will allow other researchers to perform their own analyses and answer different questions. This might prove to be the most important long-term legacy of this groundbreaking study.

Acknowledgements
I thank B. Brodie, C. McCulloch, P. Phillips, H. Sahl, B. Silverman and C. Stewart for comments and discussion. This is KBS contribution No. 949.

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Paving the way to the future of Amazonia
Carlos A. Peres

The fate of the Brazilian Amazon is threatened by a new wave of frontier expansion following new infrastructure commitments worth US$40bn from the federal Government. In a recent paper, alarming rates of deforestation and forest degradation have been predicted, which could be either pessimistic or optimistic depending on the scale of forest disturbance being considered. A more decisive preventative approach is needed to prevent further impoverishment of both the biota and rural population of Amazonia.

Brazilian Amazonia incorporates nearly 40% of the remaining tropical rainforests of the world, making it by far the largest tropical forest region under the jurisdiction of a single nation; nowhere else is forest loss occurring faster in absolute terms. Although the cumulative area cleared so far is 550 000 km² or 14% of the total forest cover of the region, deforestation rates between 1995 and 1999 averaged 1.9 × 10⁶ ha yr⁻¹, not including clearings smaller than 6.25 ha and extensive areas of forest disturbed by selective logging and ground fires¹.

These smaller scales of disturbance, although largely invisible to conventional satellite imagery, can lead to irreversible ecosystem transitions. For example, recent El Niño events have breached the forest flammability threshold of the one-third of Amazonia that repeatedly experiences strong seasonal droughts, particularly in areas where soil water retention capacity is low². Although the total forest area burned following exceptionally prolonged dry seasons remains unknown, wildfires in such years might release as much carbon as is released from deliberate deforestation³.

With El Niño events becoming increasingly more frequent and severe⁴, the probability of accidental wildfires is further aggravated by logging operations, which puncture the canopy and increase the understorey fuel load²,⁵. Once a closed-canopy forest succumbs to an initial surface fire (Fig. 1), more intensive recurrent burns in a fire-intolerant system are likely to drive rapid changes in forest structure and composition that will drastically reduce the biodiversity, hydrological and carbon-retention value of the resulting ecosystem²,⁶,⁷.

Avança Brasil
Time is rapidly running out for the effective implementation of a comprehensive network of conservation areas retaining undisturbed forest cover, particularly along frontier regions where much of the deforestation process is concentrated. This is all the more urgent given the sheer scale of infrastructure commitments earmarked by the Brazilian Government for the region under the auspices of the Avança Brasil (Forward Brazil) development scheme. Avança Brasil is a massive investment program, worth US$40bn (to be spent by 2008), including new all-weather highways, railroads, pipelines, hydroelectric dams, power lines, river-channelization projects and new port facilities⁶. The paved-road network alone in the region is expected to more than double, with about 7500 km of new paving (W.F. Laurance, pers. commun.), providing heavily subsidized access to many previously remote parts of the region for the timber, mining and agricultural sectors. Current estimates of the amount of forest that will be cleared in the next 25–35 years within a 50-km strip on either side of four highways alone range from 80 000 km² (Ref. 9) to 270 000 km² (Ref. 10). According to the Brazilian Planning Ministry, this is ‘the shortest way to the future⁸, whatever that future might be.

Part of the economic logic for paving the southern Amazonian highways comes...
from reduced transportation costs for soy bean farmers in north-central Brazil. Such farmers are becoming increasingly influential in central government policy because of the exponential growth of their exports (e.g. between 1996 and 1999, these rose from 2.99 million to 6.87 million tons to the European Union alone). Moreover, this agricultural lobby is likely to be reinvigorated because the main export markets are rapidly shying away from GM animal feeds produced in the USA and turning to GM-free soy from Brazil, where commercial GM crops remain illegal. Although frontier expansion through enhanced transportation facilities will undoubtedly benefit a few, it is unlikely to bring sustainable prosperity to most of the rural population of the region.

