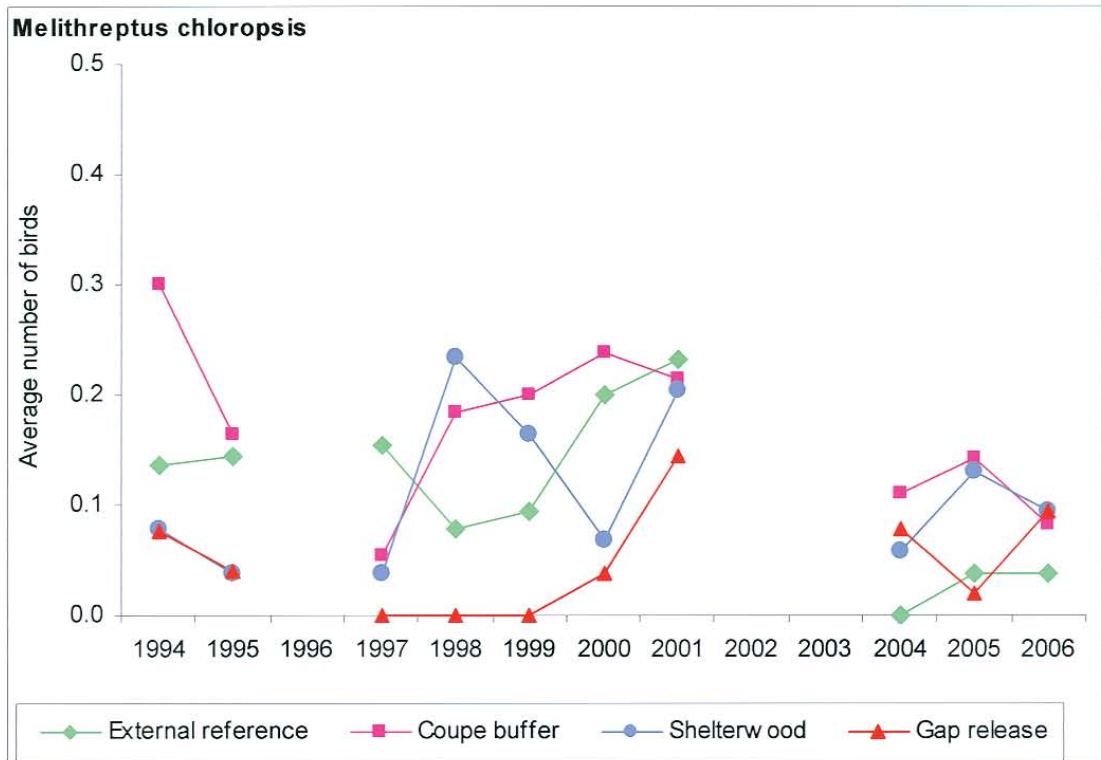


Figure 6. (cont.)

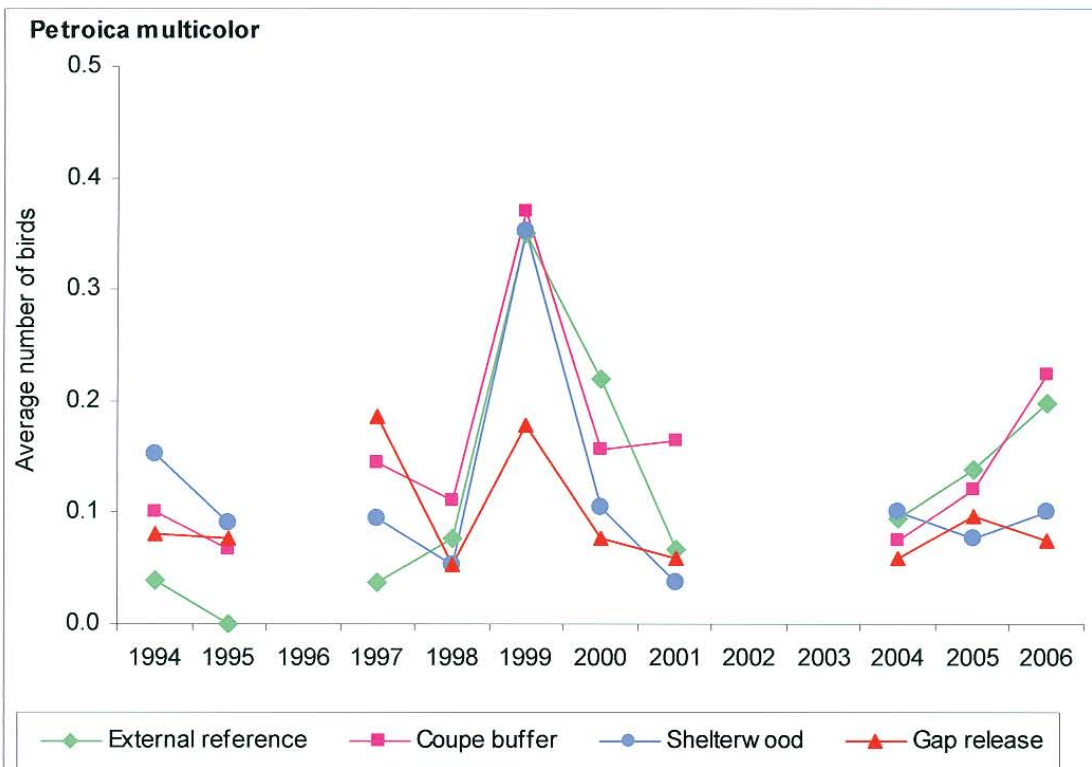
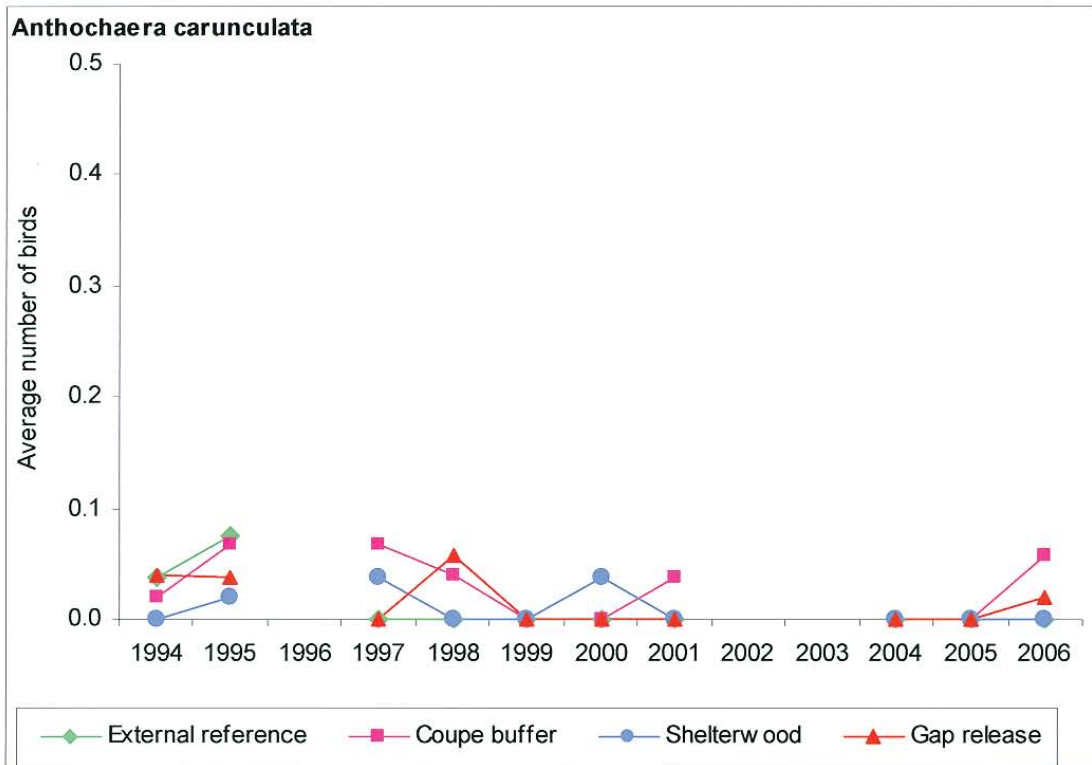


