PERSPECTIVES: ECOLOGY

Tropical Forest Synergies

Gary Hartshorn and Nora Bynum

The El Niño–Southern Oscillation (ENSO) is the cyclical expansion of warm waters in the equatorial Pacific Ocean that is responsible for the weather patterns known as El Niño. Often the havoc wrought by ENSO in the form of drought or heavy rainfall combines synergistically with human activities to cause devastation to crops and forests, particularly in the tropics. On page 2184 of this issue Curran *et al.* (*1*) report that the unfortunate synergy between ENSO events and logging in Borneo's tropical forests has led to a drastic reduction in the regenerative capability of the ecologically and economically important tree family Dipterocarpaceae.




Dipterocarp dichotomy. (**A** and **C**) Orangutans and parakeets feed on dipterocarp seeds. (**B**) A carpet of dipterocarp seedlings established during the 1987 mast-fruiting event. (**D**) Dipterocarp trees in Borneo's Gunung Palung National Park.

This is not the first time that Indonesian Borneo has demonstrated to the international community the disastrous synergistic effects of ENSO and human activities. In 1982–1983, a severe ENSO drought triggered widespread fires across the East Kalimantan forests of Borneo, burning some 2 to 3 million hectares of tropical forest. Subsequently, it was documented that fire damage was much more severe in logged than in unlogged areas because logging debris provided a ready source of fuel (*2, 3*).

Members of the canopy tree family Dipterocarpaceae dominate Southeast Asian tropical forests. In some parts of Borneo, dipterocarps constitute as much as 70% of the canopy tree biomass and 80% of the tallest canopy trees (see the figure) (*4*). Many dipterocarp species reproduce in a spectacular but irregular manner called "mast-fruiting" (*5*). This phenomenon is characterized by the synchronous production of vast numbers of single-seeded fruits once every 3 to 4 years, with very little seed production in the intervening periods.

Curran and colleagues compared government data on annual seed exports with locally documented masting events between 1969 and 1999. From this comparison they provide evidence for the immense scale of dipterocarp masting in West Kalimantan. They further demonstrate a strong correlation between the onset of dipterocarp mast-fruiting and ENSO events during the same time period. More than 50 dipterocarp tree species dispersed seed within a 1- to 2-month period every 3 to 4 years during ENSO events. The widespread influence of ENSO on dipterocarp masting throughout Borneo endorses the view that ENSO has powerful effects on the flowering and fruiting of trees in tropical forests, as well as on the population fluctuations of seed-eating birds and mammals (*6*). A further example of this ENSO synergy is provided by Chavez *et al.*, who report in a research article on page 2126 of this issue (*7*) how ENSO influences carbon fluxes in the equatorial Pacific and how these in turn affect phytoplankton blooms.

The density of dipterocarps in Southeast Asian forests is commercially as well as ecologically important. Commercial logging concerns cut high volumes of timber per unit area (many of the more than 250 species of Bornean dipterocarps are valuable sources of plywood) (*8*). Intensive logging leaves behind large areas of abundant debris that, in a negative synergy with drought conditions related to ENSO, result in an increased likelihood of fires that will further decimate the forests. It is therefore not surprising that Curran *et al.* report that commercial logging has severely damaged the ability of residual stands of dipterocarps in West Kalimantan forests to reproduce. In one of their most sobering conclusions, the authors found that since 1991 dipterocarps have experienced almost total recruitment failure (no new seedlings in 8 years) in the unlogged 90,000-hectare Gunung Palung National Park. This West Kalimantan park, although itself unlogged, is almost completely surrounded by logging concessions.

Copious fruit production through masting is thought to satiate vertebrate predators such as the bearded pig and orangutan (see the figure), as predicted by the Janzen-Connell theory of diversity in species-rich ecosystems (*9*). The lack of dipterocarp seedling recruitment in Gunung Palung since 1991 appears to be due in part to high levels of predation on dipterocarp seeds. The authors show that this increase in predation is attributable to an increase in the local density of nomadic vertebrate seed predators that may no longer be able to move through the degraded land matrix surrounding the park. It remains unclear whether or not smaller protected areas such as Gunung Palung will be able to support viable populations of these predator species in the long term.

Harvested dipterocarps constitute a substantial portion of the global plywood trade. The Curran study demonstrates that successful recruitment of dipterocarps may be dependent upon large, intact forested landscapes over which nomadic seed predators can move freely. In the longer term, conservation of dipterocarps, and indeed all tropical forests, may only succeed in the context of large, connected, protected areas and the enforcement of existing laws governing forestry and other extractive activities (*10*). In the current economic and political climate of Indonesia, it is difficult to be optimistic.

A system of large, connected, and protected areas is also likely to be vital to the long-term conservation of the nomadic vertebrate seed predators of Borneo. Increased pressure on certain wild game species from hunting is becoming more common in the accessible areas of tropical forests (*11*). Logging roads serve as conduits for commercial hunters to access previously inaccessible tropical forests and facilitate transport of meat to logging camps and other human population centers. The desecration of fauna is particularly pronounced in fragmented forests and often affects small protected areas as well. The systematic and occasionally severe depression of vertebrate populations through hunting will no doubt have profound and possibly unexpected con-

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sequences for many ecological synergies in tropical forests (*12*). The maintenance and protection of functional ecosystems involving species-rich tropical forests will surely be one of the most challenging tasks of the first decades of the 21st century.

