Demographic Threats to the Sustainability of Brazil Nut Exploitation

Carlos A. Peres, *et al.*

Science **302**, 2112 (2003);
DOI: 10.1126/science.1091698

CORRECTED 20 FEBRUARY 2004; SEE LAST PAGE

Demographic Threats to the Sustainability of Brazil Nut Exploitation

Carlos A. Peres,[1]* Claudia Baider,[3] Pieter A. Zuidema,[4] Lúcia H. O. Wadt,[5] Karen A. Kainer,[6] Daisy A. P. Gomes-Silva,[5] Rafael P. Salomão,[7] Luciana L. Simões,[8] Eduardo R. N. Franciosi,[9] Fernando Cornejo Valverde,[10] Rogério Gribel,[11] Glenn H. Shepard Jr.,[11] Milton Kanashiro,[12] Peter Coventry,[12] Douglas W. Yu,[2,13] Andrew R. Watkinson,[1,2,13] Robert P. Freckleton[14]

A comparative analysis of 23 populations of the Brazil nut tree (*Bertholletia excelsa*) across the Brazilian, Peruvian, and Bolivian Amazon shows that the history and intensity of Brazil nut exploitation are major determinants of population size structure. Populations subjected to persistent levels of harvest lack juvenile trees less than 60 centimeters in diameter at breast height; only populations with a history of either light or recent exploitation contain large numbers of juvenile trees. A harvesting model confirms that intensive exploitation levels over the past century are such that juvenile recruitment is insufficient to maintain populations over the long term. Without management, intensively harvested populations will succumb to a process of senescence and demographic collapse, threatening this cornerstone of the Amazonian extractive economy.

There is considerable interest in the promotion of nontimber forest products (NTFPs) as a tropical forest conservation strategy (*1*, *2*). Brazil nuts are a classic NTFP and are the only internationally traded seed crop collected exclusively from natural forests (*3*). In the Brazilian Amazon alone, over 45,000 tons of Brazil nuts are collected annually, with sales of over U.S. $33 million (*4*). Despite early warnings that the exploitation of this wild seed crop might not be sustainable (*5*), it has generally been argued that current seed collection intensities may have little impact on the demography of natural populations (*6*, *7*). Other reports, however, have noted that *Bertholletia excelsa* stands are often dominated by cohorts of large trees and lack juveniles (*1*, *8*, *9*), suggesting that the regeneration dynamics of natural populations have been undermined. Here we show that patterns of variation in population size structure are consistent with recruitment bottlenecks resulting from long-term harvest.

The Brazil nut tree *B. excelsa* (Lecythidaceae), the sole source of Brazil nuts, is a long-lived and widespread emergent tree in lowland Amazonian forests (Fig. 1). It produces extremely hard globose fruits (11 to 16 cm in diameter) with 10 to 25 seeds or "Brazil nuts" that remain encased after fruit fall, facilitating harvest. Under natural conditions, the fruits are typically gnawed open by agoutis [*Dasyprocta* spp. (*10*, *11*)], which scatter-hoard the seeds [see (*12*, *13*) and supporting online materials for further details on the regeneration ecology of *B. excelsa*].

We surveyed and measured all trees ≥10 cm in diameter at breast height (DBH) within 22 natural *B. excelsa* populations in the Brazilian, Peruvian, and Bolivian Amazon (Fig. 1 and table S1). Size structure data from one additional population (site 13) are restricted to the relative abundance of adults and juveniles. All populations had been subjected to different levels of seed exploitation but were otherwise located in structurally undisturbed primary forests under varying degrees of hunting pressure (*14*). On the basis of size at first flowering and fruiting, juveniles were defined as trees <60 cm DBH (*15*).

The history of seed exploitation at each site was documented using public records, interviews with local Brazil nut collectors, and/or systematic counts of fruits that had been opened by either human collectors or natural scatter-hoarders in order to determine approximately (i) the proportion of fruits removed, (ii) the proportion of trees harvested, (iii) the length of the harvesting period since 1900, and (iv) how often the annual harvest had failed to take place during this period. A principal component analysis (PCA) was then used to class harvested stands into one of four broad levels of harvest pressure (figs. S1 and S2), with unharvested stands being defined as those where no systematic seed collection took place during the 20th century. For all forest sites, we compiled ranked data on forest type (reflecting canopy openness), soil nutrient availability, annual rainfall, degree of seasonality (number of dry months with <50 mm of rainfall), and the level of hunting pressure (four classes) over the past 20 years. The main natural seed predator and seed dispersal agent (agoutis) and the main seedling herbivores were also assigned to one of four abundance classes.

The size of the trees and age structure of the stands were affected by the history of seed harvest. Persistently harvested stands were characterized by larger (and presumably older) trees and few or no juveniles (Fig. 2, A and B). Juveniles were most common in unharvested (range = 31 to 76% of all trees, $n = 5$ stands) and lightly harvested stands (10.6 to 47%, $n = 10$), uncommon to rare in moderately harvested stands (3.8 to 25%, $n = 5$), and virtually absent where seeds had been persistently collected (0.7 to 1.6%, $n = 3$). In the extreme, the only individuals <60 cm DBH at Alto Cajarí Extractive Reserve (site 6) were resprouts of trees broken by wind turbulence, which have no reproductive value (*12*).