Figure 6. (cont.)

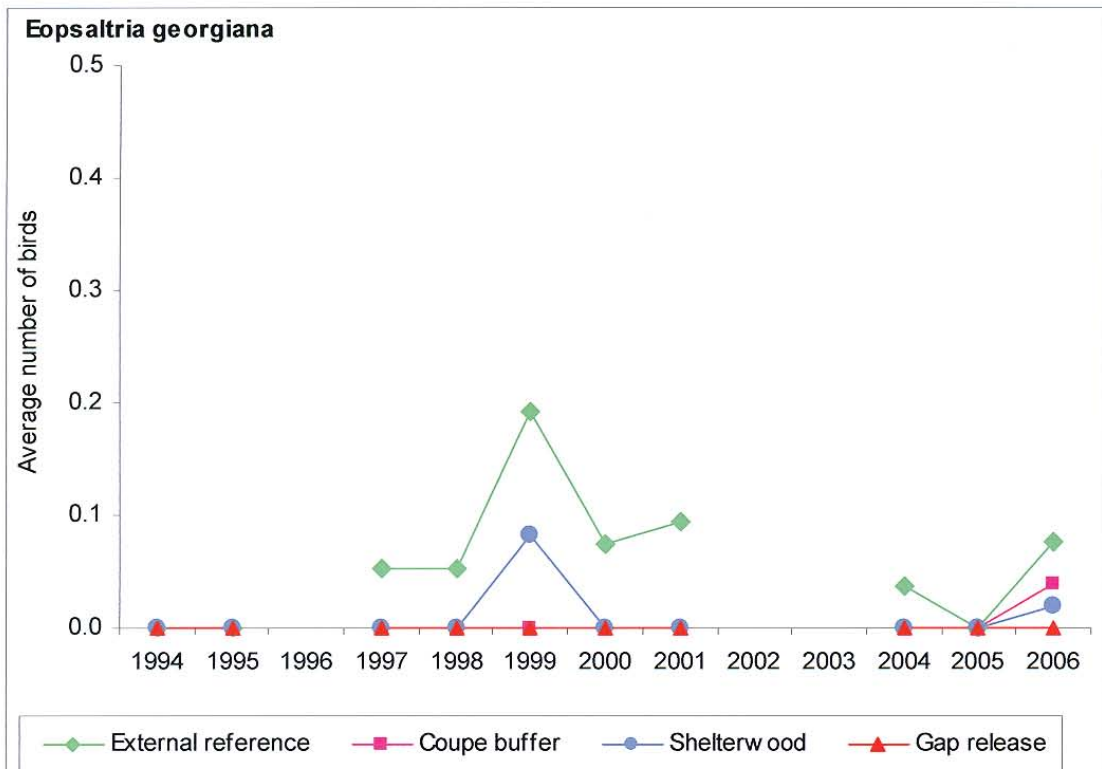
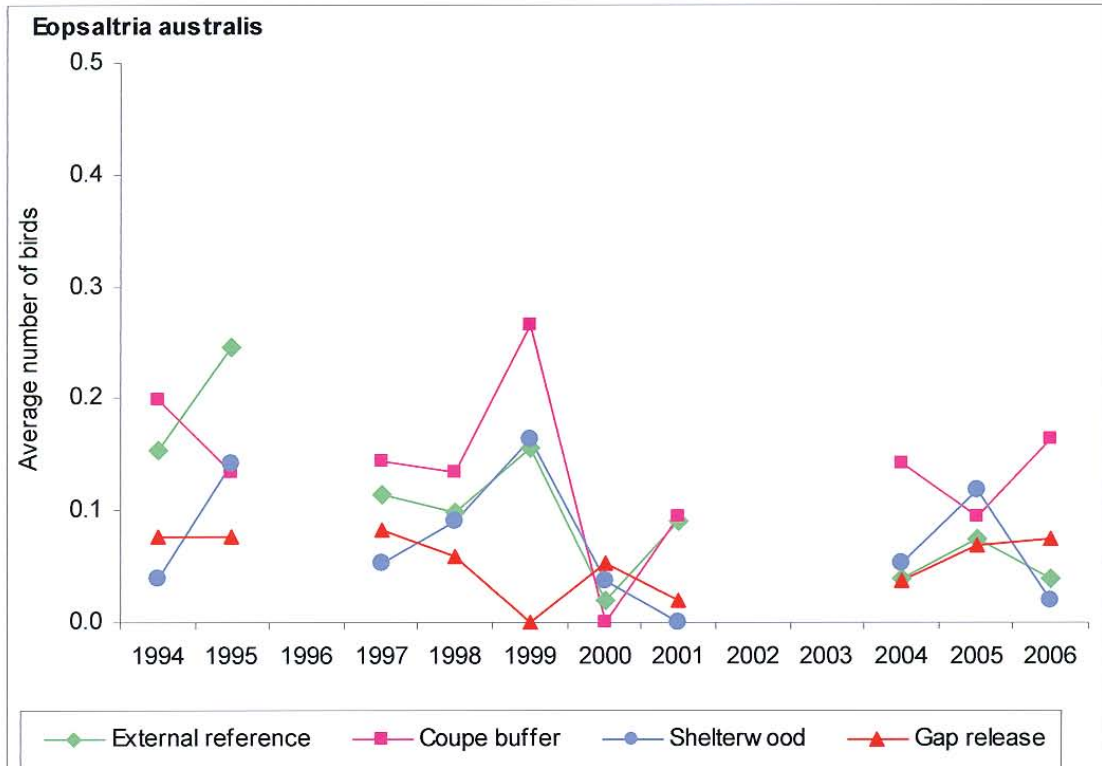


Figure 6. (cont.)

