PERSPECTIVES: ECOLOGY

Tropical Forests—Log 'Em or Leave 'Em?

Robin L. Chazdon

During the 1970s, tropical forest conservation focused on the preservation of old-growth forests. In this paradigm, conservation of much of the world's terrestrial biodiversity could be most effectively achieved by locking up and protecting what remained of the "virgin" tropical rain forests, through the creation of national parks and private nature reserves. Logging and large-scale deforestation spelled certain doom to the biological and physical integrity of tropical forests (*1*). The 1980s ushered in a new paradigm of tropical forest conservation, based on an appreciation of the inherent dynamism and regeneration potential of tropical forests (*2–4*). This ecologically focused perspective created a vision of sustainably managed tropical forests, where logging mimics natural forest disturbances and regeneration of timber species is actively promoted.

Today, tropical biodiversity conservation is undergoing yet another conceptual transition. Isolated forest fragments, logged forests, and second-growth forests are now being recognized for their value in conservation of biological diversity (*5–9*). As Cannon *et al.* point out in a report on page 1366 of this issue, a highly diverse population of tree species can be supported within commercially logged tropical forests of Borneo (*10*). Will this new paradigm offer a more promising solution to the global biodiversity crisis?

The biological and physical consequences of tropical forest logging is a subject of much debate among ecologists, conservation biologists, and foresters. Even forestry management that strives for sustainability is being questioned with regard to its economic feasibility and effect on conservation of forest biodiversity (*9*, *11*). All agree, however, that the best way to protect tropical forest biodiversity in perpetuity is to keep populations of *Homo sapiens* away. But people have never stayed away from tropical forests, and they likely never will. Charcoal deposits in sediments of wet tropical forests throughout the globe show that humans have been burning tropical forests for millennia (*12–14*).

Despite these persistent assaults, moist tropical forests are impressively resilient. Under the right conditions, these forests regenerate and gradually recover after hurricanes, landslides, clear-cutting, and conversion to pasture (*6*, *15–18*). In their new work, Cannon *et al.* show that in the tropical forest of Borneo many tree species can recover from destructive commercial logging operations, and rare species that survive damage can benefit from removal of the dominant tree competitors. Eight years after logging, tree density remained lower than in unlogged stands, but the number of tree species per number of individuals sampled was similar. Comparably, 12 years after logging operations in Peninsular Malaysia removed 50% of the trees, almost all the vertebrate species that were present in the unlogged forest were still there or had recolonized the area (*19*).

At the end of the logging road. Will logged forests herald the end or a new beginning for many tropical forest species?

Unfortunately, these results cannot be generalized to all forests. Conditions are not always favorable for the recovery of high species diversity after logging and other large-scale disturbances. Areas in which the soil has been severely compacted, removed, or eroded (*20*), or that are isolated from seed sources will likely never recover their original forest composition (*1*). Furthermore, the resilience of tropical forests does not guard against species loss or changes in species composition (*6*, *8*). Extremely rare species and those that are specialized for a single habitat are inherently more vulnerable ecologically and will inevitably decline or become locally extinct in a highly altered tropical landscape (*11*, *21*). Moreover, we know little of the effects of large-scale forest alteration on mutually beneficial species interactions (such as pollination and seed dispersal) or their consequences for maintenance of species diversity (*22*).

As yet, tropical forest ecologists do not have a formula for predicting the limits to forest recovery. Even setting the basic criteria for monitoring recovery poses a major challenge: Is ecosystem function as important as species composition, genetic variation, or population viability? The direct consequences of logging may vary greatly among populations of trees, vertebrates, and invertebrates. Indirect effects of disturbances are even more challenging to assess. The most serious of these is increased susceptibility to fire, particularly during ENSO (El Niño–Southern Oscillation) years (*23*). During the 1982–83 forest fires in Borneo, logged forests suffered greater tree mortality than unlogged forest, and fire intensity was directly related to intensity of logging (*24*). This year's extreme drought and subsequent forest fires in Indonesia and Amazonia bear witness to the large-scale indirect effects of logging and forest conversion. If human interventions can prevent the conversion of logged forest to agricultural uses or prevent extensive forest fires, a wide range of conservation objectives can be achieved in these "secondhand" lands.