We compared size distributions across sites using s^*, an index that measures the shape of the cumulative size distribution. High (or positive) values of s^* indicate populations with low median sizes (many juveniles) and a wide spread of sizes, whereas low (negative) values of s^* indicate populations with high median sizes (few juveniles) and little variance about the mean (*16*); that is, senescent populations (Figs. 1 and 2C). Because s^* explains most across-population variance in the relative abundance of juveniles ($R^2 = 0.87$, $F_{1,20} = 138.6$, $P < 0.001$), exploitation history can be used to predict the general shape of cumulative size distributions, from the least sinusoid curves, where juveniles are abundant, to the most sigmoidal curves, where juveniles are very rare or missing.

[1]Centre for Ecology, Evolution and Conservation, School of Environmental Sciences, [2]School of Biological Sciences, University of East Anglia, Norwich NR4 7TJ, UK. [3]Departamento de Ecologia, Universidade de São Paulo, São Paulo–SP, 05508–900, Brazil. [4]PROMAB, Casilla 107, Riberalta, Beni, Bolivia, and Department of Plant Ecology, Utrecht University, Post Office Box 80084, 3508TB Utrecht, Netherlands. [5]Centro de Pesquisa Agroflorestal do Acre, Embrapa, Rio Branco, Acre 69908–970, Brazil. [6]School of Forest Resources and Conservation and Tropical Conservation and Development Program, University of Florida, Gainesville, FL 32611–0410, USA. [7]Departamento de Botânica, Museu Paraense Emílio Goeldi, Belém, Pará 66040–170, Brazil. [8]Rua Aimberé 1485/94, São Paulo, SP 01258–020, Brazil. [9]Rua Dona Balduina 116, São Paulo, SP 01251–020, Brazil. [10]Proyecto Conservando Castañales, Asociación para la Conservación de la Cuenca Amazónica (ACCA), Cusco 499, Puerto Maldonado, Madre de Dios, Perú. [11]Botany Department, Instituto Nacional de Pesquisas da Amazônia (INPA), Manaus, Amazonas 69083–000, Brazil. [12]Embrapa Amazônia Oriental/DFID (Projeto Dendrogene), Belém, Pará 66095–100, Brazil. [13]Tyndall Centre for Climate Change Research, UK. [14]The Mauritius Herbarium, MSIRI, Reduit, Mauritius.

*To whom correspondence should be addressed. E-mail: C.Peres@uea.ac.uk

The long-term correlates of seed removal were confirmed in step-down and step-up multiple regression models incorporating other variables that could potentially have affected the population dynamics of *B. excelsa*; these included the geographic coordinates of each stand, density of Brazil nut trees ≥10 cm DBH, soil nutrient availability, total rainfall, strength of the dry season, the abundance of natural seed predators and/or dispersers, the abundance of seedling/sapling herbivores, and classes of canopy openness. Most of these variables were excluded from models explaining either the proportion of juveniles occurring within a stand ($R^2 = 0.89$, $F_{5,17} = 24.9$, $P < 0.001$) or the $s*$ value of cumulative size distributions [$R^2 = 0.80$, $F_{3,18} = 23.5$, $P < 0.001$ (table S2)]. The only variables other than historical levels of seed collection retained by the models were site longitude, total rainfall, and the abundance of agoutis and large herbivores. The significance of these variables could be explained by the gradual westward shift in large-scale Brazil nut harvest and trade over the past three decades. The significant relationship between large herbivore (and agouti) abundance and the percentage of juveniles (but not the $s*$ parameter) of different stands probably resulted from the key role played by (i) terrestrial browsers as seedling/sapling predators and (ii) large rodents as both seed predators and dispersers (*10–13*). However, the only key variable consistently retained in the regression models was the PCA score summarizing the history of seed harvest.

The conclusion that chronically exploited populations are experiencing a population bottleneck resulting from intensive harvest was tested using a matrix population model (*17*), which assumed that intense exploitation is applied to previously unexploited populations. We simulated populations over a period of up to 200 years after the onset of exploitation, and estimated the parameters describing the size distributions (*16*). There is a close correspondence between the observed size distributions of the exploited populations and those predicted by the model assuming high levels of seed removal (Fig. 3). The model indicates that the simulated population bottlenecks, resulting from between 20 and 200 years of Brazil nut collection, are consistent with the patterns observed in real data. This is a powerful indicator that exploited populations may succumb to a recruitment bottleneck.