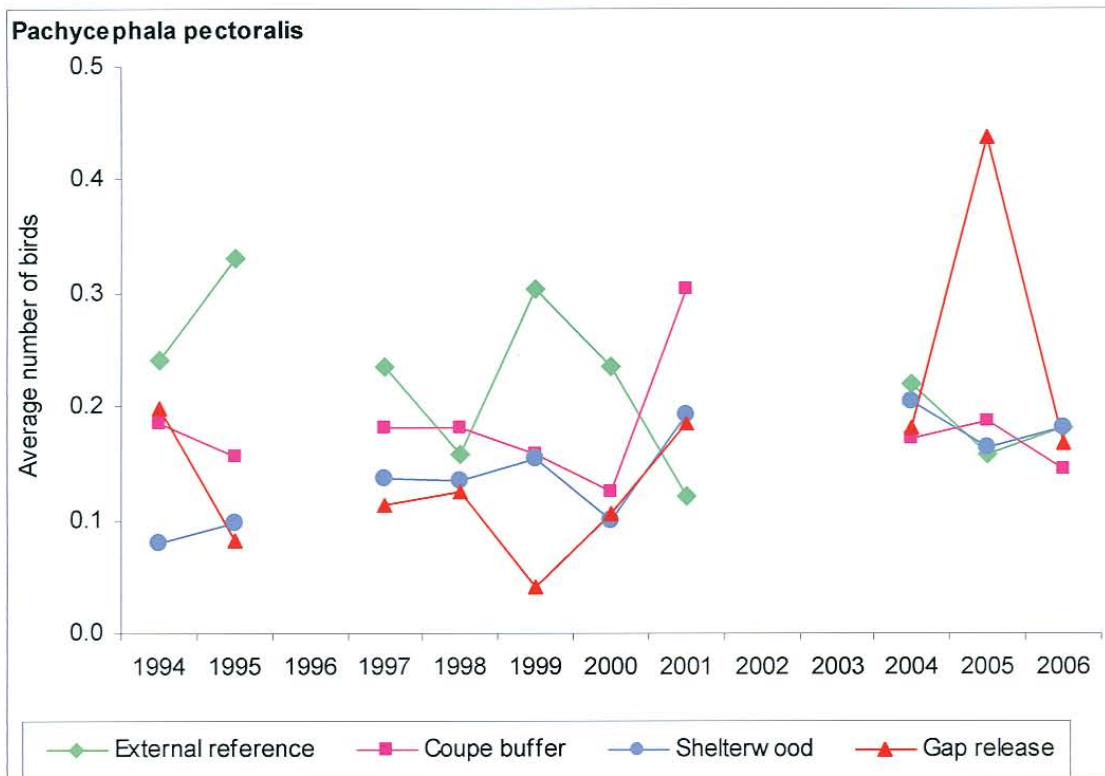
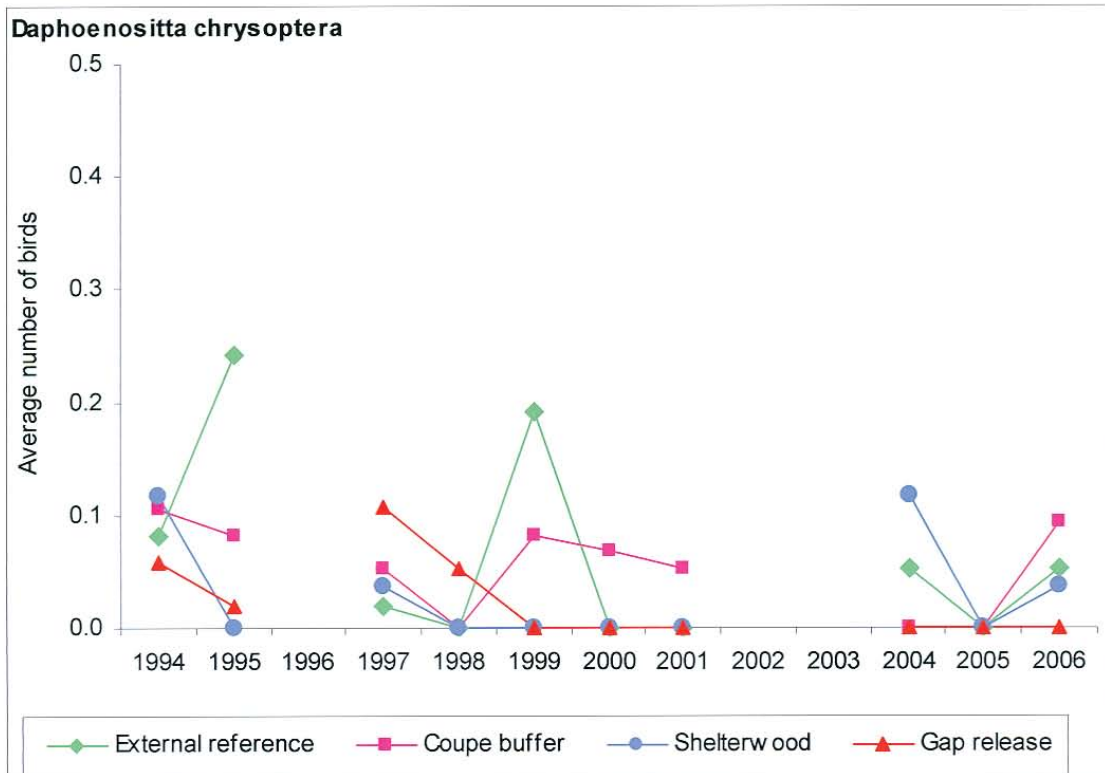


Figure 6. (cont.)



