Vertebrate Responses to Selective Logging: Implications for the Design of Logging Systems

Andrew D. Johns

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Vertebrate responses to selective logging: implications for the design of logging systems

ANDREW D. JOHNS†

Institute of Tropical Biology, c/o Department of Zoology, University of Aberdeen, Aberdeen AB9 2TN, U.K.; and Wildlife Conservation International (New York Zoological Society), Bronx Zoo, Bronx, New York 10460, U.S.A.

SUMMARY

The adoption of tropical rain forest management systems that conserve both timber stocks and the environment is increasingly viewed as a necessary development to maintain both the tropical timber trade and the forests themselves. There are no theoretical reasons why such systems should not be achievable. Ecological studies of vertebrate animal populations, and of wider ecosystem processes, can assist foresters in designing more appropriate forestry systems and in their long-term monitoring. Data are presented from two Forest Reserves in South-east Asia, Tekam in Peninsular Malaysia and Ulu Segama in Sabah, to show how simple analysis of ecological parameters may be used to quantify the extent to which logging affects the forest ecosystem and the extent to which it recovers over time.

1. INTRODUCTION

Vertebrate faunas of rain forests are complex and diverse (Harmelin-Vivien & Bourlière 1989). There can be a high degree of microhabitat specialization among some taxa, although this is not so evident as among many invertebrates (Holloway *et al.* this symposium). The responses of vertebrates to disturbance are dynamic and reflect features of the forest vegetation and environment. The extent of dietary specialization may be important in that animals specialized to exploit food sources that are less common following disturbance should, logically, also become less common. A reliance upon particular features of microclimate, or physical environmental characteristics that are changed by the disturbance, may also have a deleterious effect. On the other hand, a complex food web should show considerable resilience (*sensu* Orians 1975) to environmental fluctuations because flexibility of connectance is an important feature of such systems: disturbances affecting certain component species should be absorbed by a redirection of community relationships (MacArthur 1957).

The greater the species richness of a species group, the more sensitive it is likely to be to habitat change and thus the more useful as an indicator of changes in ecosystem processes. Studies of taxa exhibiting extreme diversity, notably the insects, are likely to demonstrate most conclusively whether or not the ecosystem regains a form equivalent to that occurring before the disturbance.

Examination of the responses of vertebrate communities, and of individual species, to disturbance caused by selective timber logging and subsequent forest management exercises has generally been based on comparative data. These normally contrast areas of unlogged forest and others logged at different times in the past (e.g. for primates, Johns & Skorupa (1987)). This information can be biased by unquantifiable initial differences between sites. It is more appropriate to monitor changes in populations occurring over time at single sites: the initial population, the effects of disturbance and the subsequent recovery or absence of recovery. Only in this way can reasons for any changes be elucidated. In the case of human-induced disturbances, such as selective logging, a potential may then exist for adjusting the form of disturbance to assist recovery of the ecosystem.

This paper examines responses of two representative vertebrate taxa, primates and birds, to moderate and high intensity selective logging operations studied in Peninsular Malaysia and in Sabah. These taxa are probably the most easily studied in rain forest. They are here examined as potential indicators of the success of ecosystem recovery in disturbed forest areas.

2. STUDY AREAS

Long-term studies of vertebrate (mammal and bird) responses to selective logging operations in South-east Asian dipterocarp forest are being undertaken at two sites, the Tekam Forest Reserve in Peninsular Malaysia, and the Ulu Segama Forest Reserve, which includes the Danum Valley Conservation Area, in Sabah, Malaysian Borneo (see Marsh & Greer, this symposium).

(*a*) *Tekam*

A long-term study began at Tekam in 1979, which established study plots in unlogged and logged forest areas. The unlogged plot was logged in 1980 and was subsequently monitored for one year to obtain data on the immediate effects of logging. All plots were resurveyed in 1987: resurveys are scheduled every six years.

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† Present address: Makerere University Biological Field Station, P.O. Box 10066, Kampala, Uganda.

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Tekam is located in the state of Pahang in the centre of the peninsula. Study sites range from 80 to 400 m above sea level, and were of a uniform vegetation type prior to logging. The vegetation is classified as hill dipterocarp forest, although it lacked extensive stands of the characteristic *Shorea curtisii* Dyer. The vegetation was instead dominated by other dipterocarps of the genera *Shorea* and *Dipterocarpus*, with large emergent legumes such as *Parkia*, *Koompassia*, *Sindora* and *Intsia*.

At a representative site (logged in 1980) selective logging involved the removal of 3.3% of trees for commercial purposes, but caused the loss of 51% of trees through incidental damage. Details of the site and the logging operation are given elsewhere (Johns 1988).