The model and field observations point to a dwindling number of increasingly older trees in persistently overexploited stands, which have not been adequately replaced by juveniles in recent decades. The clear message is that current Brazil nut harvesting practices at many Amazonian forest sites are not sustainable in the long

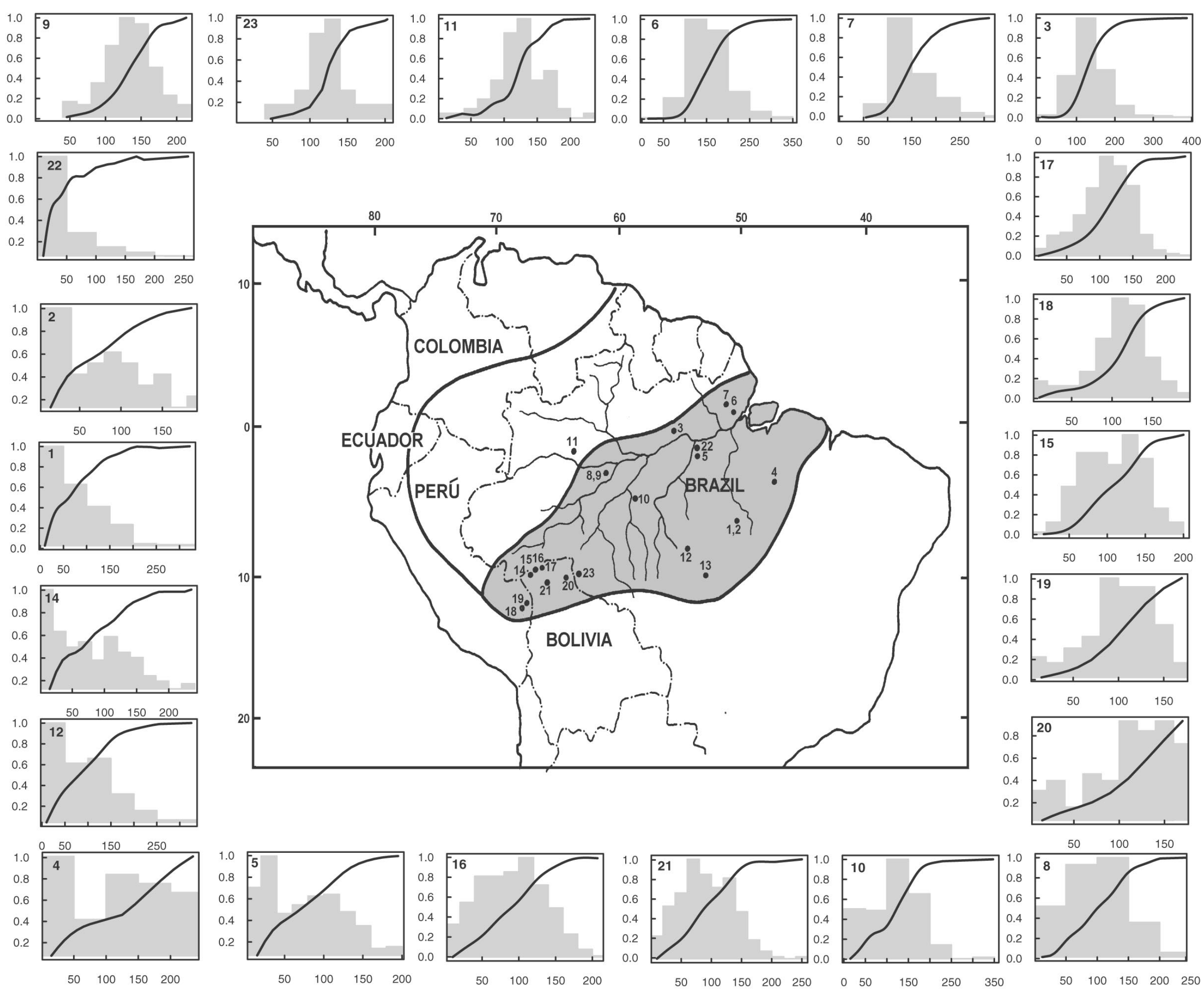

Fig. 1. Distribution of Brazil nut trees, *B. excelsa* (area surrounded by thick line on map), showing the cumulative size distribution of natural populations subjected to varying levels of seed exploitation. The shaded area indicates the region where adult trees may be locally abundant. Numbers on map and histograms refer to the 23 populations surveyed (table S1). Histograms (DBH in cm) have been ordered clockwise, beginning at the top left, according to $s*$, an index of the impact of harvesting on size structure (Fig. 2). Size structure data were unavailable for site 13.