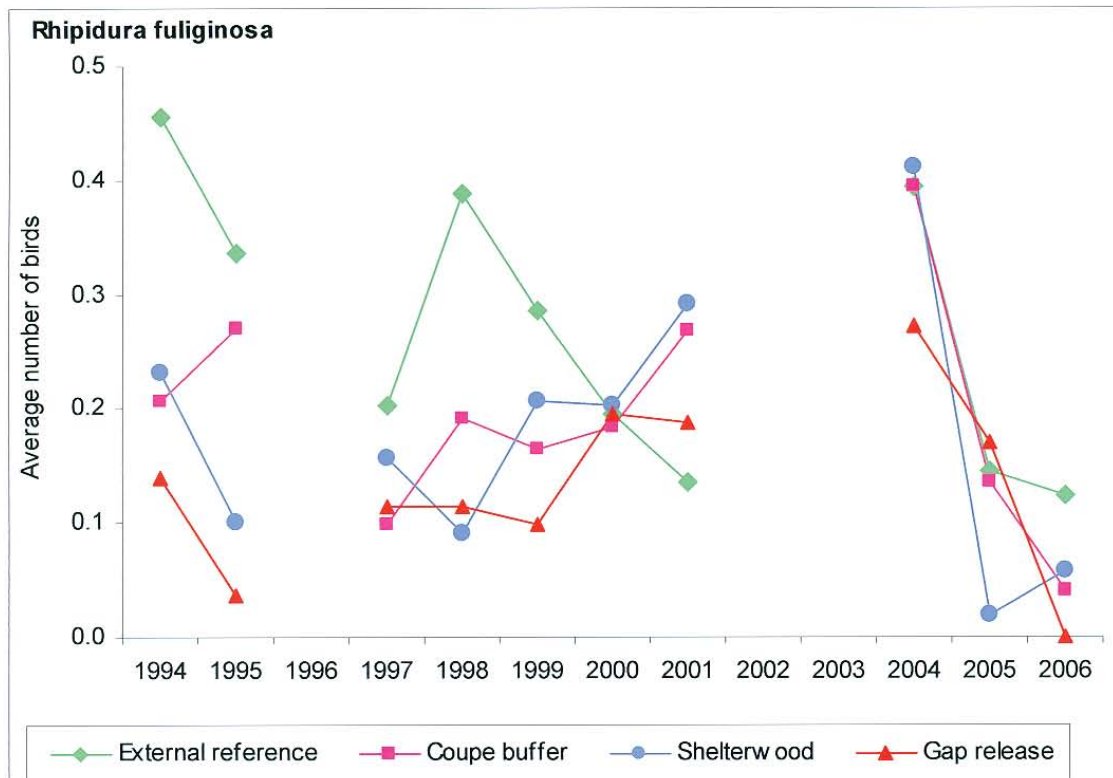
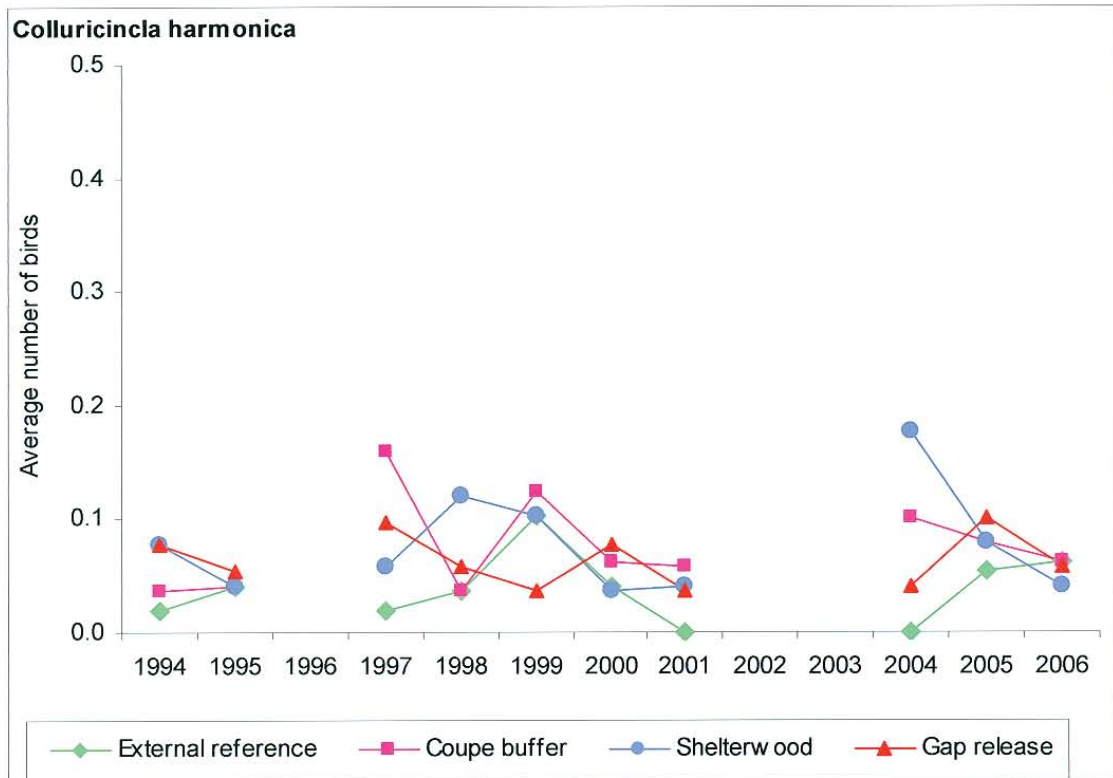


Figure 6. (cont.)