Does the resiliency of tropical rain forests imply that conservation measures are not needed to protect tropical biodiversity? Certainly not. There is a strong, widespread consensus among forest ecologists and conservation biologists that recovery of degraded or cleared forests requires close proximity to genetically diverse and demographically stable source populations. The exuberant forests of the Yucatan in Mexico and the Darien in Panama remain standing today because indigenous land uses did not irreparably harm the soil and because intact forest areas remained within the landscape to provide seeds (*13*, *25*). We know little about the influence of the surrounding landscape matrix on forest regeneration and recovery in tropical regions, an issue of high research priority (*26*). Detailed studies examining seedling and sapling regeneration in selectively logged forests are urgently needed to evaluate

The author is in the Department of Ecology and Evolutionary Biology, U-43, University of Connecticut, Storrs, CT 06269–3043, USA. E-mail: chazdon@uconnvm.uconn.edu

long-term changes in species composition and forest structure (*27*). Ecological studies of tropical forest responses to logging and other forms of forest degradation should be incorporated into regional, national, and international land-use policies.

Studies such as that of Cannon *et al.* reinforce a new paradigm in management of tropical biodiversity that embodies a regional approach and extends conservation to human-impacted lands. Just as natural forest management focuses on mimicking natural disturbances within a heterogeneous stand of forest, such regional management would maintain a diverse landscape with managed areas embedded in a matrix of intact forest. A tropical landscape containing a matrix of old-growth forest fragments, second-growth forest, logged forest, and agricultural fields could conceivably protect most of the species present in the regional biota. Regional, multi-taxa inventories of species and monitoring are needed to address this critical biodiversity issue. Examples of this kind of conservation are the UNESCO Biosphere Reserves and social forestry initiatives in India, which strive to balance biological and cultural diversity with economic development.

The regenerative capacities of degraded, fragmented, or cleared tropical forests carry a hopeful message, with clear implication about how to prevent further species loss. Although nature's cornucopia might appear to be half empty, it could just as well be half full. Today, we have a fleeting opportunity to build on these remnants, to refill the cornucopia, at least in part. If we fail to recognize the inherent worth of human-impacted areas, we will not only lose more species, but we may forfeit our last opportunity for a positive human impact on tropical forests.

References

1. A. Gomez-Pompa, C. Vázquez-Yanes, S. Guevara, *Science* **177**, 762 (1972).
2. G. S. Hartshorn, *Ecology* **70**, 567 (1989).
3. C. Uhl *et al.*, *Ecologist* **19**, 235 (1989).
4. R. J. Buschbaker, *Ambio* **19**, 253 (1990).
5. B. Finegan, *For. Ecol. Manage.* **47**, 295 (1992).
6. A. E. Lugo, *Ecol. Appl.* **5**, 956 (1995).
7. I. M. Turner and R. T. Corlett, *Trends Ecol. Evol.* **11**, 330 (1996).
8. T. C. Whitmore, *An Introduction to Tropical Rain Forests* (Oxford Univ. Press, Oxford, ed. 2, 1998).
9. R. E. Rice, R. E. Gullison J. W. Reid, *Sci. Am.* **276**, 44 (April 1997); I. A. Bowles, R. E. Rice, R. A. Mitermeier, G. A. B. da Fonseca, *Science* **280**, 1899 (1998).
10. C. H. Cannon, D. R. Peart, M. Leighton, *Science* **281**, 1366 (1998).
11. K. S. Bawa and R. Seidler, *Conserv. Biol.* **12**, 46 (1998).
12. S. P. Horn and R. L. Sanford, *Biotropica* **24**, 354 (1992).
13. M. B. Bush and P. A. Colinvaux, *Ecology* **75**, 1761 (1994).
14. J. G. Saldarriaga and D. C. West, *Quat. Res.* **26**, 358 (1986).
15. M. C. Godt and M. Hadley in *Restoration of Tropical Forest Ecosystems*, H. Lieth and M. Lohmann, Eds. (Kluwer, the Netherlands, 1993), pp. 25–36.
16. T. C. Whitmore and D. F. R. P. Burslem, in *Dynamics of Tropical Communities*, D. M. Newberry, N. Brown, H. H. T. Prins, Eds. (Blackwell, Cambridge, UK, 1998), pp. 549–565.
17. M. Guariguata, R. L. Chazdon, J. S. Denslow, J. M. Dupuy, L. Anderson, *Plant Ecol.* **132**, 107 (1997).
18. P. Mausel, Y. Wu, Y. Li, E. F. Moran, E. S. Brondizio, *Geocarto Int.* **4**, 61 (1993).
19. A. D. Johns, in *Tropical Deforestation and Species Extinction*, T. C. Whitmore and J. A. Sayer, Eds. (Chapman & Hall, London, 1992), pp. 15–53.
20. M. Pinard, B. Howlett, D. Davidson, *Biotropica* **28**, 2 (1996).
21. N. Shelton, *Ambio* **14**, 39 (1985).
22. J. Terborgh, in *Tropical Forests: Management and Ecology*, A. E. Lugo and C. Lowe, Eds. (Springer-Verlag, NY, 1995), pp. 331–342.
23. A. R. Holdsworth and C. Uhl, *Ecol. Appl.* **7**, 713 (1997).
24. J. G. Goldammer and B. Seibert, in *Fire in the Tropical Biota*, J. G. Goldammer, Ed. (Springer-Verlag, NY, 1990), pp. 11–31.
25. A. Gomez-Pompa, J. S. Flores, V. Sosa, *Interciencia* **12**, 10 (1987).
26. D. H. Janzen, *Vida Silvestre Neotropical* **2**, 64 (1990).
27. M. R. Guariguata and J. M. Dupuy, *Biotropica* **29**, 15 (1997).

