How to make wildlife conservation more compatible with production forestry: a case study from Kalimantan

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Abstract

This paper summarizes a detailed analysis of the relationship between ecological and life history characteristics of a selected number of Bornean vertebrates and their sensitivity to timber harvest and associated impacts. The data suggest that few species are negatively affected by the simple removal of commercial timber species. Associated impacts, however, such as increased hunting pressure in opened-up forest areas, increased erosion and soil compaction, slashing of lianas and ground cover vegetation, and fragmentation of once large forest areas, can significantly reduce survival chances of wildlife populations in logged forests. Many of these negative impacts can be reduced my management interventions that do not necessarily reduce timber output from a forestry concession. Based on these findings, we provide recommendations for forestry management that, if properly implemented, would increase the compatibility between logging and wildlife conservation.

Introduction

Tropical rainforests are the most species-rich terrestrial ecosystems on earth, but these forests are rapidly disappearing as land is cleared for timber, agriculture, development, and other uses. Strictly protected areas are unlikely to be large enough to conserve the full biological diversity found within tropical forests, and the fate of many species depends upon what happens to other forestlands. Forest areas used for environmentally sound and sustainably productive uses represent an opportunity for biodiversity conservation. Although not a substitute for nature reserves, many species could be conserved within a forest estate that is carefully managed on an ecologically sustainable basis (Frumhoff 1995). Productive exploitation of natural forests generally involves some modification to the ecosystem, and some change in the flora and fauna. However, management choices and operational practices can greatly influence the nature and degree of these changes. Since most tropical forests are considered poorly managed, not just for biodiversity conservation but also for productive exploitation (Poore et al. 1989), there is room for improvement (Hunter 1990; Johns 1997; Sheil & van Heist 2000).

This paper is thus based on the premise that the possibility for sustaining biological diversity in production forests requires environmentally sound management practices that incorporate available scientific knowledge concerning species vulnerability to interventions. Tropical ecologists often choose to emphasize how little is known about tropical forests. Obviously more research is needed, but 'lack of knowledge' is not an excuse for the prevalence of poor practices in forest management. Sheil and van Heist (2000) proposed that there is

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already a considerable body of ecological information relevant to the management of tropical forests, even though in practice little of this is used. They argued that to improve the status quo would require collaboration between ecologists and forest managers to develop pragmatic guidance for improved practices. The review and synthesis on which this paper is based (see Meijaard et al. in press) is one component of trying to achieve this collaboration.

Based on their findings, Meijaard et al. (in press) provided recommendations to four main target audiences:

1. Timber concessionaires
2. Government
3. Researchers and research organizations
4. Local community groups and governmental and non-governmental organizations that address community issues.

The present paper focuses specifically on recommendations to timber concessionaires, especially how changes in forestry management can lead to the maintenance of high biodiversity values in logging concessions. Using studies on different groups of vertebrates we have tried to identify common factors among species that determine sensitivity to logging. Many of these negative factors can be alleviated by relatively small changes in concession management. Although Meijaard et al.'s research focused on a particular part of Borneo (the Malinau area in East Kalimantan), their findings and the recommendations presented in this paper have wider relevance to forest management in Bornean tropical rainforests.

Material and methods

It is often difficult to determine the mechanisms by which forestry interventions affect wildlife. Yet, ecological studies help determine a range of actual and potential factors that may influence various taxa under particular circumstances. A clearly argued account of the various ecological details that might be addressed in good harvesting practices would serve as a guide to the development of more biodiversity-friendly logging guidelines. Current perceptions of supposed 'good' tropical forest management are preoccupied with silvicultural (timber production related) practices and socio-cultural issues. Yet, many ecological and taxa-centered studies, while not addressing forest impacts directly, contain relevant information about life history and habitat requirements for potentially vulnerable taxa. Ecological studies of individual species can identify possible changes in feeding, ranging or other behaviour following logging, and how these changes may affect the process of population change. Such information is useful for guiding forestry activities and further supplements studies examining logging impacts on density and distribution.

Meijaard et al. (in press) compiled the available information on a range of ecological and life history variables of Bornean vertebrates. We hoped that these variables would allow us to make predictions on the extinction probability of wildlife species (including mammals, birds, reptiles, and amphibians) in Borneo. For this, we first reviewed the scientific literature, both peer-reviewed and 'grey' literature (e.g., reports and theses), for references to the ecology and natural history of Borneo's vertebrate species. Based on the availability of information we selected the best-known groups for further analysis. We then compiled and synthesized information relating to the factors that potentially affected vulnerability for each selected species group. Some attributes that may be useful in explaining vulnerability—such as physiological tolerances—could not be included in the analysis due to lack of information. A multivariate analysis of the ecological and life history variables for each of the selected species that best predict their sensitivity to logging and associated processes is still in process. Still, the preliminary data allows us to draw general conclusions about logging and wildlife, and in this paper we will concentrate on those findings and their direct implications for concession management.