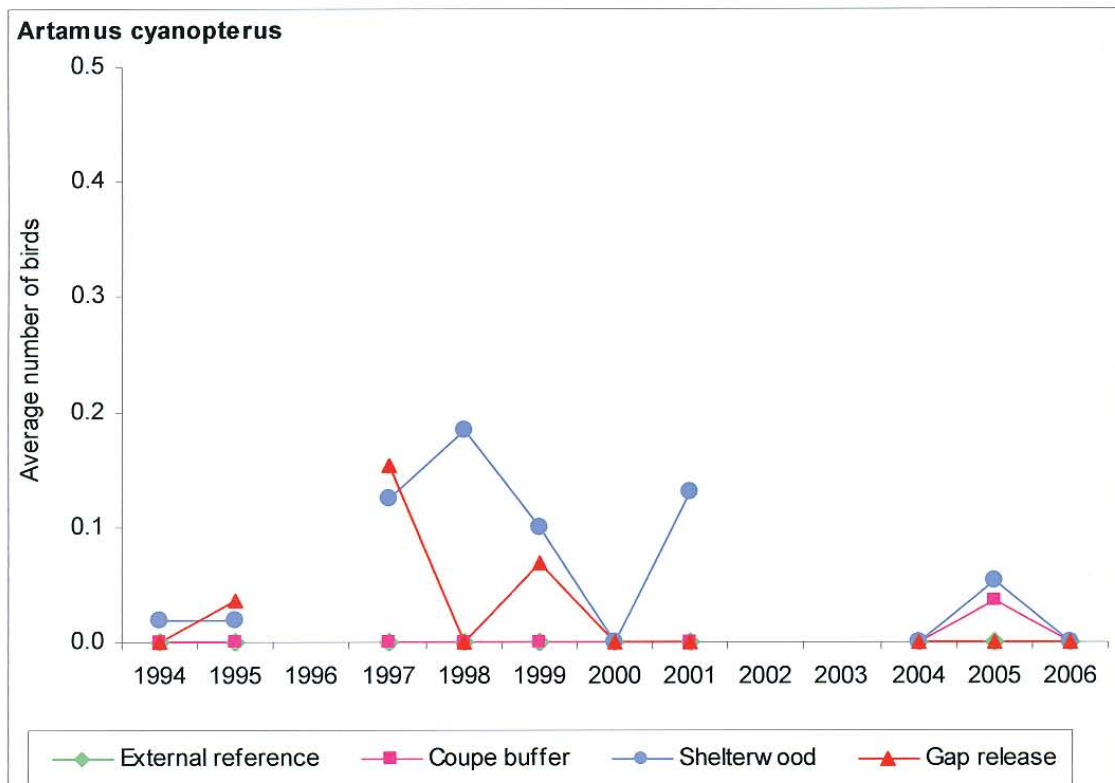
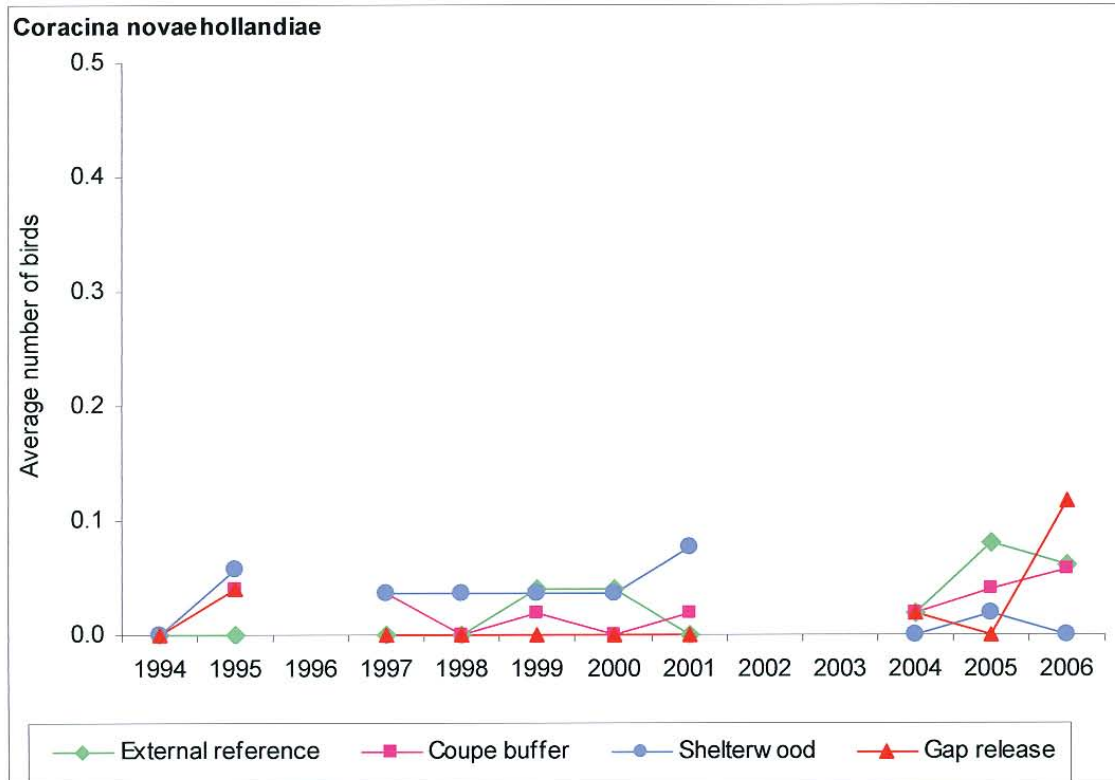


Figure 6. (cont.)

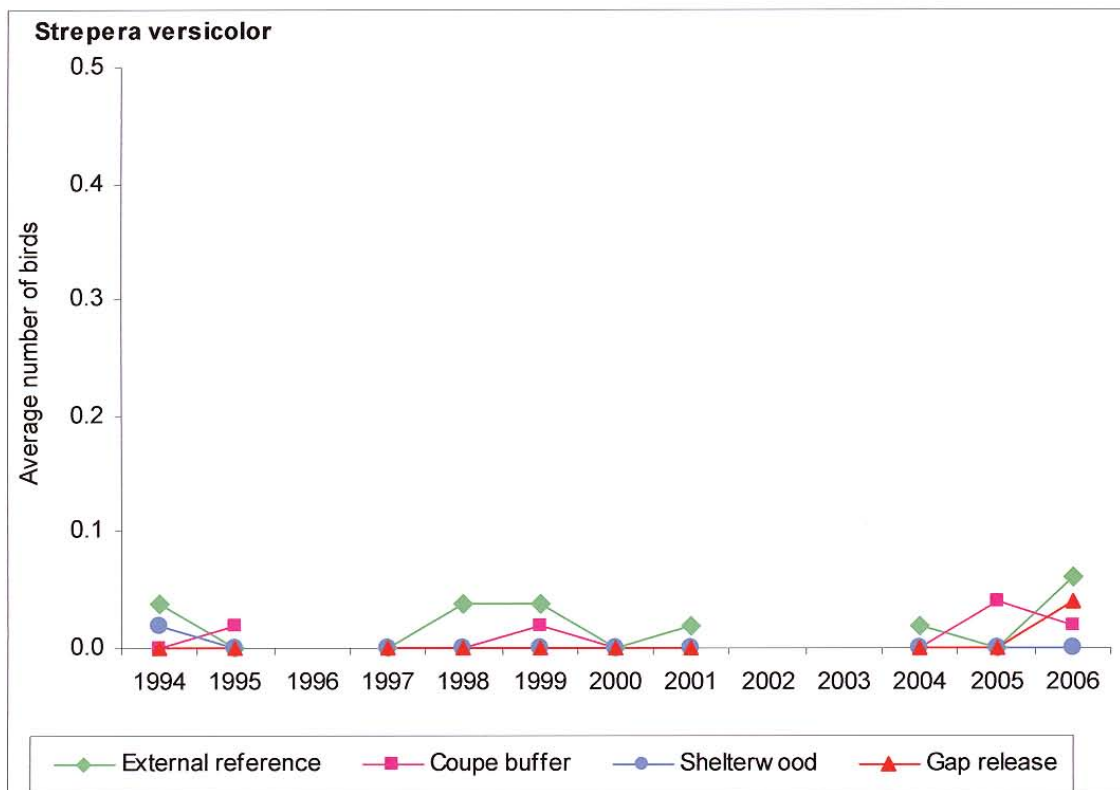
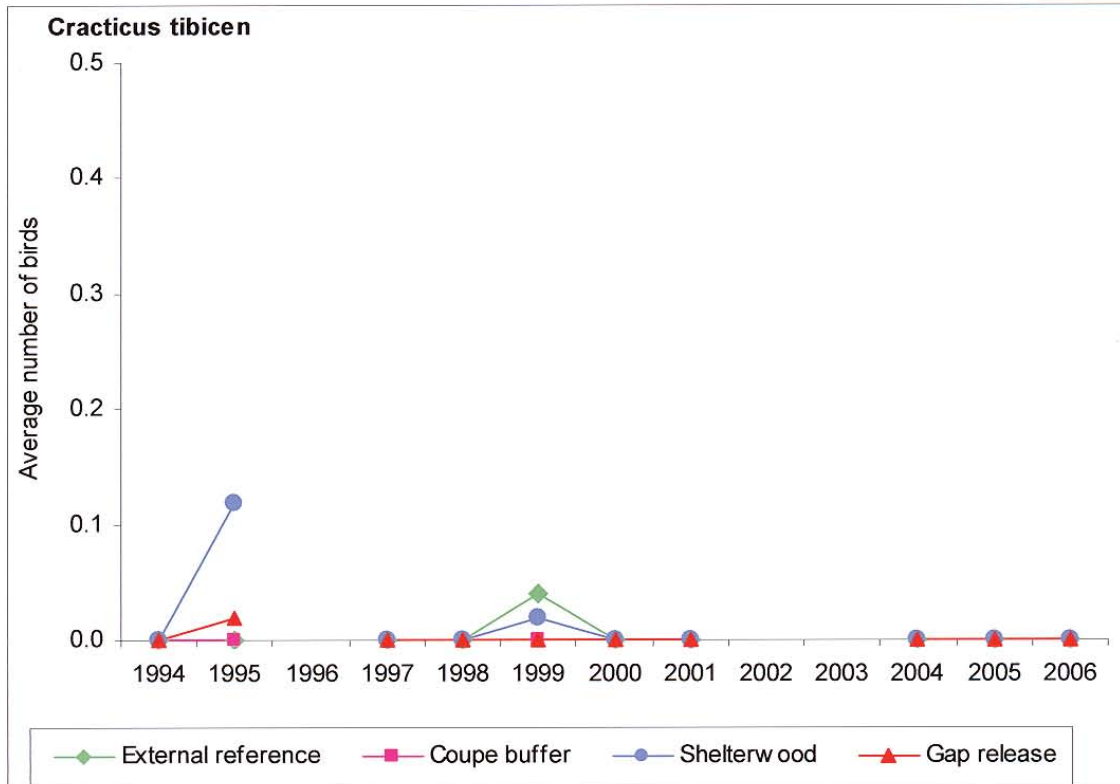