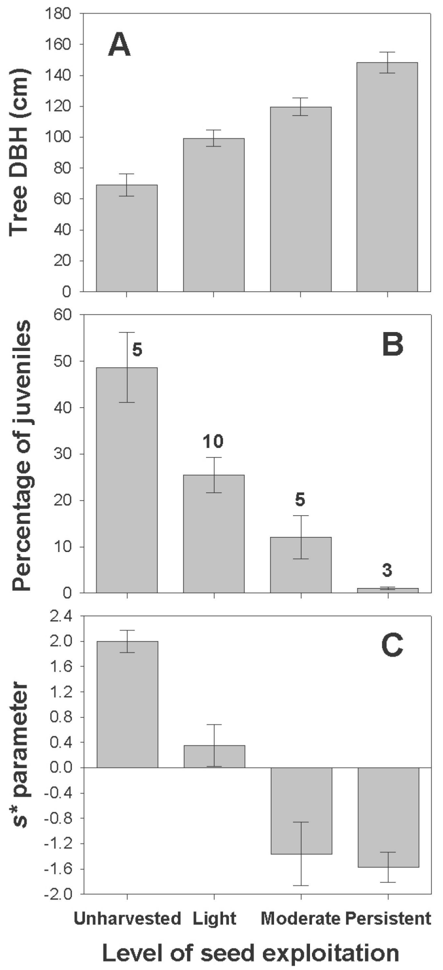

Fig. 2. Relationships between historical levels of Brazil nut collection and mean ± SE (**A**) tree size measured as DBH; (**B**) percentage of juveniles (trees 10 to 60 cm DBH); and (**C**) the summary statistic s^*, which measures the shape of the cumulative size distribution of each population. Decreasing s^* values reflect populations characterized by high median DBHs and size distributions that are increasingly sigmoid in nature. Numbers next to error bars in (B) indicate the number of populations studied.

term. Over the next few decades, however, seed production can still be maintained because of the long reproductive life-span of Brazil nut trees [>150 years (*7*)]. Populations with a recent history of intensive exploitation should be monitored closely to avoid future regeneration failure, and strangled populations harvested for several decades should be managed to facilitate recruitment pulses. Low-cost methods to encourage recruitment within natural populations need to focus on increasing the supply of juveniles by managing the annual harvest quota (the percentage of seeds removed), planting viable seeds, or transplanting nursery-grown seedlings. The spatial structure of the harvest may also be manipulated over a supra-annual cycle to facilitate recruitment pulses by relaxing harvesting in annually rotated no-take areas. This would

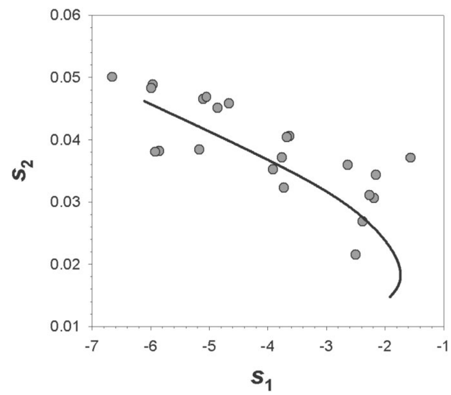

Fig. 3. Modeled and observed Brazil nut tree size structure summary statistics, which measure the median size of the population (s_1) and the slope of the cumulative density function for size at the median (s_2). Circles indicate the values estimated for all populations for which size information is available. The line represents population trajectories over 200 years for the s_1 and s_2 parameters after the commencement of harvesting predicted from a model (*17*).

increase the seed supply for natural seed predators and dispersal agents, which facilitate seedling recruitment most effectively when they are saturated by large seed crops (*10*, *12*). Subsistence hunting pressure on both seed dispersers and large herbivores could also be controlled or manipulated within Brazil nut groves to maximize the probabilities of seed germination and seedling survival.

The long-term viability of traditional Brazil nut exploitation in the context of primary forests will not, however, depend solely on a healthy age structure and stable turnover of adult populations. More immediate threats to the sustainability of this extractive industry include deforestation and forest degradation (*18*), which are most prevalent in the highly seasonal southern arc of Amazonia, where high-density *Bertholletia* stands are currently concentrated. Both sound management of natural Brazil nut tree populations and protection of the larger primary forest matrix are required to avert demographic collapse, population decline, and the erosion of this cornerstone of the Amazonian economy.