(*b*) *Ulu Segama*

Several sites in the Forest Reserve were surveyed during 1987–88 and sample areas established. These included both unlogged and logged forests, the former including the large unlogged forest bloc of the Danum Valley Conservation Area. No re-surveys have yet been undertaken by the author, although work on some taxa has subsequently been pursued (Lambert, this symposium).

The vegetation in this area is broadly classified as lowland dipterocarp forest, with some riverine vegetation along the main rivers and some areas of past human cultivation (which were not included in the survey plots). The composition of the vegetation is discussed by Newbery *et al.* (this symposium), and the survey sites covered by this study described in more detail by Johns (1989*a*). The survey sites were all approximately 150 m above sea level.

A sample logging operation examined in 1988 involved the removal of around 7% of large trees for commercial purposes and caused a loss of up to 73% of trees through incidental damage. This figure was calculated for an area logged using overhead cable systems on about half of the land and conventional tracked vehicles on the other half. Damage to the vegetation is higher under the former system (Johns 1989*a*).

3. METHODS

Primates were sampled by line transect surveys: at each site a marked trail of between 3 and 5 km in length was walked at least ten times and sightings of primates recorded. Densities were obtained through a Fourier series estimation technique (Burnham *et al.* 1981). A detailed methodology is given in Johns (1986*a*).

Birds were sampled by similar means. The same trails used for primate surveys were walked and all birds observed were noted. This was supplemented by additional observations made in vegetation types not sampled during the walked surveys. At Ulu Segama, mist netting for understorey species was also conducted. A sample of 10000 m-net-hours was obtained for each study site. Methods employed are described in more detail elsewhere (Johns 1986*b*, 1989*a*, *b*).

The use of species–abundance distributions to determine stability characteristics of a community follows Stenseth (1979). The hypotheses are:

1. A stable community is predicted to show a negative correlation between the number of species present and the variation in their densities. This shows up as a log–normal species–abundance distribution.
2. Environmental disturbance is predicted to amplify variations in the relative densities of species. This results in a log–series species–abundance distribution.
3. A recently disturbed area will show the latter species–abundance distribution, and a return to the former is expected to indicate constancy (stability) of environmental conditions, which should allow the recovery of the original community.

4. RESULTS

(*a*) *Primates*

Long-term studies of the responses of primates to selective logging operations have shown few consistent trends. At Tekam, inter-site variation in primate densities is greater than intra-site variation over a logging event and subsequent years (figure 1). The only notable trend in this example is the increased occurrence of *Macaca fascicularis*, which is a specialist of high productivity secondary habitats. At Ulu Segama, there is no consistent relationship between

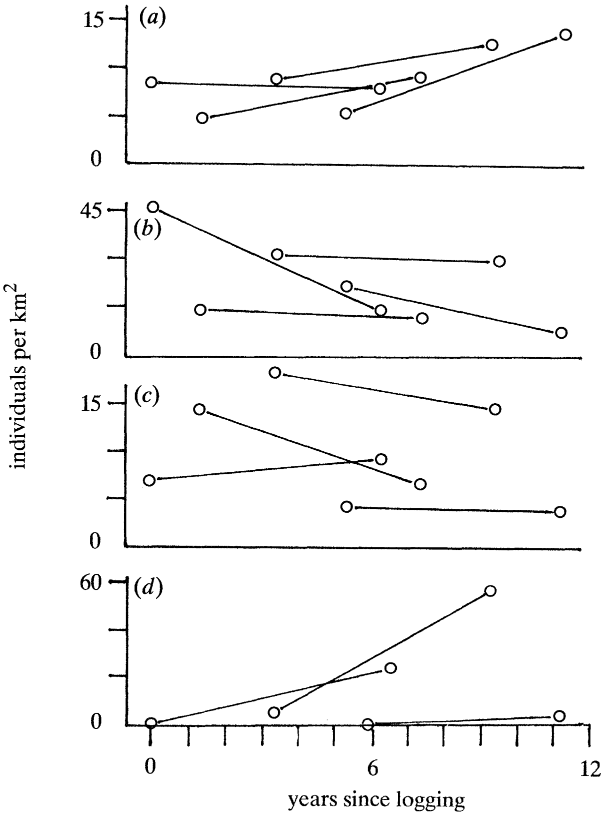

Figure 1. Estimated densities of primate species after logging (Tekam Forest Reserve, Peninsular Malaysia). (*a*) *Hylobates lar*; (*b*) *Presbytis melalophos*; (*c*) *P. obscura*; (*d*) *Macaca fascicularis*. Lines linke original and re-surveys at individual study sites.