Figure 6. (cont.)

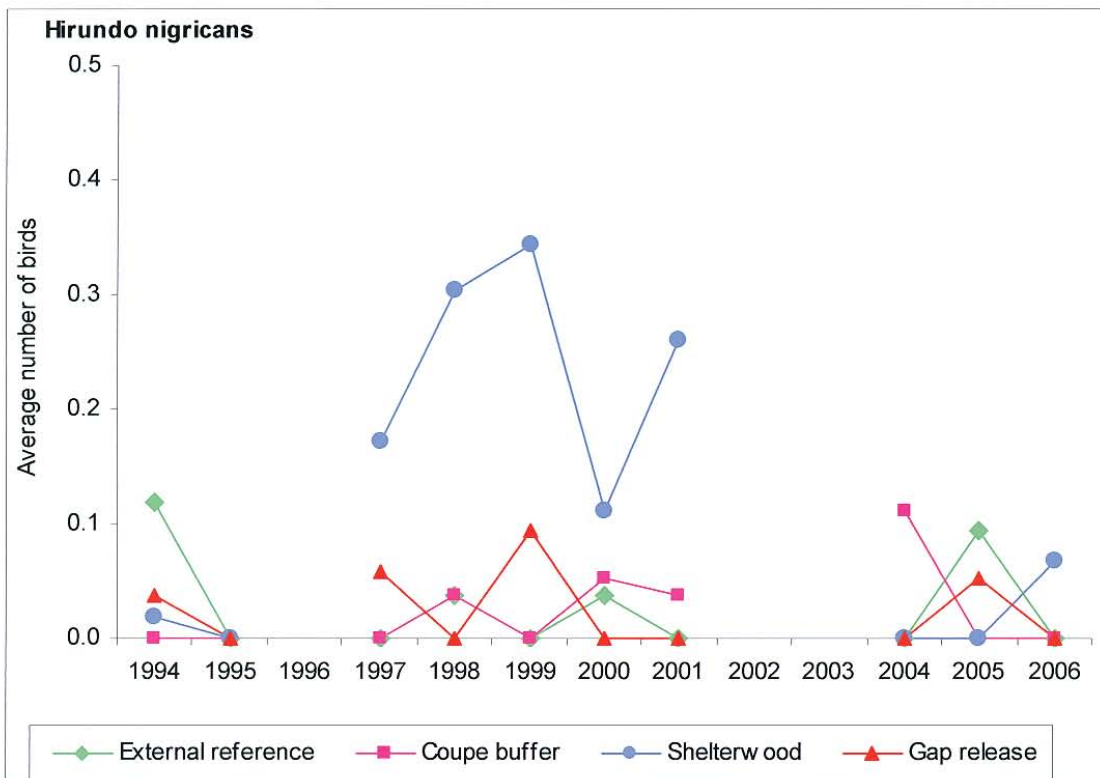
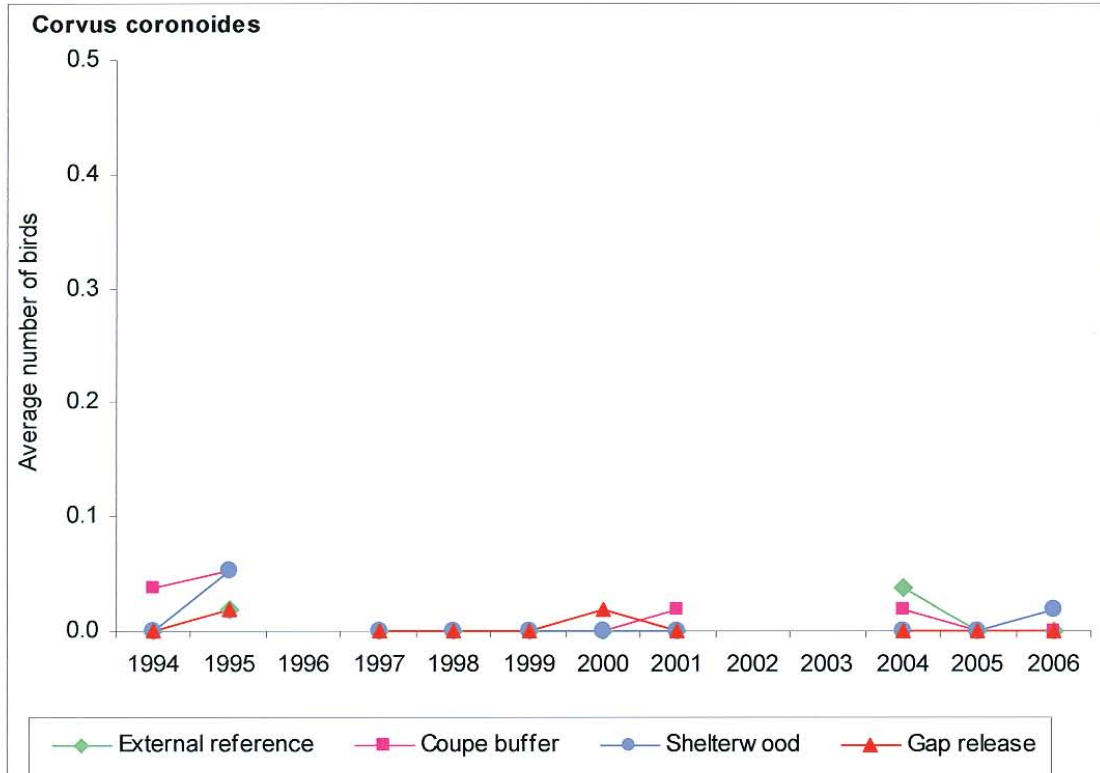
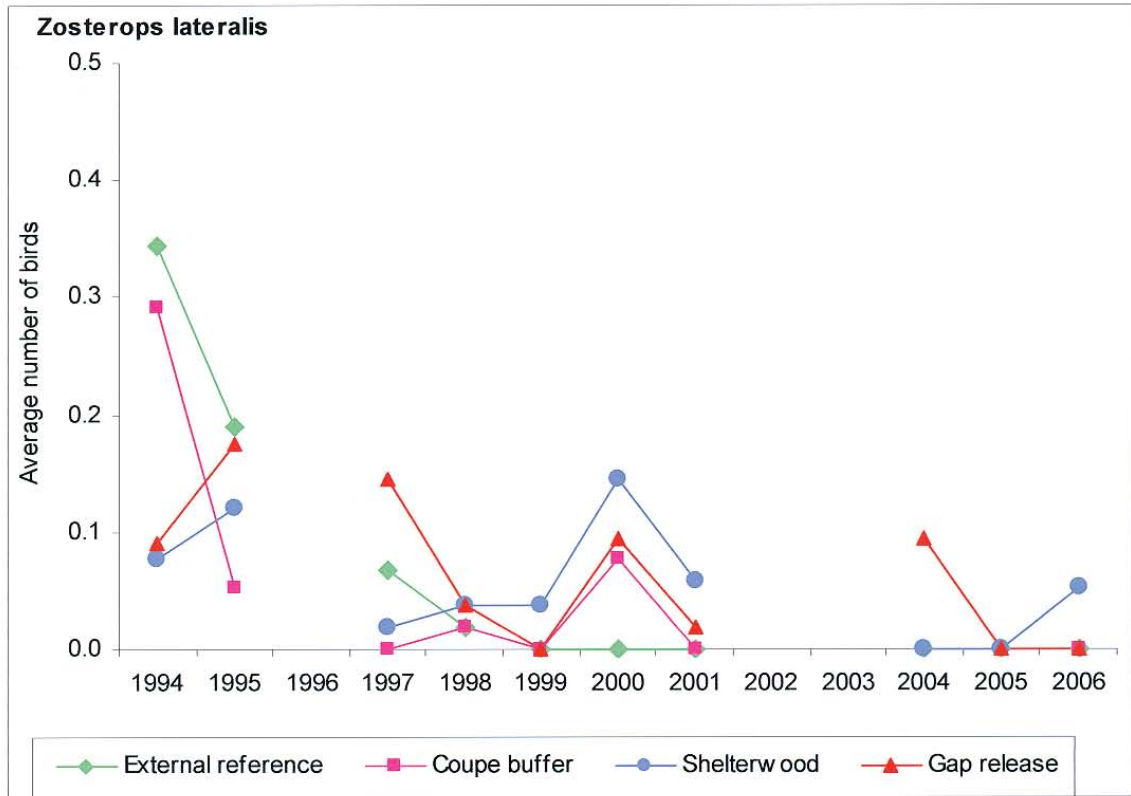