References and Notes

1. R. G. A. Boot, R. E. Gullison, *Ecol. Appl.* **5**, 896 (1995).
2. C. M. Peters, *Sustainable Harvest of Non-timber Plant Resources in Tropical Moist Forest: An Ecological Primer* (Biodiversity Support Program, Washington, DC, 1994).
3. J. W. Clay, in *Harvesting Wild Species—Implications for Biodiversity and Conservation*, C. H. Freese, Ed. (John Hopkins Univ. Press, Baltimore, MD, 1997), pp. 246–282.
4. Instituto Brasileiro de Geografia e Estatística (IBGE), *Produção da Extração Vegetal e da Silvicultura* (IBGE, Rio de Janeiro, Brazil, 2002) (www.ibge.gov.br/, accessed 1 July 2003).
5. J. Huber, *Bol. Mus. Paraense História Natural* **6**, 781 (1910).
6. V. M. Viana, R. A. Mello, L. M. Morais, N. T. Mendes, in *Floresta Amazônica: Dinâmica, Regeneração e Manejo*, C. Gascon, P. Moutinho, Eds. (Instituto Nacional de Pesquisa da Amazônia, Manaus, Brazil, 1998), pp. 277–292.
7. P. A. Zuidema, R. G. A. Boot, *J. Trop. Ecol.* **18**, 1 (2002).
8. J. M. Pires, in *The Amazon: Limnology and Landscape Ecology of a Mighty Tropical River and its Basin*, H. Sioli, Ed. (Dr. W. Junk Publishers, Dordrecht, Netherlands, 1984), pp. 581–602.
9. D. Nepstad, *et al. Ad. Econ. Bot.* **9**, 1 (1992).
10. C. A. Peres, L. C. Schiesari, C. L. Dias-Leme, *J. Trop. Ecol.* **13**, 69 (1997).
11. C. A. Peres, C. Baider, *J. Trop. Ecol.* **13**, 595 (1997).
12. C. Baider, *Demografia e Ecologia de Dispersão de Frutos de* Bertholletia excelsa *Humb. & Bonpl. (Lecythidaceae) em Castanhais Silvestres da Amazônia Oriental*, thesis, University of São Paulo, Brazil (2000).
13. P. A. Zuidema, *Ecology and Management of the Brazil Nut Tree* (Bertholletia excelsa), (PROMAB Scientific Series 6, Utrecht, Netherlands, 2003).
14. Supporting material on the study species, sampling sites, methods, and data analysis is available on *Science* Online.
15. This juvenile cutoff point was a powerful predictor of the proportion of trees <50 cm DBH ($r^2 = 0.97$) in the 23 populations considered in this study.
16. The size distributions were quantified using a logistic regression. Size distributions were expressed as cumulative distributions (as a function of DBH) and were logit transformed {logit (p) = log[p/(1 − p)]}. The logit-transformed proportions were then regressed on DBH, fitting the equation logit (p) = s_1 + s_2DBH. The parameters are the intercept s_1, which is a function of the median size of the population, and the slope s_2, which is related to variance in size. The fitted regression is effectively an estimate of the degree to which the fitted sigmoid function approaches a step function (high slope values) or a linear function (low slope values). s_1 and s_2 were found to be negatively correlated. As a single summary statistic of the nature of the size distribution, we therefore calculated the first axis score of the PCA for the two statistics measured across the 22-populations, and this is termed s^*.
17. This is a Lefkovitch structured model [adapted from (*7*)] in which the population is divided into 17 stages based on size and stage. Census data were used by Zuidema and Boot (*7*) to estimate rates of transitions between size classes and reproduction. The estimates of model parameters ignored the effects of density dependence, which has been shown to be very important in models of tropical tree populations (*19*, *20*). To account for this, we assumed that seedling survival was density dependent and reduced observed rates of survivorship to yield a population with a finite rate of population growth of 1. We only report results on size classes >10 cm DBH, hence we assume that density dependence acts before plants reach 10 cm DBH and is minimal thereafter. The model parameters were set using data on populations subject to harvesting (*7*), in which 93% of seeds may be removed. To account for this, we increased the rate of seedling production per tree to 1/0.07 = 14.3 times the observed level. Because density dependence is assumed to act on seedlings, this modification has little effect on predictions of adult size distributions.
18. Instituto Nacional de Pesquisas Espaciais (INPE), *Monitoring of the Brazilian Amazon Forest by Satellite* [INPE, São José dos Campos, Brazil, 2003 (www.obt.inpe.br/)].
19. D. M. S. Matos, R. P. Freckleton, A. R. Watkinson. *Ecology* **80**, 2635 (1999).
20. R. P. Freckleton *et al. J Appl. Ecol.* **40**, 846 (2003).

21. We are indebted to A. Sanchez Peres for inspiration to pursue this study; M. Rees, W. Sutherland, and P. Dolman for helpful comments; T. Haugaasen and many *castanheiros* for generous assistance during fieldwork; and the Center for Applied Biodiversity Sciences of Conservation International for supplementary funds to C.A.P.

Supporting Online Material
www.sciencemag.org/cgi/content/full/302/5653/2112/DC1
Materials and Methods
Figs. S1 to S3
Tables S1 and S2
References

19 September 2003; accepted 29 October 2003

ERRATUM

post date 20 February 2004

REPORTS: "Demographic threats to the sustainability of Brazil nut exploitation" by C. A. Peres *et al.* (19 Dec. 2003, p. 2112). The affiliations for Claudia Baider and Robert P. Freckleton were incorrect. For Claudia Baider, the affiliation is Departamento de Ecologia, Universidade de São Paulo, São Paulo–SP, 05508-900, Brazil, and The Mauritius Herbarium, MSIRI, Reduit, Mauritius. For Robert P. Freckleton, the affiliation is Department of Zoology, University of Oxford, Oxford OX1 3PS, UK.

LETTERS

Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 6 months or issues of general interest. They can be submitted by e-mail (science_letters@aaas.org), the Web (www.letter2science.org), or regular mail (1200 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space.