Results; species-specific responses to logging

Mammals

There are no comprehensive publications on the effects of logging and associated processes on Bornean mammals, although many have studied these issues for specific species-groups. Primates are fairly well studied in this respect (e.g., Wilson & Wilson 1975; Rijksen 1978; Johns & Skorupa 1987; Johns 1997; Plumptre & Johns 2001; Felton et al. 2003; Morrogh-Bernard et al. 2003). In general, primates, especially the more generalist feeders, appear fairly adaptable to selective logging, changing their ranging patterns and diets to accommodate changes in forest structure and composition (Johns 1997). Johns and Skorupa (1987) showed that, generally, a primate species' degree of frugivory shows a significant negative correlation with its ability to persist in recently logged forests, as expressed by comparative population densities in unlogged and adjacent logged forests. Marsh et al. (1987) suggested that another feature that can influence a primate's adaptability is its degree of terrestriality. Most Old World species capable of colonizing secondary forest are at least semi-terrestrial in habits, which must facilitate survival in small patches. This behaviour, however, also predisposes them to crop raiding, making them vulnerable to hunting.

Diets and degree of terrestriality also appear to determine the sensitivity of squirrels and tree shrews to logging. Among squirrels, there appears to be a reduction in the population density of some species, notably *Ratufa bicolor* (arboreal, frugivorous) and *Lariscus insignis* (terrestrial, feeds on fruit and insects), while populations of *R. affinis* (arboreal, feeds on seeds), *Callosciurus prevosti* (arboreal, feeds on fruits and insects), *C. notatus* (middle canopy, feeds on fruits and insects), and *S. tenuis* (small trees and ground, feeds on insects and fruits) show increases (Johns 1997). These latter species, and especially *C. notatus*, were also found to be present in higher densities after logging than before in Sarawak, but *R. affinis* densities decreased by 71% (Dahaban et al. 1996). Numbers of *R. affinis* had also declined after logging for shifting cultivation in another Sarawak area, while the density of the *Callosciurus* species did not change significantly (Bennett & Dahaban 1995). Syakirah et al. (2000) found that *R. affinis* was absent in a recently logged and further disturbed lowland forest in Peninsular Malaysia, but present in a nearby plot in which forest had regenerated after having been logged in the 1970s. Bennett and Dahaban (1995) and Dahaban et al. (1996) reported a higher density of small *Sundasciurus* squirrels [*S. tenuis* and *S. lowi* (the latter occurs in small trees and on the ground and feeds on fruits, insects and fungi)] in old shifting cultivation areas compared to primary forest, which suggest that these species benefit from the disturbance; *S. hippurus* (mostly terrestrial, feeds mostly on fruit and also insects) was not found directly and two years after logging (Dahaban et al. 1996). This mirrors findings from Peninsular Malaysia, where Laidlaw (2000) only found *S. hippurus* in Virgin Jungle Reserves and not in the adjacent logged forests, while *S. lowi* and *S. tenuis* occurred in both logged and unlogged forests, although no data on relative densities were provided. Another species, *L. hosei*, was only found in unlogged forest, and 4-year old logged forest (Dahaban et al. 1996), whereas *L. insignis* was found in recently logged forest, but not in a regenerated forest block (Syakirah et al. 2000). Also, the ground squirrel *Rhinosciurus laticaudatus* was absent from recently logged forest, but present in the regenerated forest plot (Syakirah et al. 2000). Johns (1997) suggested that terrestrial, largely insectivorous squirrels seem least able to adapt to conditions in logged forests, which would fit the observed decreases in *L. insignis* and *R. laticaudatus*, two insectivorous terrestrial species (MacKinnon et al. 1996, p. 217), and *S. hippurus*, another partly insectivorous species that occurs in low trees and on the ground, and the increase in *C. prevostii*, which is an upper canopy species.

Most *Tupaia* species are primarily terrestrial and as logging is known to affect understorey vegetation it is interesting to see how tree shrews are affected by logging. Emmons (2000) studied this in Danum Valley, Sabah by comparing animal captures in logged and unlogged areas at different times of the year. Other data are provided by Stuebing and Gasis (1989) who studied treeshrew populations in logged forest and in monospecific tree plantations. The two studies suggested that the Lesser Treeshrew *Tupaia minor*, the only arboreal *Tupaia* species, which was found to feed primarily on Orthoptera (Emmons 2000), was eliminated by logging practices that left other species unaffected, probably as a direct result of the destruction of forest canopy. The survival of other *Tupaia* species in logged areas and plantations appeared to depend primarily on the density of understorey vegetation. Emmons (2000) speculated that the large, terrestrial treeshrews which feed on earthworms and invertebrates in decomposing wood remain largely unaffected by logging when the understorey is dense, the ground surface litter layer is shady and moist, and arthropods are abundant near the surface; in plantations where there is little ground cover, the surface is drier, and arthopods and worms may descend deeper into the soil and be absent near the surface. Moreover, such tree plantations may lack decomposing wood as they are generally burned before tree planting.