Figure 6. (cont.)



Non-core species

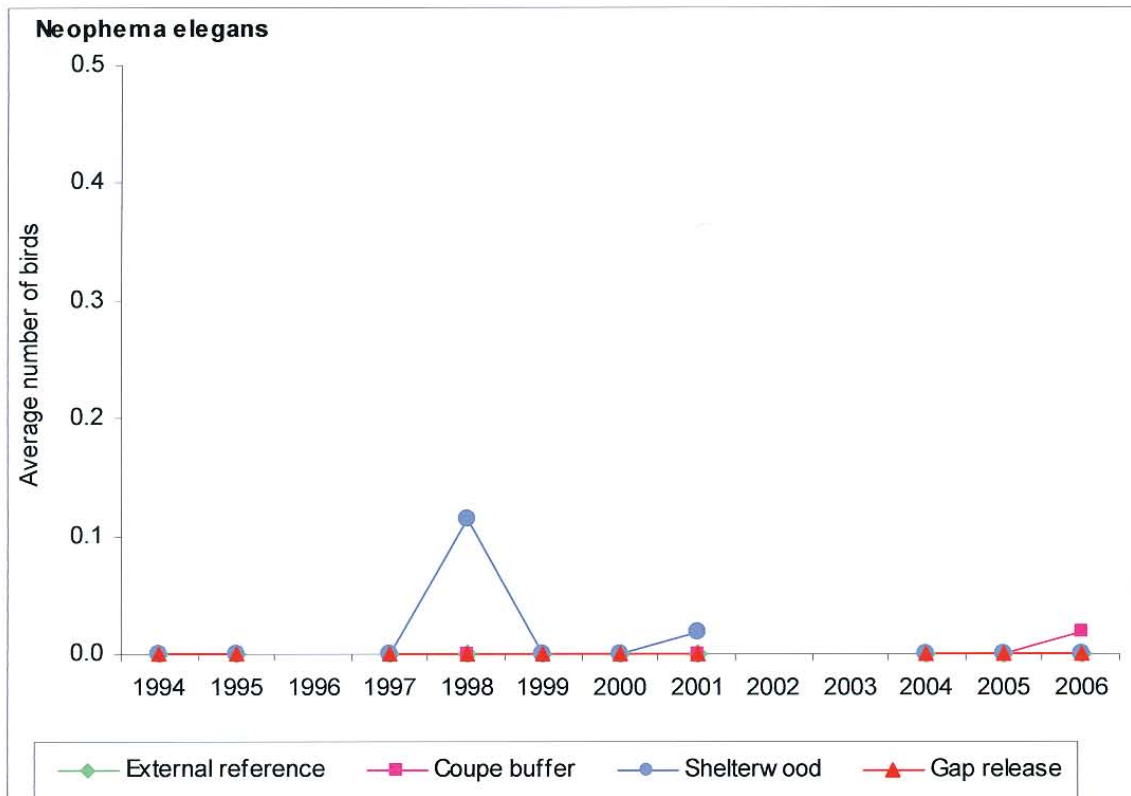


Figure 6. (cont.)

