Fragmentation – a Serious Threat to Ancient Forests: Summary of Current Scientific Knowledge

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- A Summary of the Current Scientific Knowledge -

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This paper presents a scientific overview of the effects and consequences of fragmentation of ancient (primary) forests.

Summary
Fragmentation of forests is caused by introducing a break in an otherwise intact area of forest, e.g. by deforestation or road building. Fragmentation seriously degrades or impoverishes ancient (primary) forest, making it vulnerable to fires in dry periods and future logging and hunting. Microclimate effects along the forest edges (edge effects) are an important consequence of fragmentation, altering the composition of the vegetation. Edge effects and fragmentation of ancient forests have serious consequences for wildlife and the ecology of forests, including large mammals, which require large ranges and whose absence will disrupt the ecological balance of the forest. Therefore, fragmentation is especially important in large tracts of ancient forest as it undermines their ecological integrity. Preventing the fragmentation is essential to maintaining the resilience of ancient forests and their associated flora and fauna to climate change and conserving current forest carbon stocks.

Introduction
Ancient (or primary, natural, old growth) forests are the remnants of the original forest cover originally present under the prevailing climatic regime and preceding the growth of human influence. Only 20 % of the original forest cover remains as large tracts of ancient forest[1] *i.e.* intact and fully functioning areas of primary/natural/old growth forest ecosystems dominantly shaped by natural events and with comparably small human impacts.

Fragmentation is the interruption of an area of intact forest, which creates a break in the forest landscape. The agents of fragmentation are manifold, but include logging, road building, mining and clearance of agriculture land. Previouslarge tracts of intact ancient forest are reduced to an ever smaller and increasing number of isolated patches dominated by edge effects.

Fragmentation threatens the ecological integrity of these large areas of intact, ancient forests (frontier forests[2]).

Values of Large tracts of intact ancient forests

Large tracts of intact ancient forests are important in:

- **Providing local and global ecosystem services:**
  The remaining areas of large tracts of ancient forests are vital to the global ecosystem. In addition to local or regional ecosystem services such as regulation of rainfall and the supply of water, large tracts of intact ancient forest provide ecosystem services that are of global importance, particular in regulating atmospheric gases (see below).

- **Maintaining a "cradle" of biodiversity.** Large tracts of intact ancient forest are important reservoirs of biodiversity. Because of their long standing and relatively lower levels of human disturbance, ancient forests are typically richer in biodiversity than other semi-natural forests or plantations. In addition, the large extent of the forested area permits large mammals, such as primates, to exist in viable numbers. The economic and ecological benefits of most elements of biodiversity harbored in large tracts of ancient forests still remains to be yet assessed.
- **Regulating atmospheric gases, including O_2 and CO_2.** Large tracts of ancient forest play a major role in maintaining the balance between the oxygen and carbon content of the atmosphere. Deforestation and fragmentation increase vulnerability of carbon stocks within ancient forests.
- **To a limited extent, absorbing current anthropogenic emissions of CO_2.** Ancient forests are important stores of carbon. It is now recognised that, in recent years, intact, ancient forests have been able to absorb a proportion of increased carbon dioxide (CO_2) emitted as a result of man's activities. However, it should be noted that this effect is considered short term.
- **Their value as livelihoods and cultural homes of indigenous peoples**
  Indigenous peoples and traditional forest dwellers depend on these intact ancient forests for their traditional livelihoods and their culture.
- **Their intrinsic value as landscapes:** ancient forests have an intrinsic or ethical value.

Consequences of Fragmentation

Fragmentation of intact ancient forest is the first step in their degradation, leading to a loss of ecosystem services and ultimately the loss of the forest itself. Degradation of large tracts on ancient forests results in: disruption of water supplies, leading to droughts in some places and floods in others; deterioration of water quality, as the forest will no longer be able to filter and purify the water and increased soil erosion, leading to a higher frequency of landslides and the silting up of rivers. Climate will be affected, both locally and also globally, as large tracts of ancient forests play a key role in the functioning of the global biosphere through carbon and water cycling. The planet's ability to cope with climatic change will be diminished though a loss of genetic biodiversity. In addition, effects may be remote from the actual site of forest degradation; e.g. a recent study has reported that lowland deforestation in Costa Rica has seriously affected the formation of clouds characteristic of Costa Rica's montane cloud forest[3]

Effects of fragmentation

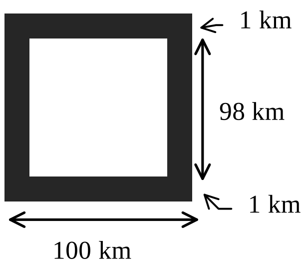
Fragmentation of ancient forests is now recognised as an important factor in the degradation of the forest ecosystem. Fragmentation is particularly deleterious in areas of large tracts of ancient forests as these are of high biodiversity with a fully functional ecosystem, which is undermined by fragmentation.