Civets form a highly diverse and prominent group of carnivores in the Old World tropics. On Borneo alone, there are nine species (Payne et al. 1985). There are both terrestrial and arboreal species. In addition, despite their taxonomic status within the Carnivora, some civets feed almost exclusively on fruit, generally favoring sugar-rich and soft-pulped fruit (Rabinowitz 1991; Heydon & Bulloh 1996). In Sabah, Heydon and Bulloh (1996) recorded a marked decrease in civet density in logged forests. Predominantly carnivorous species were reduced in greater extent than palm civets, which incorporate larger quantities of fruit into their diet. On the other hand, however, in Peninsular Malaysia, Johns (1983) recorded civets as being extremely scarce in unlogged forest. Immediately following the onset of logging several additional species of civet moved into the area. A similar result was reported by Syakirah et al. (2000), who recorded the Malay Civet *Viverra tangalunga* only in recently logged forest, but not in forest regenerated after logging in the 1970s, while Stuebing and Gasis (1989) found *Paradoxurus hermaphroditus* exclusively in plantation areas and not in logged forest. In contrast with the previous results, and those by Heyden and Bulloh (1996), Colón (1999) found in a two-year study that densities of *V. tangalunga*, a largely frugivorous species, were 57% higher in an unlogged site than in a logged one; also, fruit comprised a larger proportion of diet in unlogged forest compared to logged forest. The small-toothed palm civet *Arctogalidia trivirgata* was only found in regenerated and unlogged forest, but not in recently logged forest (Syakirah et al. 2000).

From these data, it can be tentatively concluded that arboreal, frugivorous civets are little affected by logging, whereas terrestrial species, that are carnivorous or feed on insects might be negatively impacted by logging. An explanation for the decline in the latter group is not straightforward. Colón (1999) did not find a decline in the availability of invertebrates in logged forest. Her data showed, however, that fruit constituted a larger percentage of the diet among *V. tangalunga* in the unlogged forest compared to the logged forest, which suggest that reduced fruit availability was the cause to its decline after logging. This appears to be in contrast to the increased densities of other frugivorous civets. Possibly, logging leads to increased competition for fruit, in which *V. tangalunga* loses out to other species. Another possible explanation is that palm civets climb into the trees to eat fruit, whereas *V. tangalunga* eats it off the floor. Maybe the fruiting species that benefit the palm civets in logged forest are not ones that drop lots of still-edible fruit to the floor, or alternatively fruits are removed by palm civets (and other species) before they drop to the ground.

As in primates, squirrels, and civets, the sensitivity of forest ungulates to the effects of logging appears to be primarily determined by their diets. Mouse-deer (*Tragulus* spp.) selectively feed upon fallen fruit from a wide range of species, remaining in one vegetation type and in one small home range throughout the year. Both *Tragulus* species are especially dependent upon fallen fruit of strangling figs (*Ficus* spp.) (Heydon & Bulloh 1997), although they also feed on other items (see Matsubayashi et al. 2003). Of all the ungulate species on Borneo, mouse-deer appear to utilize food items with the highest nutritive value. The two species of muntjac (*Muntiacus* spp.) feed primarily on fruits and browse, being selective for plant parts, and remain within one or a few vegetation types throughout the year. Sambar deer are generalist grazers and browsers that feed on a range of grasses and plant parts; they prefer forest edges, riverbanks, grassy clearings, secondary scrub, and open farmlands (Nowak 1999), but they also occur in dense interior forest.

Johns (1997) found *Tragulus* to be more common in logged forests than in mature forests in Peninsular Malaysia. Densities tended to decrease again in older logged forests. However, in Sabah, Heydon (1994) and Davies et al. (2001) reported an average decrease of 55–66% in the density of *T. javanicus* and a 71–90% decrease in the density of *T. napu* in selectively logged forest compared to unlogged forest. Mouse-deer densities were positively correlated with fruit abundance (Heydon 1994), which decreased primarily because of the removal of strangling figs. Heydon (1994) suggested that their obligate frugivory limited their ability to compensate for the reduced abundance of selected fruits found in logged forests by utilizing browse. However, the ecological adaptability of mouse-deer was observed by Laidlaw (2000), who regularly encountered *Tragulus* spp. (not identified to species level) in tree plantations and bush land in Peninsular Malaysia. The utilization of disturbed habitats by *T. javanicus* was confirmed by Matsubayashi et al. (2003) who found that in Sabah, these mouse-deer primarily feed in crown-gap areas dominated by bamboo stands, probably because they prefer fruits and soft leaves of pioneer plants with lower concentrations of secondary metabolites. For frugivorous animals these crown gap areas are good foraging sites because many pioneer plants in gap areas produce fruit several times a year, whereas most climax species in mature forest produce fruit once a year in limited season (Whitmore 1998).

Duff and colleagues (1984) and Heydon (1994) reported an increase in the frequency of *Muntiacus muntjak* sightings in logged forests compared to unlogged forests, and the latter author reported a concurrent decrease in *M. atherodes*. *M. muntjak* appears to include a higher proportion of browse within its diet than the two species of mouse-deer and *M. atherodes* (Barrette 1977). This may explain its better competitive ability in logged forests. Grazers are generally not dependent upon undisturbed forests and are generally not negatively affected by logging activities (Davies et al. 2001). Sambar (*Cervus unicolor*) make use of logging roads to feed on roadside grasses; it appears that they use such roads as alternative forage areas and as corridors between favourable forest sites, including logged areas. Their numbers are positively correlated with the area of severely degraded forest and negatively associated with the area of climax stage forest (Heydon 1994).