PERSPECTIVES: HIGH-PRESSURE PHYSICS

Superconductivity in a Grain of Salt

Russell J. Hemley

Seventy years ago, Bernal proposed that all materials would become metals if compressed under sufficiently high pressure (*1*). Taking this idea one step further, Abrikosov predicted that electron pairing, the mechanism that creates superconductivity, would be enhanced in metals at high density (*2*). For years, these tenets remained untested and generated controversy (*3*) owing to a lack of adequate experimental techniques. A series of breakthroughs in the past year have not only placed this field on a sound experimental footing but are revealing new and surprising phenomena. The most recent example, reported on page 1333 of this issue by Eremets *et al.*, is a study of the rather ordinary ionic solid CsI (*4*). When compressed to more than 200 GPa (2 megabars), CsI is not only a metal but also a superconductor in its very high density state (*4*).

Enhanced online at www.sciencemag.org/cgi/content/full/281/5381/1296

Every field has its benchmark organism; in the field of high-pressure research, CsI is the equivalent of the molecular geneticist's *Drosophila* or *Escherichia coli*. Study of its transformations and transmutations under pressure—phase transitions, equations of state, optical spectra, soft modes, disproportionation, and metallization—by static compression, shock waves, and theory has served as a testing ground both for new ideas about compressed matter and for new techniques to study it. The new report is another chapter in the not-so-simple story of this simple salt. Eremets and colleagues from Osaka University (*4*) pressed CsI into the metallic state (*5*, *6*) and directly measured the temperature and pressure dependence of the electrical resistance of the sample. They first provide direct evidence for metallization, at 115 GPa. Upon further increase in pressure a characteristic drop in resistance was found at 2 K near 180 GPa. Moreover, application of a magnetic field caused the resistance to reappear, a convincing sign of superconductivity.

Many advances in high-pressure techniques have been made in recent years, but probing the electronic transport properties of materials at megabar pressures has been a major challenge: It is difficult to run current through microscopic samples as small as 1/10th the diameter of a human hair inside the pressure cell and to accurately measure it. Moreover, the necessary complementary magnetic measurements were equally difficult because of the small sample size. These obstacles were overcome during the past year with the development of ultrasensitive techniques in diamond anvil cells. Amaya's group from Osaka University has pioneered the development of electrical techniques and tested them on a growing number of materials under pressure. The latest milestone is the first report of the application of the technique to above 200 GPa—nearly doubling their previous record pressure.

Experiments on CsI inevitably seem to generate new questions, and with this new report some earlier issues return. Disproportionation of the material to form elemental Cs and I was proposed to explain an apparent difference in the static and shock-wave equations of state (*7*). This discrepancy was finally resolved with the identification (*8*) of the high-pressure crystal structure (see figure). But the volumes of the elements are in fact lower as phase-separated components than in the compound, thereby

The author is at the Geophysical Laboratory and Center for High Pressure Research, Carnegie Institution of Washington, Washington, DC 20015, USA. E-mail: hemley@gl.ciw.edu