- **Edge effects**

An important consequence of forest fragmentation is the increase in forest edges. Along these edges of forests are strong microclimatic gradients, or edge effects. These include light, temperature, soil moisture content and wind turbulence. It has been suggested that a 500-1,000 m (0.5 - 1.0 km) buffer zone is needed to accommodate all edge effects[4]. Edge effects increase dramatically with fragmentation, see Figure 1. Importantly, as fragmentation and deforestation continues, the proportion of the remaining total area of ancient forest affected by fragmentation increases.

Figure 1 Forest Fragmentation and Edge Effects

Consider a hypothetical block of forest 100 km x 100 km with edge effects extending for 1 km (shown in black) as shown in Scenario (A). In Scenario (B) a feature, e.g. a road is built through the forest block separating the block into two. In Scenario (C) a second feature crosses the forest block, further disecting the block. The total area of the forest is considered constant.

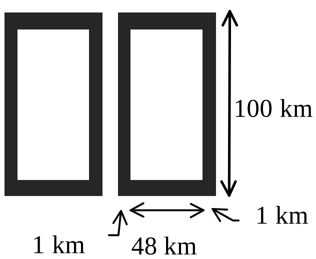


Scenario (A) Forest in a single block

Total area = 100 km x 100 km = 10,000 km^2

Area affected by edge zone = (2 x 100 km x 1 km) + (2 x 98 km x 1 km) = 396 km^2

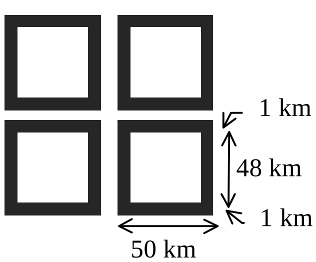
% of forest area affected by edge zones =396/10,000 x 100 % =**4.0 %**



Scenario (B) The forest has been cut in half by, e.g. a road

Total area = 2 x (100 x 50) km = 10,000 km^2
Total area affected by edge zone
= 2 x [(2 x 100 km x 1 km) + (2 x 48 km x 1 km)] = 592 km^2

% of forest area affected by edge zones 592/10,000 x 100 % = **5.9 %**



Scenario (C) The forest is now cut into four blocks

Total area = 4 x [50 km x 50 km] = 10,000 km^2
Total area affected by edge zone
= 4 x [(2 x 50 km x 1 km) + (2 x 48 km x 1 km)] = 784 km^2

% of forest area affected by edge zones 784/10,000 x 100 % = **7.8 %**

In both Scenario (B) and (C), the area influence by edge effects increases as fragmentation increases, whilst the total area of forest remains the same as in Scenario (A). In Scenario (C) the area influenced by edge effects is has approximately double that in Scenario (A).

Edge effects influence the trees that comprise the ancient forest. It has been estimated that fragments of forests up to 10 km^2 will be composed almost entirely of edge-affected habitat[5]. Not only do more trees die near ancient forest edges, but a higher proportion these trees are large[6]. Large, mature trees are important for animal shelter and reproduction.

Microclimates along edges are hostile to regeneration. Seed germination in rainforest fragments has been shown to be impaired, with seeds in ancient forest fragments suffering from edge effects including hotter, drier conditions and increased light penetration[7].

Edge microclimates affect forest structure, leaf fall and turnover in plant community[8]. There is a shift to pioneer tree species away from tree species characteristic of old growth areas along the forest edge. There is also an increase in tree structural parasites such as vines, which block out light, further preventing forest regeneration[9]. Edge vegetation structure is important as it acts as a barrier to invasive or weedy species. Seed crossing was found to be higher when edge vegetation was thinned and penetrated deeper into the interior of the ancient forest[10].