Little is known about the remaining Bornean ungulates, *Sus barbatus* and *Bos javanicus*. Based on what is known of Bearded Pig ecology it can be inferred that logging impacts on major fruiting crops can affect their migratory patterns, distributions, and possibly densities thereby influencing dispersal and regeneration of other fruiting species (e.g., Meijaard 2003). Hoogerwerf (1938 in Brookfield 1997) suggested that grasslands, savannas, and secondary forests are the favoured *B. javanicus* habitats rather than rainforest in which they were hardly able to survive. This was also reported by Banks (1931) who claimed that *B. javanicus* depends on forest areas that were cleared for agriculture, as they feed in secondary forest and on agricultural fields, and that dense forest areas are of little use to this species. Because *B. javanicus* is often found in the vicinity of agricultural fields and forest gardens, where they destroy crops, they are hunted as pests. It is therefore expected that it benefits from forest clearing, except when high hunting pressure keeps populations down.

Birds

Lambert and Collar (2002) recently provided a list of Sundaic bird species that are most likely to be affected by the processes of logging, fragmentation, and hunting. Terrestrial and understorey insectivorous species were particularly vulnerable to the effects of logging, and to a lesser extent some insectivores, particularly sallying species, that inhabit the lower and mid-levels of the forest. Birds typical of the canopy appeared to be much more resilient, and, with the exception of the highly specialized Green Broadbill (*Calyptomena viridis*), frugivorous and nectarivorous species were rarely suspected of declining in logged forests. The groups that are most affected by logging comprise: (1) some extreme lowland specialist species, because logging in these forests is most intense (Black Hornbill *Anthracoceros malayanus*, Crestless Fireback *Lophura erythrophthalma*), (2) nomadic species, or species requiring large areas (hornbills, raptors), (3) primary forest species, intolerant of logging disturbance (Great Argus *Argusianus argus*, some trogons, some woodpeckers, some babblers, and some flycatchers), and (4) species that require large cavities for nesting in.

The most seriously affected taxa are those species of the primary forest interior. Terrestrial insectivores and low- to mid-understorey flycatchers are consistently vulnerable to logging practices (Johns 1989; Lambert 1992a, b; Thiollay 1992). Among avian understorey insectivores, both the number of species present and their proportional representation within the population sample changes following logging at moderate intensities. Lambert (1992a) identified, among others, trogons *Harpactes* spp., woodpeckers (Picidae), wren babblers (*Kenopia striata* and *Napothera* spp.), and flycatchers (*Cyornis* spp. and *Ficudela* spp.) as prone to decline in logged forests. Declines are believed to reflect the loss of understorey vegetation, foraging substrata and the associated cryptic insect prey that understorey insectivores specialize on (Robinson 1969). However, physiological conditions (i.e., high temperature and water stress) appear more significant than local food abundance in determining the ranging of some understorey species in Panamanian forests (Karr & Freemark 1983). Microclimatic conditions are altered by loss in canopy cover and understorey species are often reluctant to cross open spaces or dense second growth that separates remaining patches of undisturbed forest. Forest interior insectivores may also be displaced by flycatcher species more characteristic of edge habitat, or by the invasion of bulbuls (Pycnonotidae). These transient frugivorous species are associated with rapidly growing pioneer species, but also include insects in their diet. The fruits found in regenerating logged forests may support higher abundances of insectivore-frugivores, such as bulbuls, and result in increased competition with specialized insectivores, but evidence is lacking.

Frogs and toads

Frogs and toads (= anurans) display a large diversity of reproductive modes with complex life cycles that include a larval form (tadpoles) requiring different habitats and resources than the adult forms (e.g., Inger & Voris 2001). Some Bornean species of amphibians carry out almost their entire life cycles in leaf litter. Other species inhabit the lower canopy only, using small vines and other water holding plants and substrates for egg deposition and tadpole development. Anurans may therefore be sensitive indicators of habitat quality because in order to complete their life cycles they may require a greater variety of specialized resources in a specified order.

Logging may directly and indirectly affect anurans through its impact upon ponds and streams in the immediate vicinity of logging operations, on watersheds throughout the area, and through impacts on microhabitat conditions in the forest leaf litter in non-riparian habitats. Streams and ponds provide microhabitats for frogs and most frogs require aquatic habitats for reproduction. Frog species that rely on water held in plants and treeholes will be heavily impacted by the direct loss of sites to deposit eggs. During development and metamorphosis, larval frogs are sensitive to changes in water chemistry and physical characterisitics of aquatic habitats. Research in Sabah showed that destruction of the lower vegetation and destruction of the floor litter leads to extreme levels of erosion during rains with enormous increase in sedimentation levels in streams, while also affecting water chemistry (Douglas et al. 1992; 1993). Sedimentation has a clear, detrimental effect on reproduction in several species of stream-breeding frogs, effectively preventing survival of tadpoles (R. Inger, *in litt.*, 3 October 2003). Changes in nutrient composition, pH levels, and temperature may lead to malformations and death among larval anurans (Feder & Burggren 1992; Ouellet et al. 1997).