Forensic Science and Academic Science

IN HIS EDITORIAL "FORENSIC SCIENCE: Oxymoron?" (5 Dec., p. 1625), Donald Kennedy questions the scientific basis of forensic evidence examination and concludes by questioning, and prodding at, the efforts of forensic scientists to improve the reliability of forensic evidence. To some extent, the field of forensic science must acknowledge these criticisms. Overshadowing this scolding, however, is the more troubling divide between academic and forensic science that is prevalent throughout and, unfortunately, encouraged by Kennedy's Editorial. A glaring illustration of this division was the unsuccessful National Academies' project on Science, Technology and Law "to examine science and its uses in forensic examinations." A review of the members of this program reveals that not a single forensic scientist was included. Would such a project examine "science and its uses in chemistry" without a chemist? This attitude ignores the fact that, although forensic science has developed through the integration of principles from every scientific field, it has evolved into its own scientific discipline. The fact is that there is a great deal of science that cannot be packaged into standardized and verifiable techniques developed to be run by technicians. A recent example was the use of chemical microscopy to tie microscopic paint spheres found on victims' bodies to a specific manufacturer and end-use: the truck painting plant where Gary Ridgway, the Green River serial murderer, worked. Rather than have a drawn-out trial over four counts of murder based on "verified" DNA evidence, this paint evidence was significant enough to induce Ridgway to forgo a trial and admit guilt to 48 counts of murder to avoid a likely death sentence. The mystery in forensic science is not why practitioners do not want a more scientific technology for analyzing crimes, as Kennedy asks, but rather, why traditional sciences will not work with forensic science, rather than above it. Forensic science may be a redundant phrase, but it is not an oxymoron.

Image not available for online use.

Fingerprinting techniques are just some of the many areas of forensic science.

CHRISTOPHER S. PALENIK[1,2]* AND SAMUEL J. PALENIK[2]

[1]Department of Geological Sciences, University of Michigan, 425 East University Avenue, Ann Arbor, MI 48109–1063, USA. [2]Microtrace, 1750 Grandstand Place, Elgin, IL 60123, USA.

*To whom correspondence should be addressed. E-mail: cpalenik@microtracescientific.com

More on Molecular Electronics

TWO RECENT NEWS STORIES BY ROBERT Service ("Next-generation technology hits an early midlife crisis," 24 Oct., News Focus, p. 556; "Nanodevices make fresh strides toward reality," 21 Nov., News of the Week, p. 1310) provide the impression that the field of molecular electronics stalled and then suddenly revived. The specific contributions described in the 21 Nov. news story are just two of a large number of breakthroughs that have been reported by many research groups over the past several years. Progress in the field has been continuous and is accelerating dramatically.

The entire premise of the 24 Oct. article was based on a straw man created through inflated expectations and knocked down with rumor. Rather than being based on published material (as was the 21 Nov. story) or presentations made in public meetings, this article relied on unattributed sources and fragmentary second-hand information. There were several errors and omissions in the article that yielded a distorted view of the field.

For example, the article erroneously stated that, in 1999, the Hewlett-Packard (HP)–University of California, Los Angeles (UCLA) team tried to create "transistors that used the movements of molecules." We were not attempting to create transistors but were demonstrating the concept of two-terminal electronic-tunneling switches that could be toggled by electrical pulses. Stating that a "transistor" was a goal set false expectations for the research and the applications for which the switches were intended.

A schematic of rotaxane molecules between wires shown in the 24 Oct. news report is described by Paul Weiss as "somewhere between naïve and misleading." We note that this figure was commissioned by editors of *Science* for its 21 Dec. 2001 issue, in which molecular electronics was hailed as the breakthrough of the year. Neither Fraser Stoddart nor Jim Heath was consulted to confirm if this figure accurately depicted their research—yet this figure was by inference attributed to them. Taken out of the context originally intended by the editors of *Science*, it is easy to ridicule such a diagram.

Service also made much of a nonpublic presentation to the Defense Advanced Research Projects Agency (DARPA) contractors by Stan Williams, which included a brief description of reversible switching in one particular metal-molecule-metal system that was caused by the growth and dissolution of metallic nanoparticles. This was reported in the article as an unanticipated failure that caused Jim Heath to end his partnership with HP. This is a fabrication on the part of Service's unnamed sources, and neither Heath nor Williams was asked if this was indeed true. The UCLA, Caltech, and HP groups formed a team with a common architectural vision in 1997. As a risk minimization strategy, each partner has pursued somewhat different paths to ensure that the team is successful. We have recently reported two different 64-bit memories (*1*, *2*), which was a major aim of the DARPA program. Having two alternative and complementary approaches from which to select or blend is a major strength of the team, and just one of the reasons we continue to work together.

JAMES R. HEATH,[1] J. FRASER STODDART,[2] R. STANLEY WILLIAMS[3]

[1]Department of Chemistry, California Institute of Technology, 1200 East California Boulevard, Pasadena, CA 91125, USA. [2]Department of

Chemistry and Biochemistry, University of California, Los Angeles, 405 Hilgard Avenue, Los Angeles, CA 90095, USA. [3]Hewlett-Packard Labs, 1501 Page Mill Road, Palo Alto, CA 94304, USA.

References
1. Y. Luo *et al.*, *Chem. Phys. Chem.* **3**, 519 (2002).
2. Y. Chen *et al.*, *Nanotechnology* **14**, 462 (2003).