Secondary growth may eventually achieve a balance between exposure and regeneration. However, if the regeneration environment is harsh (e.g. Brazilian Atlantic forest, where burning of plantations and herbicide application are routine), the forest is unable to regenerate at the edge or to buffer its interior resulting in impoverishment of the remaining ancient forest interior[11].

- **Effects on ecosystem function**

A patchwork of forested areas differs markedly from continuous forest in composition and ecology[12]. Fragmentation leads to genetic isolation of plants and animal species, reducing genetic biodiversity of species.

Fragmentation of ancient forests affects the resident large mammals and can induce far-reaching changes in the ecology of the forest. Species with a wide range, e.g. large mammals[13] are particularly vulnerable to fragmentation, not only from genetic isolation but also as it restricts their ability to roam in search of food. Forest dwelling, large mammals require locks of habitat that are thousands, if not tens of thousands, of square kilometres in size[14]. Many large mammals that depend on forests are endangered, including the great apes (gorillas, chimpanzee, bonobos and orangutans) species of tigers, elephants and bears. Ultimately, this could result in a loss of large mammal species, reducing biodiversity.

Large mammal species have important influences on forest ecosystems. Their disappearance, especially predators, from ancient forest ecosystems can lead to elevated abundances of smaller species in fragments, thereby upsetting the ecological balance of the ancient forest. This effect is not restricted only to predators, the survival of certain tree species is considered at risk in the Brazilian Atlantic forest either from local extinctions of fruit eating vertebrates (mostly birds and mammals) which are key to seed dispersal, or from their restricted range caused by fragmentation[15].

Ultimately, loss or restriction of a required habitat for a species can eventually lead to its extinction. If this species is a “keystone species” in ecological terms (i.e. performs a key linkage in the food web or as a seed dispersal agent), then its extinction may cause cascade of linked extinctions, altering the food web[16]. This can have deleterious effects to the functioning of the ecosystem and the local and global ecosystem services provided by large tracts of ancient forests.

Fragmentation effects are not restricted to vertebrates. Numerous studies have shown butterflies, ants, beetles and termites respond negatively to fragmentation and edge effects[17]. Therefore, fragmentation has serious consequences for wildlife and the ecology of ancient forests.

- **Forests, carbon stocks and climate change**

Fragmentation of ancient forests associated with deforestation plays an increasingly important part in increasing the vulnerability of carbon stocks, especially with regard to the expected impacts of climate change.

Globally, ancient forests represent a significant terrestrial store of carbon. Forests have been shown to take up carbon from the atmosphere and this is thought to have absorbed a proportion of anthropogenic emissions[18]. Indeed, intact ancient forest in the Amazon has been shown to take up carbon from the atmosphere at a rate that approximately offsets current rates of deforestation. Whilst this is considered a short-term effect, predicted to level off 2030-2050[19], it demonstrates the importance of conserving carbon stocks in ancient forests.

In terms of terrestrial carbon stocks, fragmentation of ancient forests leads to increased fires, especially during periods of drought (e.g. such as those caused by El Niño events). Intact rainforest was found to be much more resistant to drought because old growth forests retain more moisture more effectively than fragmented or secondary forests[20]. Both logging and fires themselves increase vulnerability to future burning[21]. Burning results in the catastrophic release of carbon stocks held in trees.

Predicted effects of climate change show a marked decrease in rainfall in certain areas, including the northern Amazon[22]. This will increase the number of El Niño like drought periods. Thus, if fragmentation increases the vulnerability of the forest to fires induced by drought, fragmentation will also diminish the resilience of ancient forests such as the Amazon to the effects of climate change.

Fragmentation of ancient forests is likely to affect the ability of species to migrate in response to climate change[23]. By increasing the isolation of habitats, fragmentation is expected to interfere with the ability of species to move in response to shifting climatic conditions. Species with poor mobility or sensitive to dispersal barriers will do less well than those with a weedy nature. Many models of species migration during climate change have neglected the effects of forest fragmentation.

Preventing fragmentation of forests is therefore essential to maintaining the resilience of ancient forests and forest flora and fauna to climate change and conserving current forest carbon stocks.

Fragmentation is a serious threat to forests - now!

Direct effects of fragmentation of ancient forests on forest plants and animals give only part of the story. Fragmentation of ancient forests opens them up to further logging, mining and hunting. It has been estimated that present rates of annual deforestation for Brazilian Amazonia represent less than half of the forest area that is impoverished each year[24]. Satellite data do not include damage from non clear-cut and burn logging by logging crews and surface fires, which increases the vulnerability of the ancient forest to future fires.