Curran *et al.* have convincingly demonstrated the negative synergy of ENSO events and logging in Borneo's West Kalimantan. Their work also illustrates the positive synergy that can result from the collaboration of a diverse set of partners, including several teams of international and Indonesian researchers, an international aid agency, nongovernmental organizations, and government officials, to produce and synthesize the diverse information presented here. Such long-term, interdisciplinary, and collaborative work represents a standard toward which scientists working on international environmental issues should aspire. How unfortunate, then, that this collaboration has produced a picture of a magnificent ecological phenomenon that appears to be in danger of collapsing.

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PERSPECTIVES: ANTARCTIC BIOGEOCHEMISTRY

Icy Life on a Hidden Lake

Warwick F. Vincent

The discovery of life in a deep rift-valley lake sounds like news from an earlier century, but not if the lake in question happens to be in one of Earth's least accessible places and represents a testing ground for exploration elsewhere in the solar system. Three reports in this issue provide new insights into the origins and biology of the deep ice overlying Lake Vostok and give an intriguing set of first indications of a microbial ecosystem in the waters beneath.

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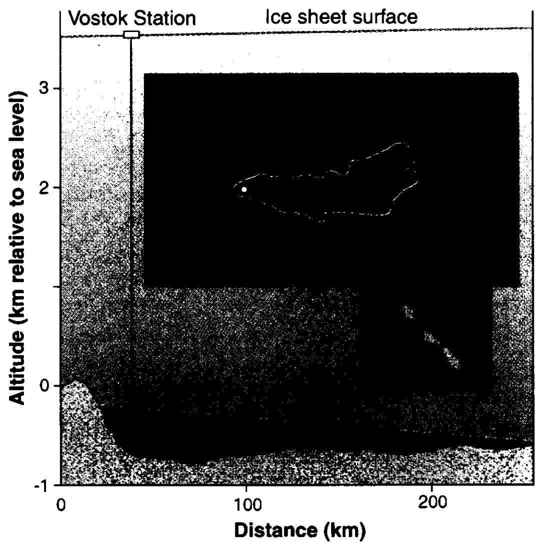
Lake Vostok is a vast expanse of liquid fresh water (see the figure). With a maximum depth greater than 500 m, it is deeper than Lake Tahoe, and it has a surface area similar to that of Lake Ontario. But Lake Vostok lies far from these more familiar waters, in the coldest, most remote part of Antarctica. It is the largest of at least 68 lakes located 3 to 4 km beneath the East Antarctic Ice Sheet and maintained in a liquid state by geothermal heating, pressure, and insulation by the overlying ice (*1*). Microbial ecologists have long speculated on what kind of microscopic life-forms might exist in these cold, dark waters; microorganisms reign supreme in many parts of Antarctica and show a remarkable ability to survive and even thrive under extreme polar conditions (*2*), perhaps even in Lake Vostok.

On page 2138, Jouzel *et al.* (*3*) present isotopic and other evidence that the lower part of the Vostok ice core is derived from underlying lake water. This layer of lake ice has a total estimated thickness of 210 m and a deuterium and oxygen-18 signature that differs substantially from the overlying glacier ice. The data suggest that Lake Vostok was formed under a climate warmer than the past 420,000 years and that its water has a mean age of 1 million years or older.



Life in Lake Vostok? The smooth plateau of snow and ice floating on the lake is distinguishable from the rough terrain of the surrounding ice sheet that buckles as it moves across the underlying bedrock (**top inset**). The Vostok drill site (•) is at the southern end of the lake where the overlying ice sheet is 0.5 km thinner and is underlain by slowly accreting lake ice. The deep drilling operation (red vertical line) recovered a section of the lake ice, providing samples of ancient Lake Vostok water containing bacteria [**bottom inset**, from (*5*)].

Priscu *et al.* (*4*) show on page 2141 that samples of Lake Vostok ice contain bacteria in relatively high concentrations, many of them associated with particles. Using DNA fingerprinting techniques, they found that the microbial community has a low biodiversity and is composed of taxa that are closely related to modern-day Proteobacteria and Actinomycetes. By comparing their data with fractionation studies of liquid and frozen portions of lakes in the McMurdo Dry Valleys region of Antarctica, the authors were able to extrapolate from the Vostok ice to the underlying lake water. Their calculations indicate that Lake Vostok contains inorganic nutrients, dissolved organic carbon, and bacteria: all the ingredients for an active microbial ecosystem.

Karl *et al.* (*5*) provide important complementary information on the microbiology of the Lake Vostok ice on page 2144. Using a variety of staining and biochemical techniques, they confirm the presence of bacteria in the lake ice (see the figure), although at lower cell concentrations than in the ice examined by Priscu *et al.* Most importantly, their assays included measurements of respiratory activity. The results show that the melted core samples contain viable, actively respiring cells.

Three questions need to be addressed in interpreting these new data from the Vostok ice core. First, do the bacterial and geochemical analyses accurately reflect what is in the ice, or are they contaminants from the core

CREDIT: TOP INSET: RADARSAT-1 IMAGE/THE CANADIAN SPACE AGENCY; BOTTOM INSET: FROM (5)

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