A recent report by Laurance et al. predicts that, by 2020, deforestation will increase by up to 506,000 ha yr$^{-1}$, whereas degradation of pristine (defined as those areas free from nonindigenous uses) or lightly degraded forests will increase by between 1.53 and 2.37 $\times 10^6$ ha yr$^{-1}$. This comprehensive analysis is based on current spatial data on deforestation, logging, mining, forest vulnerability to fires, protected areas, and other existing and planned infrastructure projects. Even according to the ‘optimistic’ scenario of Laurance et al., pristine and lightly degraded forests will each comprise 27.5% of the region, with another 28% of the region being either heavily degraded or deforested. Their ‘nonoptimistic’ scenario predicts that only 4.7% of the region will remain in pristine condition, with lightly degraded forests comprising 24.2%, and heavily degraded or deforested areas another 42%. Should the full scale of Avança Brasil go ahead, remaining tracts of undisturbed, roadless wilderness will dwindle and retreat to remote western corners of the region, well away from the major highway axes expected to fragment the heart of Amazonia.

**Scales of disturbance**

Although the analysis by Laurance et al. uses the past to predict the future, it could be too pessimistic or too optimistic depending on the scale of forest disturbance considered. The aftermath of Avança Brasil in newly accessible areas will not necessarily repeat the history of road-mediated forest disturbance in aging Amazonian frontiers. Existing highways paved 20–30 years ago tend to occur in the drier, more seasonal eastern and southern flanks of the region where mechanized logging operations are deterred for shorter periods of the year. Moreover, in areas where mean annual rainfall exceeds 2000 mm, forests depleted of their commercially valuable timber are less likely to be replaced by viable agricultural enterprises, even if distance from the nearest road is controlled for, simply because of the effects of rainfall. Although Laurance et al. incorporate forest-fire vulnerability into their models, which is partly a function of rainfall seasonality, they do not explicitly take into account the effects of rainfall. Their predictions might, therefore, overestimate deforestation and severe forest degradation in central-western Amazonia (e.g. along the Humaitá-Manaus highway).

However, their models could also overestimate the area of pristine and lightly degraded forests remaining by 2020. Because of its extensive navigable river network, Brazilian Amazonia is more physically accessible to extractive activities than appears to be, provided that local human populations are large enough to exert a significant effect on the area. For example, large game species and other prime forest resources can be overharvested and driven to local extinction in 75–86% of the region by hunters on foot, provided the hunters are willing to walk up to 9–12 km from the nearest river or road (C. Peres and I. Lake, unpublished); and this requires no additional roads. This could happen throughout a largely unprotected forest landscape occupied by a burgeoning rural population, which grew from 2.2 million to 4.3 million between 1970 and 1991. Avança Brasil is likely to encourage new waves of immigrants, perhaps doubling the total population again from the current 17 million in two decades. Amazonia already has the most biased income distribution in Brazil (which, as a country, has one of the worst earning inequalities in the world) and this could increase with an influx of immigrants. The outcome of disturbance projections could, therefore, be substantially different if the projections do not take proper account of the size, distribution, economy and dynamics of the human population across the region.

**Frontier expansion**

Nevertheless, Avança Brasil will undoubtedly increase the rate of frontier expansion, which, in Amazonia, is effectively translated into forest degradation, fragmentation and deforestation. Laurance et al. have done a huge service in exposing the environmental costs of this blueprint both within and outside Brazil. Following the ancient Greek practice of shooting the messenger of bad tidings, the Brazilian Ministry of Science and Technology poured fierce but poorly founded criticism upon this study, describing it as an ‘exercise in pessimistic futurology’. Other strong critics in Brazil point out that this is symptomatic of a scientifically unjustified Northern agenda, masqueraded as an obsession with saving the Amazon, which would have the effect of denying indigenous peoples economic growth and prosperity. But killing the bearer of bad news will not change the environmental consequences of this development program, which could spiral out of control.