Many of the ancient forests of Madagascar (a "hotspot" of biodiversity) have become critically fragmented to the point where they are considered unlikely to maintain present levels of biodiversity, nor support viable populations of lemurs[25].

The patterns of deforestation in the ancient forests of the Amazon basin are planned to change. Previously, large-scale deforestation has been along the river and few roads through the Amazon basin. However, new projects such as "Avança Brazil"[26] are set to dissect the heart of the basin. Deforestation along the planned new roads is predicted to lead to a patchwork of forest, decreasing the extent of intact ancient forest.

Conclusion

Fragmentation seriously degrades or impoverishes ancient forests, making them vulnerable to fires in dry periods and future logging and hunting. Large tracts of intact, ancient forests are important reservoirs of biodiversity and fragmentation is especially important as it undermines their ecological integrity. Edge effects and fragmentation have serious consequences for wildlife and the ecosystem function of ancient forests, including large mammals, which require wide ranges and whose absence will disrupt the ecological balance of the forest. Preventing fragmentation is essential to maintaining the resilience of ancient forests and forest flora and fauna to climate change and conserving current forest carbon stocks.

References

[1] WRI (World Resources Institute) (1997) The Last Frontier Forests: Ecosystems and Economies on the Edge. WRI, New York. http://www.wri.org/wri/ffi/lff-eng/

[2] WRI definition

[3] Lawton, R.O., Nair, U.S., Pielke Sr., R.A. & Welch, R.M. (2001) Climatic impact of tropical lowland deforestation on nearby cloud forests. *Science*, **294**, 584-587.

[4] Laurance, W.F. (1997). Introduction, Section II: Physical Processes and Edge Effects. *In*: Laurance, W.F. & Bierregaard, R.O. (eds.) *Tropical Forest Remnants: Ecology, Management and Conservation of Fragmented Communities.* University of Chicago Press, Chicago. pp. 29-32.

Gascon, C., Williamson, G.B. & da Fonseca, G.A.B. (2000). Receding forest edges and vanishing reserves. *Science*, **288**, 1356-1358.

[5] Gascon, C., Williamson, G.B. & da Fonseca, G.A.B. (2000). Receding forest edges and vanishing reserves. *Science*, **288**, 1356-1358.

[6] Laurance, W.F., Delamônica, P., Laurance, S.G., Vasconcelos, L and Lovejoy, T.E. 2000. Rainforest fragmentation kills big trees. *Nature*, **404,** 836.

[7] Bruna, E.M. 1999. Seed germination in rainforest fragments. *Nature*, **402,** 139.

[8] Gascon, C., Williamson, G.B. & da Fonseca, G.A.B. (2000). Receding forest edges and vanishing reserves. *Science*, **288**, 1356-1358.

[9] Laurance, W.F., Pérz-Salicrup, D., Delamônica, P., Fearnside, P.M., D'Angelo, Jerozolinksi, A., Pohl, L & Lovejoy, T.E. (2001) Rain forest fragmentation and the structure of Amazonian liana communities. *Ecology*, **82**, 105-116.

[10] Cadenasso, M.L. & Pickett, S.T.A. (2001) Effect of edge structure on the flux of species into forest interiors. *Conservation Biology*, **15**, 91-97.

[11] Gascon, C., Williamson, G.B. & da Fonseca, G.A.B. (2000). Receding forest edges and vanishing reserves. *Science*, **288**, 1356-1358.

[12] Noss, R.F. & Cooperrider, A.Y. (1994) *Saving Nature's Legacy: Protecting and Restoring Biodiversity.* Island Press, Washington DC.

Laurance, W.F. & Bierregaard, R.O. (1997) *Tropical Forest Remnants: Ecology, Management and Conservation of Fragmented Communities.* University of Chicago Press, Chicago.

[13] Foreman and Collinge, S.K. (1996) The "spatial solution" to conserving biodiversity in landscapes and regions. In: DeGraaf, R.M. and Miller, R.I. (eds.) *Conservation of Faunal Diversity in Forested Landscape*. Chapman and Hall, London. pp. 537-568.