Virtually all leaf litter anurans depend upon the structural but constant diversity of the leaf litter microhabitat for predator escape, nesting, and upon the diversity of leaf litter arthropods for food (Scott 1976; Vitt & Caldwell 1994, 2001). Logging, primarily through the creation of gaps, drastically affects the ground level environment of tropical forests through changes in incident light, temperature, humidity, and rates of litter accumulation. The removal or change in quality of the leaf litter directly and indirectly affect anurans through loss of microhabitats that provide refuges from predators and dessication and through reduction in food resources (Zou et al. 1995); the greatest diversity of leaf litter arthropods was in the mature forest. The effect of variation in leaf litter arthropods – the primary food of leaf litter anurans – on growth and reproduction is virtually unstudied in the tropics (see Vitt & Caldwell 1994).

Evidence for amphibian declines following logging was provided by Iskandar (1999a, b), who studied this topic in North Sumatra. He found that logged forests contained only about 20% of the individuals found in an unlogged forest of the same area. Abundance was strongly correlated with the amount of forest litter. As opposed to these findings, Iskandar (2003) reported that in areas in Malinau where logging was performed in 1995–1996, the relative abundance of amphibians and reptiles was about 2.1 specimens per plot (n = 21), but in unlogged forest the relative abundance was only about 0.95 specimen per plot (n = 51). At present, there is no explanation as to why the unlogged area has fewer specimens compared to other areas affected by logging, although the species composition in these areas is more or less the same. One possible explanation is that both the reduced impact logging and conventional logging plots in Malinau still had more or less closed canopy forest, and that the difference between these plots and unlogged forest was small. In the North Sumatran study mentioned above, every large tree had been cut in the logged areas.

In conclusion, the wide range of ecological specializations in Bornean frogs makes it hard to generalize on the effect of logging on species richness and abundance, but it appears that at least some species are little affected by logging. Clearly, species such as *Fejervarya cancrivora* and *Rana nicobariensis* cope well with logging as these are commensals of man and not rain forest species. Whether any forest species are truly unaffected by logging remains unclear.

Reptiles

Little useful information was found on the effects of logging on Bornean reptiles (but see Meijaard et al., in press). Hunting and collecting, however, has significantly reduced (locally to extinction) populations of terrestrial and fresh water turtles and crocodiles.

Fish

Rachmatika et al. (unpublished) conducted extensive surveys of the fish faunas of the upper and lower Seturan River in the Malinau area. Among others they investigated how fish species are affected by logging. The results showed that hillstream loaches and other site-specific demersal species (*Gastromyzon spp*., *Garra borneensis*, etc.) seem the most affected but some benthopelagic herbivorous or frugivorous species (*Lobocheilos bo* and *Tor spp*.) also appear absent in logged areas. Rachmatika et al. reported that these results are coherent with the life-history of the species present and with the few available published references (Martin-Smith 1998a,b). Given their low mobility, their sensitivity to siltation and their general abundance in undisturbed sites, the suckerbelly loaches (*Gastromyzon*, *Neogastromyzon*, *Protomyzon*) and the stone-lapping minnow (*Garra borneensis*) could be used as early warning bioindicators for monitoring logging impact.

A very depauperate fauna characterized ponds and their outlets, and a total of only 16 species was recorded from this type of environment. All the vulnerable demersal species were absent except for one specimen of *Anguilla malgumora* at the outlet of one of the ponds. Some species appeared, however, to be over-represented in ponds: *Cyclocheilichthys armatus*, *C. repasson*, *Nemacheilus saravacensis* (36%), *Puntius sealei* (29%). *Betta unimaculata* seemed to prefer outlets and was absent or rare in the ponds proper.

Several of the surveyed species present specific auto-ecological or biological features that might be of importance in the context of existing logging or coal-mining operations in the region. Since demersal species live on or near the river bottom and feed on benthic organisms, they could be affected by excessive siltation created by logging infrastructure (culverts, crossing of river by heavy equipment, etc.). Eels (*Anguilla*), spiny eels (*Mastacembelus, Macrognathus*), bagrid (*Leiocassis* sp., *Hemibagrus* spp.) or sisorid catfishes (*Glyptothorax platypogonoides*), hillstream loaches (*Gastromyzon*, *Neogastromyzon*, etc.) are all demersal fishes.

Other potentially vulnerable species are the benthopelagic fishes that feed on micro-algae (*Lobocheilos bo*, some *Osteochilus sp*., *Tor spp*.) or forest fruits and plants (*Leptobarbus melanotaenia, Tor spp*.). These fishes can be affected by a reduction in food availability following logging.