ROBERT SERVICE'S NEWS STORY ON MOLECULAR electronics, addressing memory and logic devices based on self-assembled organic monolayers ("Next-generation technology hits an early midlife crisis," News Focus, 24 Oct., p. 556), provides an important update on a controversial topic. The proponents of this "technology" have buried us in hype for several years. They promised workstations that will operate for decades powered by only a small battery (*1*), 100 high-end workstations on a grain of sand (*2*), and, more recently, 1000 Pentiums on the same base (*3*). Although it has been admitted that logic will require devices with gain (*4*), no such molecular device has yet been identified. Such unreasonable advertising should have aroused the skepticism even of novices.

Serious questions about this field have been raised for several years after talks by proponents at American Chemical Society and Materials Research Society meetings. Results that are claimed to represent technology must be subjected to examination of manufacturability and device reliability, issues that have been nearly completely ignored. Any device that cannot be made reliably in the lab is unlikely to become the basis of a technology in 5 years, despite what Jim Heath said about molecular-based memory at the UCLA debate in September (*5*).

Much of the present situation is a result of publication, primarily in the press, and of reports that do not include important experimental details. The lack of full papers is a prime characteristic of the field of molecular electronics, and this makes it impossible to fully evaluate the experiments. It is time to demand much more information.

EDWIN A. CHANDROSS
MaterialsChemistry LLC, 14 Hunterdon Boulevard, Murray Hill, NJ 07974, USA.

References
1. J. Heath, S. Williams, *Chem. Eng. News* **77**, 6 (1999).
2. See www.chem.ucla.edu/dept/Faculty/heath/.
3. J. R. Heath, in *Reducing the Time from Basic Research to Innovation in the Chemical Sciences: A Workshop Report to the Chemical Sciences Roundtable* (National Academies Press, Washington, DC, 2003), pp. 56–63.
4. J. F. Stoddart, J. R. Heath, *Chem. Phys. Chem.* **3**, 519 (2002).
5. Much of the UCLA debate is now available on the California Nanosciences Institute Web site (www.cnsi.ucla.edu/mainpage.html). A number of issues in molecular electronics are addressed in detail in my presentation.

ROBERT F. SERVICE'S NEWS STORY "NEXT-generation technology hits an early midlife crisis" (News Focus, 24 Oct., p. 556) misquotes me and does not sufficiently delineate two of the effects observed in molecular electronics.

I am quoted as referring to results reported in the literature on negative differential resistance (NDR) as "artifacts." As I pointed out to Service, the earlier data were measured in different experimental testbeds than ours. I did not imply that the earlier published data were artifacts nor that the published data were in question, but that they gave different apparent results, and that we could use all of the data in toto to understand the underlying phenomena. The discussion of this work also does not correctly attribute our recent results to our collaboration with James Tour at Rice University and David Allara at Penn State, nor does it correctly name the instruments used in recording our data—scanning tunneling microscopes. NDR is a well-established phenomenon and has been observed when atoms or molecules have been reacted on semiconductor surfaces (*1*, *2*) or when single metal atoms have been deposited on metals (*3*).

There appears to be further confusion in the molecular electronics community over separating two different effects—NDR and conductance switching. Our work on switching, also done in collaboration with Tour and Allara, and the earlier work indicate that the switching is robust, controllable, and due to the molecules in the junction (*4*–*6*). Once again, the results of measurements in all testbeds must be considered in understanding, testing, and exploiting this phenomenon.

Finally, I made a point to the article's author that all cartoons (such as the one shown in the article) have the potential to be misleading. It is incumbent upon those of us in nanoscience who draw them to test them against reality. In our own work, by discovering where our cartoons were not correct, we have repeatedly been led into fruitful, unanticipated areas for further exploration.

PAUL S. WEISS
Department of Chemistry and Physics, The Pennsylvania State University, 152 Davey Laboratory, University Park, PA 16802–6300, USA. E-mail: stm@psu.edu

References
1. P. Bedrossian *et al.*, *Phys. Rev. Lett.* **63**, 1257 (1989).
2. I. W. Lyo, E. Kaxiras, Ph. Avouris, *Phys. Rev. Lett.* **63**, 1261 (1989).
3. M. F. Crommie, C. P. Lutz, D. M. Eigler, *Phys. Rev. B* **48**, 2851 (1993).
4. M. A. Reed *et al.*, *Appl. Phys. Lett.* **78**, 3735 (2001).
5. Z. J. Donhauser *et al.*, *Science* **292**, 2303 (2001).
6. Z. J. Donhauer *et al.*, *Jpn. J. Appl. Phys.* **41**, 4871 (2001).

Response

THE USE OF THE WORD "ARTIFACT" WAS NOT a quotation but was based on Weiss's comments, which indicated that his findings challenged earlier results. The article omitted details of Weiss's collaborations for space reasons and misidentified the instrument that made the experimental measurements as a scanning electron microscope. Finally, the cartoon shown in the article was intended as an example of the potential fallibility of all models.

ROBERT SERVICE

International Agricultural Research

A NEW EVALUATION BY THE WORLD BANK OF the Consultative Group for International Research (CGIAR) and its 16 research centers has prompted me to give my views on the importance and contributions of international agricultural research and the confusion in which CGIAR now finds itself. The World Bank reports that plant breeding research at CGIAR centers has declined 6.5% annually for the last decade. Moreover, growing restrictions have been placed on the funding the centers receive.