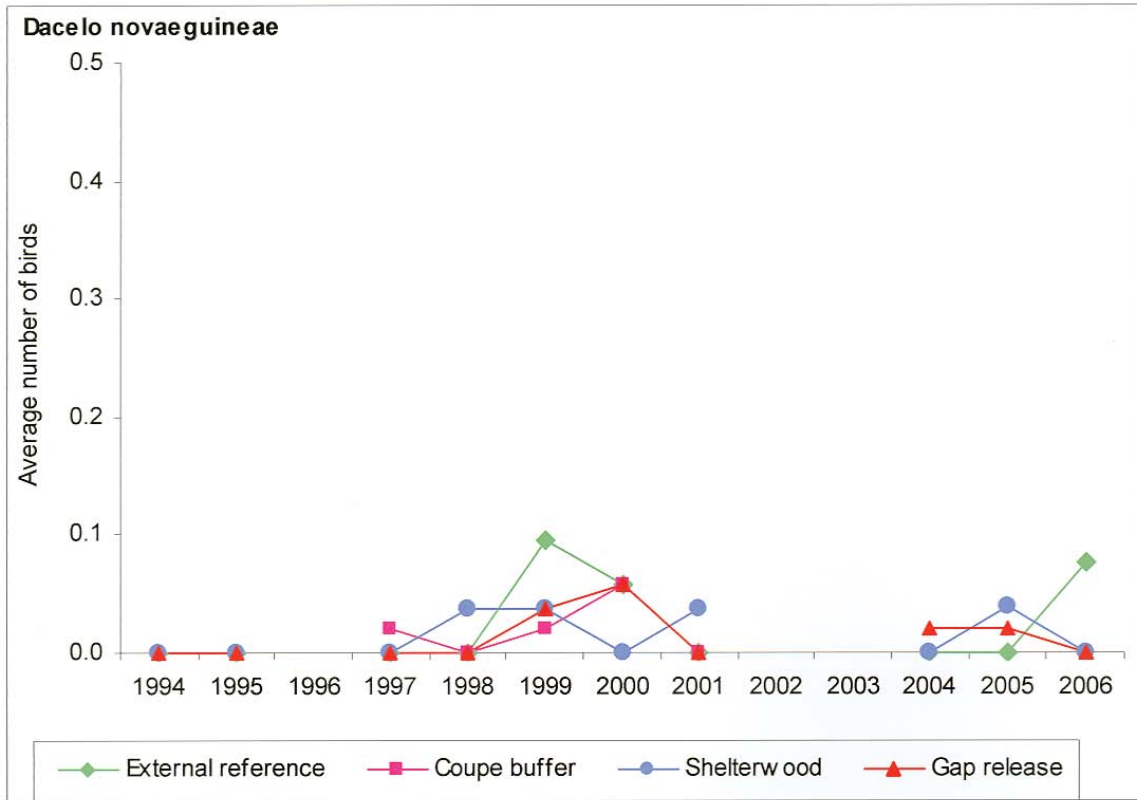


Figure 6. (cont.)



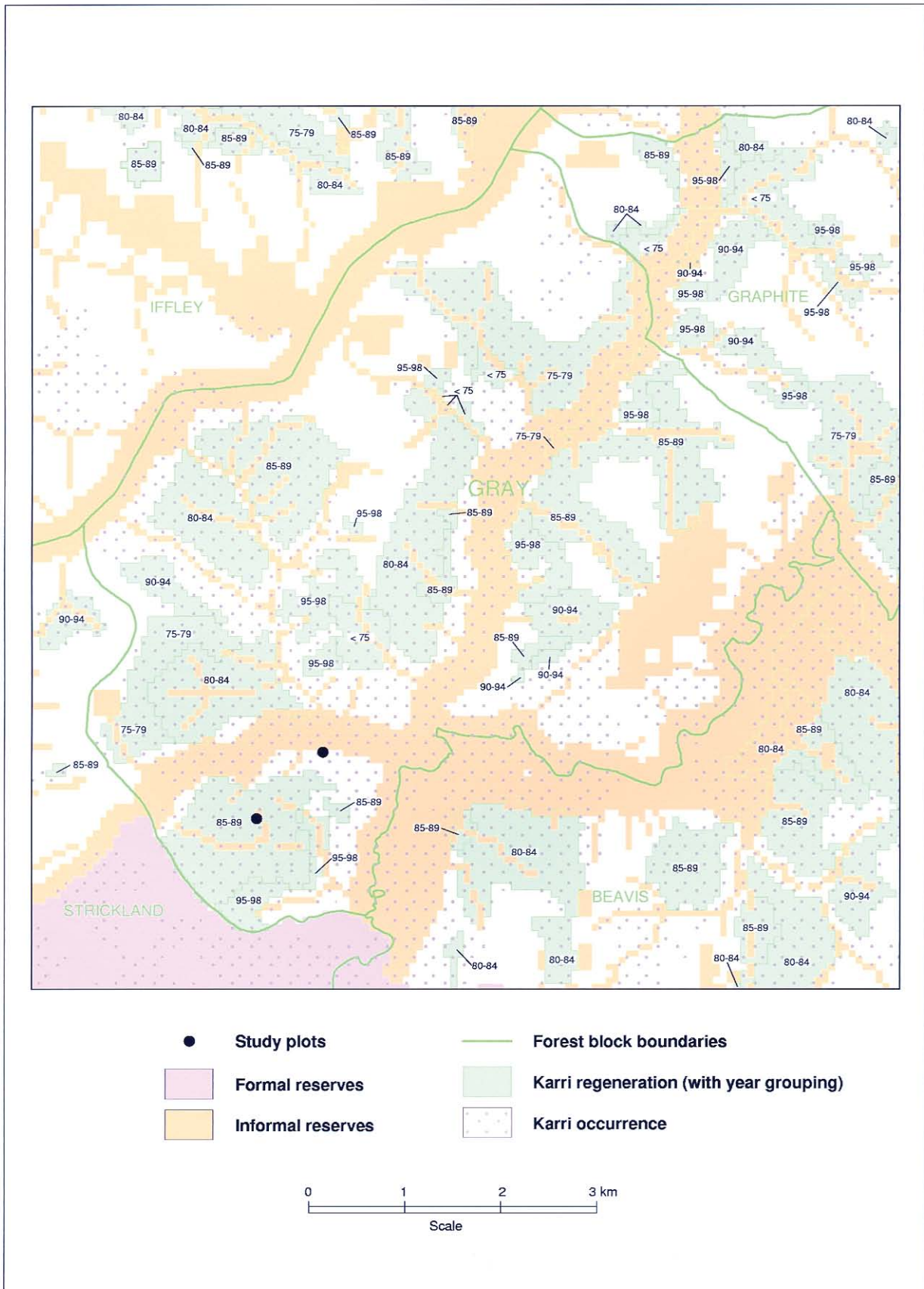


Figure 7. Map of Gray and surrounding forest blocks (c. 8 000 ha), showing location of the two plots, extent of clearfelling of karri forest, year of regeneration, and spatial configuration of unlogged forest (formal and informal reserves), as at 1999. Formal reserves include national park; informal reserves are road, river and stream reserves. Neither is available for logging.