Discussion

In this paper we have documented the responses of a wide range of vertebrates to the effects of logging. Although vertebrate species vary widely in their ecological requirements there appear to be common determinants of the effects of logging on their survival. Maintaining a dense and moist understorey seems to be particularly important for many species. Also maintaining connectivity between forest patches appears important, as is the protection of fruit trees such as figs and retaining dead wood. Meijaard et al. (in press) also discussed the effects of hunting, which often affect species much more than logging itself (Bennett et al. 2002). Although this is a generalization — e.g., in some areas of Java and Sumatra little hunting takes place, but species are seriously threatened by forest loss (e.g., Robertson & van Schaik 2001; Kinnaird et al. 2003; Hedges et al. in review) — it is probably true for most parts of Borneo. Despite the successful establishment of many protected areas where the forest remains largely untouched by logging, many of these areas are increasingly becoming ‘empty forests’ (Redford 1992). The threat posed by hunting is especially great in tropical forests, because of the extremely low productivity of edible wildlife (Bennett et al. 2002). Hunting is likely to lead to changes in wildlife population densities, distributions, and demographies which can then lead to shifts in seed dispersal, browsing, competition, predation, and other community level dynamics. How all these factors relate to each other remains unclear, but the overall result is that most larger vertebrates in Borneo and some specifically targeted species such as turtles, crocodiles, ungulates, and certain birds have in many areas been hunted to virtual extinction (Bennett et al. 1997; Bennett et al. 1999; Robinson et al. 1999; Bennett & Robinson 2000).

The three factors of logging, fragmentation and hunting often occur simultaneously, and it is not always possible to determine the individual contribution of each factor to a perceived population decrease or increase of certain species—indeed they will almost certainly act together. Lambert and Collar (2002), who analyzed existing datasets on birds, stated that there appear to be fundamental differences between the effects of logging and fragmentation on Sundaic lowland forest species. Selective logging usually results in the loss or extreme rarefaction of certain insectivorous species, particularly those of the dark understorey and in terrestrial foraging guilds, but there is little evidence of intolerance to logging in the majority of frugivorous and nectarivorous species. Also, arboreal and canopy species that primarily feed on fruit were much less affected, or even benefited from some logging. This mirrors findings by Crome et al. (1996) who similarly found that few, if any, bird and small mammal species, were negatively affected by logging in the Australian tropics. By contrast, fragmentation affects a broad range of bird species—omnivores, insectivores, frugivores and nectarivores— and including virtually all species negatively affected by logging.

The effects of logging on mammals to some extent mirrors those on birds, with terrestrial and insectivorous squirrels and civets appearing most severely affected by logging. These results are based on fewer data than those for birds. No detailed studies have been conducted on the effects of fragmentation on Sundaic mammals, although Meijaard et al. (in press) used distribution data of island mammals in the Sundaic region to model the effects of fragmentation on mammal survival in small forest areas.

Overall, it appears that increased hunting pressure in logging concessions (because of high local demands for bush meat and increased road density after logging) is having a very high impact on species that are targeted by hunters (ungulates, primates, specific bird species, such as hornbills and Straw-headed Bulbul *Pycnonotus zeylanicus*, and turtles and crocodiles). Logging seems to primarily affect species that rely on abundant invertebrate populations in the understorey, while some non-flying arboreal species seem to be affected by the increased opening of the forest canopy. Fragmentation, finally, appears to mostly affect species that occur at low densities and have large home ranges (carnivores, and migrating species). More work will soon be conducted on the individual contribution of each of these factors to species declines following logging, but the available data already allow some tentative conclusions and recommendations for improved production forestry management.

Recommendations to production forestry in Kalimantan

Having approximated how vertebrate species are affected by logging, we would like to highlight some of the changes in concession management that could significantly boost wildlife survival in logged forests. Firstly, it is important to realize that, according to Act No. 5 of 1990 of the Government of Indonesia, concession managers in Indonesia have the obligation to prevent any activities detrimental to the survival of protected species (Ministry of Forestry 1990). This legal requirement has generally been ignored in the past and in many cases forests have been logged and clear-cut irrespective of the protected species that inhabited the areas. Clearly, improved law enforcement in concessions and increased accountability of concessionaires for their forest management is needed.

In addition, Meijaard et al. (in press) pointed out the inadequacy of the Act no. 5 of 1990 on protected species, because many species that are threatened with extinction are not included on the list of protected species. There is an immediate need to address this issue by investigating which IUCN listed species are presently not protected in Indonesia. With regards to this we suggested the following priorities regarding Malinau's species. Prime candidates for inclusion on the Indonesian list of protected species are *Ciconia stormi*, *Manouria emys*, *Orlitia borneensis*, and *Pelochelys cantorii* (all listed as Endangered by the IUCN), *Lophura erythrophthalma*, *Pycnonotus zeylanicus*, *Ptilocichla leucogrammica*, *Rollulus rouloul*, *Spilornis kinabaluensis*, *Treron capellei*, *Amyda cartilagina*, *Notochelys platynota*, and *Macaca nemestrina* (all listed as Vulnerable), and *Presbytis hosei* (listed as Data Deficient by the IUCN). In addition, the government should investigate whether some species that are presently protected can be hunted for subsistence, e.g., *Cervus unicolor*, *Muntiacus muntjak*, *Tragulus javanicus*, and *T. napu*; this would require a change in the protection status of these species. Before doing so, the government should bear in mind that forest-dependent species such as the mouse-deer (*Tragulus* spp.) require the protection of large forest areas from settlement and fragmentation before any hunting can be considered potentially sustainable.