[14] WRI (World Resources Institute) (1997) The Last Frontier Forests: Ecosystems and Economies on the Edge. WRI, New York. http://www.wri.org/wri/ffi/lff-eng/

[15] Cardoso de Silva, J.M. & Tabarelli, M., (2000) Tree species impoverishment and the future flora of the Atlantic forest of northeast Brasil. *Nature*, **404**, 72-74.

[16] Myers, N. (1993) Biodiversity and the precautionary principle. *Ambio*, **22**, 74-79.

[17] Laurance, W.F., Vasconcelos, H.L. & Lovejoy, T.E. (2000) Forest loss and fragmentation in the Amazon: implications for wildlife conservation. *Oryx*, **34**, 39-45.

[18] Houghton, R.A., Skole, D.L., Nobre, C.A., Hackler, J.L., Lawrence, K.T. & Chomentowski, W.H. (2000) Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. *Nature*, **403**, 301-304.

Pacala, S.W. et al., (2001) Consistent land- and atmosphere-based US carbon sink estimates. *Science*, **292**, 2316-2320.

[19] Cramer, W., Bondeau, A., Woodward, F.I., Prentice, I.C., Betts, R.A., Brovkin, V., Cox, P.M., Fisher, V., Foley, J.A., Friend, A.D., Kucharik, C., Lomas, M.R., Ramankutty, N., Sitch, S., Smith, B., White, A. & Young-Molling, C. (2001) Global response of terrestrial ecosystem structure and function to CO_2 and climate change: results from six dynamic global vegetation models. *Global Change Biology*, **7**, 357-373.

Meterological Office/Department of the Environment, Transport and the Regions (2000) Climate change: an update of recent research from the Hadley Centre. Brachnell, UK. Available at:
www.metoffice.gov.uk/research/hadleycentre/pubs/brochures/B2000/index.html

[20] Williamson, G.B., Laurance, W.F., Oliveira, A.A., Delamônica, P., Gascon, C., Lovejoy, T.E. & Pohl, L. (2000) Amazonian tree mortality during the 1997 El Niño drought. *Conservation Biology*, **14**, 1538-1542.

[21] Cochrane, M.A., Alencar, A., Schulze, M.D., Souza Jr., C.M., Nepstad, D.C., Lefebvre, P. & Davidson, E.A. (1999) Positive feedbacks in the fire dynamic of closed canopy tropical forests. *Science*, **284**, 1832-1835.

Nepstad, D.C., Verissimo, A., Alencar, A., Nobre, C., Lima, E., Lefebvre, P., Schlesinger, P., Potter, C., Moutinho, P., Mendoza, E., Cochrane, M. & Brooks, V. (1999) Large-scale impoverishment of Amazonian forests by logging and fire. *Nature*, **398**, 505-508.

[22] Cramer, W., Bondeau, A., Woodward, F.I., Prentice, I.C., Betts, R.A., Brovkin, V., Cox, P.M., Fisher, V., Foley, J.A., Friend, A.D., Kucharik, C., Lomas, M.R., Ramankutty, N., Sitch, S., Smith, B., White, A. & Young-Molling, C. (2001) Global response of terrestrial ecosystem structure and function to CO_2 and climate change: results from six dynamic global vegetation models. *Global Change Biology*, **7**, 357-373.

Meterological Office/Department of the Environment, Transport and the Regions (2000) Climate change: an update of recent research from the Hadley Centre. Brachnell, UK. Available at:
www.metoffice.gov.uk/research/hadleycentre/pubs/brochures/B2000/index.html

[23] Noss, R.F. (2001) Beyond Kyoto: forest management in a time of rapid climate change. *Conservation Biology*, **15**, 578-590.

[24] Nepstad, D.C., Verissimo, A., Alencar, A., Nobre, C., Lima, E., Lefebvre, P., Schlesinger, P., Potter, C., Moutinho, P., Mendoza, E., Cochrane, M. & Brooks, V. (1999) Large-scale impoverishment of Amazonian forests by logging and fire. *Nature*, **398**, 505-508.

[25] Ganzhorn, J.U., LowryII, P.P., Schatz, G.E. & Sommer, S. (2001) The biodiversity of Madagascar: one of the world's hottest hotspots on its way out. *Oryx*, **35**, 346-348.

[26] Laurance, W.F., Cochrane, M.A., Bergen, S., Fearnside, P.M., Delamônica, P., Barber, C., D'Angelo & Fernandes, T. (2001) The future of the Brazilian Amazon. *Science*, **291**, 438-439.