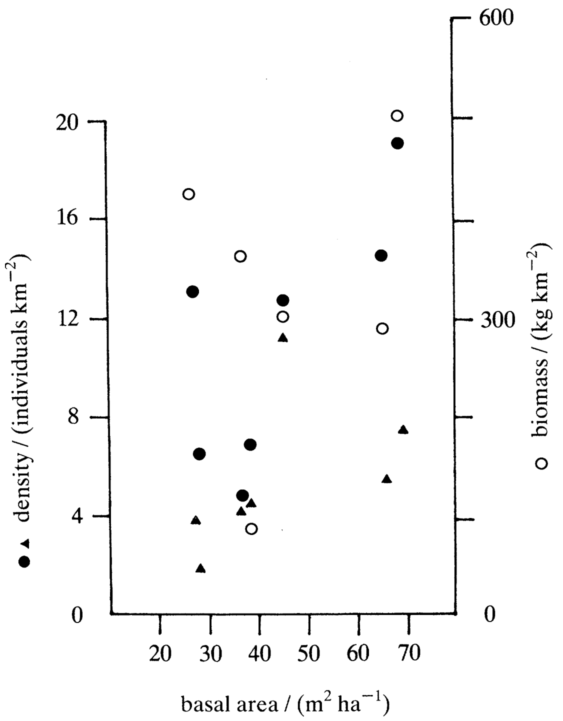

Figure 2. Relationships between primate density and biomass, and damage levels during logging (Ulu Segama Forest Reserve, Sabah). ● = *Presbytis rubicunda*, ▲ = *Hylobates muelleri*.

population densities and the degree of damage as indicated by forest basal area (figure 2).

Primates often take a long time to respond to environmental change, however. Infant:female ratios at Tekam suggest that in the long-term some species may be better able to persist than others (table 1). Six years after a logging event breeding rates appear depressed in all species. Twelve years after logging in Ulu Segama there is some evidence of drops in the abundance of some species (table 2), but this needs to be monitored further to determine if it is a real trend.

Table 1. *Estimated infant:female ratios among primates after selective logging (Tekam Forest Reserve, Peninsular Malaysia)*

(Data from one site (C13C in the southwest of the Forest reserve); 6–30 females sampled in each case.)

species	infant:female ratio unlogged forest	during logging	6 months after logging	6 years after logging
Hylobates lar	0.50	0	0.50	0.33
Presbytis melalophos	0.41	0	0.13	0.14
P. obscura	0.31	0	0.09	0.20
Macaca fascicularis	0.28	0.18	0.18	0.25

Table 2. *Primate densities in unlogged and logged forests (Ulu Segama Forest Reserve, Sabah)*

(The list omits two riverine species (*Macaca fascicularis*, *Nasalis larvatus*) and a phenotype of *Presbytis* (of uncertain affinity), all of which occur erratically through the study area.)

	Individuals per square kilometre		
species	unlogged forest	6-year-old logged[a]	12-year-old logged[a]
Pongo pygmaeus	0.3	0.7	1.1
Hylobates muelleri	5.3	7.8	4.1
Presbytis rubicunda	13.6	9.8	8.8
P. hosei	2.0	3.6	3.9
Macaca nemestrina	15.8	10.0	24.0

[a] Mean of two sites.

Table 3. *Similarity of unlogged and logged forest avifaunas as described by Horn's Index of Overlap (data from Tekam Forest Reserve, Peninsular Malaysia)*

	Area and time elapsed since logging (years)							
area	C13C 0	C5A 1–2	C1A 3–4	C2 5–6	C13C 6–7	C5A 7–8	C1A 9–10	C2 11–12
C13C	—							
C5A	0.10	—						
C1A	0.38	0.43	—					
C2	0.04	0.71	0.49	—				
C13C	0.07	0.22	0.33	0.37	—			
C5A	0.09	0.66	0.49	0.78	0.46	—		
C1A	0.36	0.19	0.52	0.29	0.32	0.57	—	
C2	0.09	0.38	0.23	0.46	0.32	0.32	0.29	—

(*b*) **Birds**

Surveys of logged forests at Tekam have located all but five of 193 species found in unlogged forests. At Ulu Segama, all but ten of 223 species were recorded by the author in logged forests during 1987–88, and several more have subsequently been observed in logged areas by F. Lambert. Statistics of species presence or absence are of low utility, however, in examining community processes.