Once, the list of protected species is updated in accordance with global threat levels, there is an important need to identify the activities that are most detrimental to the survival of these species. As pointed out above, hunting is one of the most damaging to certain species that are targeted for consumption or trade, and its regulation should be a top priority in well-managed logging concessions. In Borneo, low forest productivity for wild animals places limits on the amount of exploitation and habitat modification that can be done sustainably. Bennett and Robinson (2000) and Fimbel et al. (2001) provided suggestions of how to curtail hunting in forest concessions. This includes:

- Closing non-essential roads as soon as the operations are complete, which prevents hunter access from those roads, reduces market access, commercial hunting, and illegal trade, and it also reduces the opportunities for illegal re-entry logging;
- The establishment of conservation zones within the concession where hunting is not allowed;
- A prohibition on snare hunting as wasteful and unselective;
- A prohibition on hunting protected species;
- The banning of commercial hunting throughout the concession;
- The development of a system of official hunters for controlled legal take of certain species for subsistence;
- Ensuring that adequate fresh protein supplies are available to all staff and workers, thereby removing the need for them to hunt;
- Link pay to productivity in an effort to reduce time available to employees for hunting;
- Preventing logging company vehicles from carrying wildlife, thereby ensuring that they cannot be used for wild meat trade. Security checks at concession entry/exit points can enforce this measure as well as increasing security and preventing log theft.
- Use contractual clauses specifying that violation of any of these regulations may result in loss of job, and meaningful enaction of this to malefactors.

Habitat heterogeneity and structural diversity are amongst the most important factors determining species-rich communities in natural forest settings, and the maintenance of these factors is important. Interventions may also be directed towards conserving specific resources or features (e.g., food trees, lianas, salt licks, caves, clean rivers), with importance for certain taxa. Such measures are relevant within harvesting zones, although these should be taken in addition to the identification of larger areas that will be excluded from any harvesting. Our recommendations concerning this include the following:

Reducing incidental damage to forests during harvesting. In particular, it is important to reduce the area of severely damaged forest, along tractor skid trails and log-loading areas, where vegetation and topsoil are most often removed. These areas are usually colonized first by vines and later by pioneer tree species. In general, except for some herbaceous *Ficus* and some lianas such weedy pioneers are not a good food resource for the majority of mammalian and avian frugivores (Chivers 1980). Worse still for vertebrate frugivores is the fact that one, or at most a few, species of pioneers tend to dominate in any particular area. Areas dominated by such trees and vines are in effect food deserts to many frugivores. Any reduction in the area of heavily disturbed forest should benefit frugivores by limiting the growth of pioneers. Also, minimizing the number of discontinuities in the canopy should reduce the impact on locomotion of nonvolant arboreals animals (Putz et al. 2001). Specific measures such as mapping important food or habitat trees, and special sites (e.g., burrows, wallows, riparian areas, salt springs), planning placement of skidder roads, use of light-weight, narrow, and wheeled rather than caterpillar skidders should reduce damage and reduce opportunities for invasion by pioneers. Practices can be improved if skidders are used; examples would be to drive with the blade up, reversing out of skid trails, and exploring extraction routes on foot rather than from the cab. Such changes require training and modified incentive schemes — but should lower operating costs as well as reducing damage. Other low-impact extraction methods should be explored, these include extraction by draught animals, lighter machinery, machinery with broad rubber tires, helicopters and skyline cables. These can considerably reduce soil compaction and erosion, and damage to non-harvested trees and vegetation in general.

Preserve canopy and mid-canopy fig trees. Regarded as a keystone food resource for a wide range of tropical frugivores, fig trees have special significance in preserving fauna. Figs (*Ficus* spp.) are especially important for wildlife as they provide fruit throughout the year, and fulfil vital nutritional needs, such as the calcium needed by vertebrates living on otherwise mineral poor diets (see O'Brien et al. 1998). Strangling figs also provide important refuge habitat for primates, civets, bats, rodents, squirrels, bears, binturongs, and birds. Because of the canopy germination habit of many figs, protection of larger mature individuals appears the only viable measure of conservation during felling (Johns 1997); however, given the extended length of time to maturity, efforts should be made to conserve as many figs as possible, regardless of age.

Interior forest conditions should be better protected. Many vertebrates, especially amphibians, reptiles, and forest interior birds, require moist, relatively shady conditions. By maintaining as much canopy as possible, lower levels of the forest will not be subject to the drying influences of intense sunlight. Preserving the forest canopy will also aid in preserving leaf litter habitat. Roads and trails should be planned carefully, and constructed in a way that minimizes canopy damage. They should be kept short and narrow (a maximum overall width of 4 m is recommended by DFID 1999) and, if possible, overhead canopy contact should be maintained. The area scraped and compacted by heavy machinery should be minimized; this is more effective revegetation management than attempting to rehabilitate these areas following logging (Pinard et al. 1996; Pinard et al. 2000).

Standing dead or part dead trees should be left standing or intact. Large, old and hollow trees have considerable significance for many forest taxa that utilise or are dependent on them, e.g., hornbills (Datta 1998; Whitney et al. 1998; Whitney & Smith 1998), woodpeckers (McNally & Schneider 1996) and other hollow tree users (Zahner 1993), including bears, civets, and porcupines. The loss of such large stems can have long-term influences (Gordon et al. 1990) and, although not well documented, is a potential cause of otherwise inexplicable decline or failure in forest regeneration in various parts of the world, another factor possibly being the loss of mycorrhizal fungi that slows down recolonisation of clear-fells. Trees that are infected by heart-rot should be retained as much as possible as these provide hollows of importance to vertebrates that use them for breeding, nesting, and food storage. A traditional silvicultural technique for fighting heart-rot fungi is too remove dying and dead trees and burning them (Elouard 1998), and it needs to be assessed how much is gained or lost in economic and ecological terms if this practice is continuated.