**Future measures**

Although the Brazilian Government has taken some positive strides towards balancing the needs of economic growth and biodiversity conservation, a more decisive preventive approach is needed to avert even the best-case scenarios in these recent projections. A federally coordinated land-use plan for zoning the entire Amazon should be effectively implemented before the floodgates are opened by Avança Brasil to unleash new disturbance agents. So far, these efforts have been at best fragmentary, based on no particular ecologically rational criteria, and pursued by individual states in isolation and under different spheres of political influence. Every measure and policy incentive to retain unlogged primary forest cover within private, communal or public landholdings should be vigorously pursued. These might include financial compensation to local communities or municipal administrations for the opportunity costs of holding on to undisturbed forests, which might become a reality if Brazil reverses the current policy of rejecting carbon-offset funds from bilateral or multilateral agreements.

Another cost-effective option that could go well beyond the commitment of Brazil
to meet the IUCN-proposed 10% expansion target of protected areas, would be the massive sequestration of newly accessible public lands into strictly protected areas, extractive reserves and sustainable forestry areas (National Forests). This would reduce the supply of free-for-all forest resources in public lands, which are likely to continue to attract ‘cut and run’ logging operations. A recent study has shown that nature reserves greatly reduce local deforestation rates, even if they exist only ‘on paper’ and are yet to be implemented in practice15.

Zoning regulations in the Amazon urgently need to be reorganized from a historically messy land titling system and need to include many more large forest reserves under varying degrees of protection ranging from people-free parks to areas under benign forms of exploitation. The private timber industry also needs to be severely restricted through steeper taxes and enforceable penalties, which could help fund field operations deployed by financially frail environmental agencies.

Although Brazilian legislators can pride themselves in having a highly sophisticated set of environmental laws, such laws tend to lack teeth in the vast Amazonian frontier. Haphazard frontier expansion without commensurate investments in government institutions to effectively enforce conservation legislation only perpetuates the boom and bust cycle that will continue to impoverish both the biota and rural population of the Amazon.

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The use and abuse of population viability analysis

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A recent study by Brook et al. empirically tested the performance of population viability analysis (PVA) using data from 21 populations across a wide range of species. The study concluded that PVAs are good at predicting the future dynamics of populations. We suggest that this conclusion is a result of a bias in the studies that Brook et al. included in their analyses. We present arguments that PVAs can only be accurate at predicting extinction probabilities if data are extensive and reliable, and if the distribution of vital rates between individuals and years can be assumed stationary in the future, or if any changes can be accurately predicted. In particular, we note that although catastrophes are likely to have precipitated many extinctions, estimates of the probability of catastrophes are unreliable.

Population viability analysis (PVA) is a modelling tool that estimates the future size and risk of extinction for populations of organisms1,2. PVA works by using life-history or population growth-rate data to parameterize a population model that is then used to project dynamics and estimate future population size and structure3. User-friendly PVA software packages allow conservation managers to predict future population sizes and risks of extinction for any population they choose4. Because of this ease of application of PVAs, it is important to determine and understand the limits to their predictive accuracy1,4–6. Brook et al. have tested the predictive accuracy of PVA using data from many populations and conclude that PVA is not a useless tool, and that it should not be dispensed with in favour of alternative untested methods.

Do PVAs work?

The predictive accuracy of a PVA will depend on the purpose to which it is being applied. In practice, there has been a range of alternative uses. PVAs can be used to: (1) predict the future size of a population1,5,6; (2) estimate the probability of a population going extinct over a given time6; (3) assess which of a suite of management or conservation strategies is likely to maximize the probability of a population persisting7; and (4) explore the consequences of different assumptions on population dynamics for small populations8.

In reality, only the predictive accuracy of the first two cases is estimable, as there are rarely sufficient replicate populations from which to collect data to determine whether the comparative predictions of the third use are accurate, and the fourth use has not generated testable predictions.

There are two ways that the predictive accuracy of PVAs can be assessed. The first approach is to use historical data and, at a point in the future, predict the population size and compare this to what actually happened. To avoid circularity, the data used to parameterize the model should not include data from the time-period over which predictions are made. The