An Index of Overlap (Horn 1966) applied to matched samples of the Tekam avifauna suggests that not only do the logged forests possess a different avifaunal community structure, but that it shows no signs of re-converging with that of unlogged forest even 12 years after the logging event (table 3). Changes in individual species abundances are most marked among groups of small species, particularly of understory foliage-gleaning and terrestrial insectivores (table 4). Species of a few groups tend to become dominant. The total number of species in the sample declines: a reflection of the fewer numbers of rare species and consequently higher equitability typical of disturbed systems.

Species–abundance distributions (table 5) show no evidence of a return to a log-normal species–abundance distribution even 11–12 years after logging, but a decreasing fit to a log-series curve in the Tekam example might suggest the beginnings of a recovery to

Table 4. *A comparison of feeding guild membership within samples of 800 individual birds observed at one site over time (Tekam Forest Reserve, Peninsular Malaysia)*

(For definitions of feeding guilds, see Johns (1986*b*).)

		percentage sample ($n = 800$)		
trophic group	feeding guild	before logging	1–6 months after	6–7 years after
frugivores	terrestrial	0	0.4	0
	arboreal	10.6	10.6	14.9
faunivore/frugivores	arboreal	11.5	10.3	5.8
insectivore/frugivores	terrestrial	0.6	0	0
	arboreal	15.1	8.8	39.2
insectivore/nectarivores	arboreal	3.9	2.0	4.5
insectivores	terrestrial	3.6	1.4	0
	bark-gleaning	5.3	3.4	3.0
	foliage-gleaning	31.1	34.5	28.5
	sallying	16.2	24.1	2.0
carnivores	raptors	2.0	4.5	2.0
	piscivores	0.1	0	0
no. species in sample		120	100	86

Table 5. *Species–abundance distributions of bird communities in unlogged and logged forests*

	regression coefficient	
area and forest type	log–normal	log–series
Tekam Forest Reserve		
unlogged	0.99	0.96
1–2-year-old logged	0.93	0.97
5–6-year-old logged	0.86	0.95
11–12-year-old logged	0.75	0.85
Ulu Segama Forest Reserve		
unlogged	0.95	0.88
6-year-old logged	0.89	0.91
12-year-old logged	0.87	0.95

a point of stability. There is no sign of this occurring in the Ulu Segama example.

5. DISCUSSION

(*a*) *Vertebrate populations*

Analysis of ecosystem responses to logging disturbance have suggested that, globally, a loss of up to about 50% of trees during felling and management operations may not cause permanent damage (Nicholson *et al.* 1988; Johns 1992). Although there is a considerable initial impact in terms of reduction of numbers of some species of plants and animals, the level of resilience shown by the community is remarkably high. Almost all vertebrate species present in unlogged forest either persisted or had recolonized by 12 years after the logging event. A few species, particularly those dependent upon over-mature trees, may require much longer (e.g. Lindenmayer *et al.* 1991). Even so, given time, it is probable that the flora and fauna would regenerate to pre-logging levels. Time is a constraining factor, however, given the long period likely to be required for the complex community structure of unlogged forest to be regained, and the economics (investment and amortization) of maintaining viable forest management operations.

However,in many dipterocarp forests, logging levels are already in excess of 50% of trees lost. It might be supposed that the abundance of many forest species would be correlated with the degree of damage and thus that species losses will become more pronounced. However, results from the studies reported here suggest that even high tree loss rates do not inevitably cause reductions in the populations of all species. Primates, and frugivorous birds such as hornbills, retain their numbers even with the loss of 73% of trees recorded in the Sabahan example in this study. Some small, less mobile species do show population reductions in heavily damaged forests (see Lambert, this symposium), although this is not inevitably the case (Pattemore & Kikkawa 1975). To a large extent it reflects the extent of invasion of non-forest species.

In general terms, the patchy distribution of food resources in logged forest (Johns 1988) may affect ranging patterns, breeding success and even gene flow, unless species are able to re-occupy the regenerating forest and restore an even dispersion of individuals. Most forest species do appear able to recolonize successfully, even under intensive felling operations (Johns 1989*a*; Dranzoa & Johns 1991).

It should be repeated that some species will be adversely affected by logging, and that the number of species whose populations are critically affected is likely to be related in some way to the severity of disturbance. Even the highly adaptable primates are adversely affected under some circumstances (Johns & Skorupa 1987). It may be predicted that species loss is a logarithmic function. At a high level of timber extraction and associated damage, the loss of a few more trees due to poor felling or management practices would cause disproportionately more losses than would be the case under low logging levels. Following this argument, it may also be predicted that repeated logging before full regeneration has taken place is likely to cause permanent reductions of biological diversity. In conditions where the economics of forest management requires the improvement of timber productivity, which means altering the balance of species in favour of fast-growing commercial timbers that can be harvested at an early age, the high initial losses of natural vegetation cover are unlikely ever to be regained.