Retain ground cover. Of special note in Indonesia, is that within the logging regulations, concession-holders are legally required to repeatedly slash all undergrowth and climbers for several years after felling with the intention of reducing aggressive 'weeds' and encouraging regeneration; in practice, though, this has a deleterious effect on many species, including rattan and timber seedlings (see 2003a; Sheil et al. 2003b). Unfortunately this activity seems to have been largely unrecognised by conservationists and has not been assessed. In Malinau, it is notable that compartments slated for logging are often incompletely accessed due to extreme gradients and rugged difficult terrain — so it is not uncommon for more than half a logged compartment to remain unlogged after harvesting is 'complete' — in contrast the slashing treatment is applied on foot and no areas are omitted making it a much more general and obvious impact on 'logged areas' (D. Sheil, pers obs. 1998–2003). Even if applied properly, the silvicultural benefits of the technique appear limited while the impacts on biodiversity and communities are considerable (note that the impacts of slashing on wildlife are not closely assessed but it is clear that the understorey is greatly affected (Sheil et al. 2003a, b; Sheil unpublished data). Slashing of undergrowth and climbers may be as damaging to the forest as harvesting itself and we suggest that the policy that stipulates it be reviewed.

Prevent siltation of streams. Many amphibians, and some reptiles, birds, fish, and possibly otters and the Otter Civet (*Cynogale bennettii*) depend on clear water for breeding and feeding. Proper drainage systems that feed into vegetated areas and well-constructed and well-maintained bridges and culverts are important in keeping streams clear. Furthermore, law requires the establishment of logging exclusion zones around streams and waterways. Proper implementation of these laws will have a significant positive impact on aquatic ecosystems in timber concessions.

Avoid soil compaction. Whenever possible soil compaction should be reduced by limiting logging activities to dry periods, or by planning different working areas for dry weather and wet weather to minimize erosion (DFID 1999). Many species of tropical reptiles and amphibians are fossorial or spend significant periods of time below ground. Logging during dry periods may also limit stream siltation resulting from opening of the canopy. One means to improve soil recovery is to ensure that small woody waste ('brash') is added onto the surface of skid trails during operations – this reduces erosion and increases subsequent biological activity in the soils, speeding soil recovery.

Maintain interior forest connectivity. Maintaining corridors of interior forest can have positive effects on the vertebrate fauna (Marcot et al. 2001). Corridors of habitat connect patches of undisturbed forest, thus facilitating dispersal of animals that will not enter open areas. In Meijaard et al.'s (in press) recommendations a forest area network is suggested. This is based on two forest elements: reserved areas and linking corridors. Reserved areas are protected for what they are or what they do (e.g., watershed protection, hunting areas, grave-sites, critical habitat for particular species). Corridor forests are sections of forest required to keep these reserved areas connected to each other.

*Ensure adequate recovery periods***.** There is a need of the organization of annual felling coupes with some degree of dispersal throughout the forest to facilitate regeneration and migration of wildlife disturbed by logging (DFID 1999). If possible, this should involve closing some roads temporarily so that animals can migrate undisturbed and hunting pressure is reduced. The main means to do this is to dismantle river crossings (culverts) or by gating, and, when no longer in use, roads should be permanently closed (blocked or partially destroyed) (Mason & Thiollay 2001) and rehabilitated to a more natural condition.

*Ensure implementation of legal requirements***.** Means of enforcement should be built into guidelines. Since the Ministry of Forestry and local governments control logging and the concession controls security, it should be a combination of self-policing with check-ups by KSDA, and other designated government representatives. Opportunities for involvement and verification should be given to other major stakeholders (community representatives, NGOs etc.) and to agreed third parties. Foresty certification audits, if applicable, provide one means to gauge success.

If carried out in areas selected for logging, these recommendations should help considerably in protecting populations of vertebrates in tropical forests. However, these recommendations will not be successful without an overall plan for sustainable management of tropical forests and appropriate implementation of enforcement measures. Blockhus et al. (1992) proposed such a plan, which included

- Creation of a protected system linked by natural forest corridors;
- Establishment of monitoring programs to ensure effective implementation;
- Implementation of remedial action before changes are irreversible.

Finally, long-term goals should balance economic benefits with environmental costs to conserve all components of biodiversity, including vertebrates.

Conclusion

Our research has indicated that well-managed selective logging can be compatible with wildlife conservation in Kalimantan. This appears to go against the general opinion among conservationists that logging and conservation are mutually exclusive, which is probably related to the fact that, so far, logging in Kalimantan has not incorporated into its management many of the required measures that would reduce the impact of logging on wildlife. There is therefore much room for improvement. We suggest a number of changes in concession management and legal matters that could significantly improve survival chances of vertebrates in Bornean production forests. Whether my recommendations are implemented primarily depends on the willingness of the Indonesian government to enforce its own conservation laws.

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