International agricultural research began in Mexico in 1943 and has grown into an international system of collaborative research, seed exchange, and training organizations that helped build many national agricultural research systems in developing countries.

In only 10 years, wheat and rice harvests in Asia doubled, hunger declined, and incomes improved. The international wheat, rice, and maize programs that had developed high-yielding technologies became the models for a collaborative international research network.

In 1971, the Rockefeller and Ford Foundations, the World Bank, FAO, UNDP, and USAID created CGIAR, a donors' club dedicated to funding an expanded international research system. Over the next 30 years, the number of research centers grew from 4 to 16, covering the major food crops and farming systems in food-deficit, low-income countries. The total budget increased 10-fold—to nearly US$400 million per year.

But somehow in this evolution, the CGIAR lost touch with its original purpose—to feed the hungry. It has become an unwieldy and uncoordinated beast, with too many masters and proliferating goals.

Yet, a well-focused international agricultural research system that backstops and complements national agricultural research organizations and smallholder farmers is a vital component in a global research system. CGIAR must return to its original purpose and to its greatest comparative advantage—developing improved food crop varieties, using a combination of conventional plant breeding techniques and new techniques of biotechnology, with complementary crop management practices, to address major production issues in both the favored and the more difficult marginal lands.

Another concern stems from the spilling over of the controversy about genetically modified (GM) varieties from industrialized into developing countries, which has paralyzed legislative action on GM crops. We should not underestimate the degree of resistance to GM crops in many countries, although it is heartening to see Argentina, Brazil, China, and India moving ahead with well-considered applications of biotechnology.

I am optimistic that multinational biotechnology companies are willing to devote more resources to solving the problems of poor farmers and consumers. Creative partnerships have been established between private and public research institutions—especially universities, but also CGIAR centers—with financial support provided by private companies, governments, and private foundations. In addition, CGIAR, with seed collections representing much of the genetic diversity in the major food crops, is in a unique position to negotiate with the private sector to generate GM technology that benefits the poor, in return for access to its gene banks.

The World Bank is in a unique position, with its US$50 million of CGIAR funding (until recently completely unrestricted; it now assigns half its contribution to multicenter research initiatives called Challenge Programs), to work with other donors to expand unrestricted funding in the CGIAR, which will help greatly to rationalize priority setting. The Bank can also help refocus the CGIAR mission on raising smallholder agricultural productivity in the near term, rather than trying to be all things to all people.

NORMAN E. BORLAUG
Texas A&M University, College Station, TX 77843, USA.

CORRECTIONS AND CLARIFICATIONS

Reports: "Demographic threats to the sustainability of Brazil nut exploitation" by C. A. Peres *et al*. (19 Dec., p. 2112). The affiliations for Claudia Baider and Robert P. Freckleton were incorrect. For Claudia Baider, the affiliation is Departamento de Ecologia, Universidade de São Paulo, São Paulo - SP, 05508-900, Brazil, and The Mauritius Herbarium, MSIRI, Reduit, Mauritius. For Robert P. Freckleton, the affiliation is Department of Zoology, University of Oxford, Oxford OX1 3PS, UK.

News Focus: "Wanderlust in the western margin" by R. A. Kerr (12 Dec., p. 1889). The observation made by Brian Mahoney of the University of Wisconsin, Eau Claire, and his colleagues was misstated. They did in fact find evidence that the Belt Supergroup supplied sediment to British Columbia's Nanaimo basin. Their conclusion—that the Nanaimo is not far traveled—was correctly stated.

News of the Week: "The ultimate gene gizmo: Humanity on a chip" by E. Pennisi (10 Oct., p. 211). In the second column, second paragraph, *Arabidopsis tumefaciens* should be *Arabidopsis thaliana*.

Reports: "DCP-1, a *Drosophila* cell death protease essential for development" by Z. Song *et al*. (24 Jan. 1997, p. 536) and "Requirement for DCP-1 caspase during *Drosophila* oogenesis" by K. McCall and H. Steller (9 Jan. 1998, p. 230). Annotation of the *Drosophila* genome [M. D. Adams *et al.*, *Science* **287**, 2185 (2000)] has shown that the *dcp-1* gene is located within an intron of another gene, CG3941. P-element alleles of *dcp-1* described in these two papers also disrupt expression of CG3941. Several phenotypes that were previously attributed to loss of *dcp1*, including melanotic tumors, small imaginal discs, and dumpless egg chambers, have now been shown to be due to disruption of CG3941 [B. Laundrie *et al.*, *Genetics* **165**, 1884 (2003)]. However, single mutations in *dcp-1* show defective germline cell death, and loss of *dcp-1* contributes to the ovary phenotype previously reported for the P-element alleles. Thus, the original ovary phenotype reported for the P-element alleles was due to the combined loss of *dcp-1* and CG3941. The role of *dcp-1* in somatic cell death is currently under investigation.