(*b*) *Assessing ecosystem change*

In a consideration of the results generated from model ecosystems, Pimm (1979) has stressed that large disturbances affecting complex ecosystems are most likely to cause reduction in numbers rather than widespread species deletions. Complex ecosystems will also be stable to the effects of any species deletions, except where the species lost is a predator (Pimm 1984). Because few predators are deleted by forest disturbance through logging, the absence of an animal species following logging can usually be attributed to environmental factors.

In practice, the precise environmental factors to which species may be responding are difficult to define. The abundance of individual species may be more dependent upon such indefinable factors than upon the structure and design of the community. Only in a few cases may the absence of individual species be correlated with, for example, eutrophication of the water system, or critical levels of soil compaction, or the slowing-down of leaf litter decomposition. It is also unlikely that groups of species will be accurate indicators of stability characteristics of the ecosystem.

Community level changes are more useful as a means of evaluating the effects of disturbance. Statistical techniques such as indices of overlap can be used to monitor the convergence of disturbed with undisturbed faunas. More analytical techniques such as the interpretation of species–abundance or species–area curves may provide useful information. Species–area curves would be mathematically most robust (Stenseth 1979), but require a very high investment in data collection. Even the analysis of species–abundance distributions requires large and standardized samples. In the example given, species–abundance data from Sabah suggest that regeneration of the initial (unlogged) forest avifauna might well take much longer than an economically allowable rotation time for a managed timber resource. Re-establishment of the log–normal species–abundance distribution in logged forest might be taken as indicative of successful regeneration, and thus that the community will accrue successfully to the original community. However, there is no evidence to support this *per se*. This result would indicate constancy of environmental conditions that is one of the prerequisites for recovery of the original community. On the other hand, a community in old logged forest that continues to show a log–series species–abundance distribution has not regained a stable state, and re-logging applied to such a community will have a further degradative effect.

(*c*) *Implications for forestry*

Viable rain forest management units, Forest Reserves or series of Forest Reserves, are necessarily large and will contain a variety of forest vertebrates. The numbers of individual species persisting during and after the logging of portions of the total forest area will depend on how closely the forest management procedure mimics natural regeneration processes (Skorupa & Kasenene 1983), which necessarily includes a consideration of the total areas left in a largely undisturbed state (Harris 1984).

For economic reasons, minimal intervention systems, which cause little damage to the forest, are rarely practised. The size and frequency of gaps caused by logging will be sufficiently great as to cause the invasion of pioneer species of both plants and animals (Whitmore 1991). Under the forest management systems employed in dipterocarp forests, a high initial offtake is required to meet start-up costs and the proportion of commercial timber trees in the forest may need to be increased to meet economic goals (Johns 1992). Levels of intervention will far exceed natural disturbance levels, and changes will occur within the ecosystem. It is the responsibility of scientists that these changes be quantified and that an assessment be made of the ability of the ecosystem to maintain a functional state and, further, to recover its initial form.

The management of natural tropical forests for timber production is a difficult and expensive procedure generally with small profit margins, due largely to under-pricing of the product (World Bank 1991). It is possible to demonstrate ways in which commercial operations can be improved, in terms of their environmental impact, without increasing costs (Marn 1982; Malvas 1987; Hendrison 1991). This involves a consideration of both biotic and edaphic factors. The adoption of demonstrable 'best practice' (Poore 1989) essentially requires the exercise of Government control over logging activities to ensure compliance with regulations set to control damage levels (TELESIS 1991). This may limit degradation and thus there is some possibility of the hardwood crop regrowing without further investment. The extent to which less damaging logging methods are becoming employed varies between countries (Schmidt 1991), but it is clear that global acceptance of 'best practice' is far in the future. Furthermore, the adoption of 'best practice' will not necessarily equate with the development of sustainable harvesting systems since such a system has never been demonstrated (Whitmore 1991).

The incorporation of information on the responses of wildlife into forest management decision-making is, in most forest regions, equally far in the future. As outlined above, however, animal communities respond quickly and are highly dynamic in the face of disturbance to the habitat. A monitoring system that incorporates faunal parameters will give a more accurate assessment of the state of the ecosystem than would an assessment based solely on tree regeneration dynamics. The recovery of animal groups to pre-logging standards, or at least to a point of stability, when viewed alongside the recovery of a timber resource sufficient to support re-logging, will show whether or not the management system applied can be viewed as sustainable. Means whereby data from monitoring of wildlife can be used to this aim have been suggested. Their use in practice will be reliant on their acceptance by foresters, and, more especially, the extent to which the foresters themselves are actually in control of the forest resources.

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