The Forgotten Megafauna

Dennis M. Hansen and Mauro Galetti

Large terrestrial vertebrates—called megafauna—play key roles in ecosystem dynamics by feeding on plants and by maintaining habitat heterogeneity (1). A global wave of megafauna extinctions occurred 50,000 to 10,000 years ago, when many large continental mammals were lost (2–5).

Classical definitions of megafauna are based on such continental mammals and are variously given as animals larger than 44 kg (6) or above 1000 kg (7). Here, we argue that the megafauna concept should be extended beyond an absolute animal size to be context-dependent.

In any given ecosystem, the largest vertebrates have ecosystem impacts that are similar on a relative scale to those of the largest vertebrates in another ecosystem: One ecosystem’s megafauna is another ecosystem’s megafauna.

An ecosystem function that clearly illustrates this argument is animal-mediated seed dispersal. Here, the link between animal body mass and ecosystem function is straightforward: The larger the fruit-eating animal (frugivore), the larger the fruits it can consume. Thus, extinction-mediated “ecological shrinkage”—the loss of species interactions—in community-level seed dispersal roughly scales with frugivore body mass.

Scientists have argued that in continental Central and South America, the extinction of the classic mammalian megafauna—such as giant ground sloths and gomphotheres—caused disruption of seed dispersal for large fruits (4, 5). However, on islands, the extinction of large birds and reptiles in the past two or three millennia has led to similar disruptions (8, 9). In both locations the demographic and genetic consequences of large vertebrate extinctions for plants are likely similar—for example, disruption of long-distance gene flow or changes in species composition (10, 11). Yet, by the classic definitions, large insular vertebrates would not be considered megafauna.

The magnitude of loss of frugivorous megafauna is currently most dramatic on islands, as illustrated by the smaller drawn sizes of the giant ground sloth and the gomphothere from South America, compared with the elephant bird in Madagascar and the giant tortoise of Mauritius. However, many continental regions are poised to catch up.

To illustrate our point, we have examined tropical and subtropical faunas from three kinds of ecosystems: continental, continental islands, and oceanic islands. For each fauna, we compared the body masses of the largest extant frugivorous vertebrate—mammal, bird, or reptile—to the largest that has gone extinct since the late Pleistocene.

On continents, the body masses of extant frugivores are an order of magnitude lower than those of extinct frugivores; in contrast, in some continental and oceanic islands, body masses of extant animals are two or even three orders of magnitude lower than those of their extinct predecessors (see the supporting online material).

For instance, the largest frugivores in South America were gomphotheres (7580 kg), whereas the largest living frugivores are the tapirs (300 kg). On the continental island of Madagascar, the role of largest frugivore has passed from the elephant bird (450 kg) to the radiated tortoise (10 kg). On Mauritius, giant tortoises weighing up to 100 kg were the largest native frugivores; today, the title goes to a fruitbat weighing only 0.54 kg.

Thus, the loss of the island giants—tortoises, lizards, and flightless birds such as the dodo that were once found on many islands—has, in relative terms, led to a greater megafaunal downsizing than the extinction of even the largest gomphotheres in South America (see the figure).

Moreover, in the relatively species-poor and simple island ecosystems, cascading effects of megafaunal loss may manifest themselves faster and with more devastating results than in more complex continental ecosystems. For example, lost megafaunal seed-dispersal interactions on islands will not be compensated for by surviving frugivores, because they are too small. In continental ecosystems, there is a higher functional redundancy, with medium- and even small-sized species capable of filling at least part of the megafaunal niche (12).

Anthropogenic impacts are set to cause further extinctions among large vertebrates, with dramatic consequences for ecosystem dynamics (11). If all currently threatened vertebrate frugivores were to go extinct, the relative ecological shrinkage in many continental ecosystems would equal that of islands. For instance, if all threatened frugivores in South America were to go extinct, the largest remaining frugivore would be the howler monkey, weighing 9 kg—a factor of 700 less than the giant ground sloth. Even some islands
stand to suffer further losses; in Mauritius, the largest nonthreatened native frugivore is the gray white-eye, a bird weighing a mere 0.009 kg (see the supporting online material).

An extended megafauna concept has the potential to promote synergy between otherwise disparate research and conservation foci, and to facilitate broader syntheses of ecosystem-level effects of extinctions of the largest vertebrates and the resulting ecological shrinkage. It is high time to more fully understand and ameliorate the recent and ongoing losses of all “the hugest, and fiercest, and strangest forms” (13).

COMPUTER SCIENCE

Automating Science

David Waltz1 and Bruce G. Buchanan2

The idea of automating aspects of scientific activity dates back to the roots of computer science, if not to Francis Bacon. Some of the earliest programs automated the processes of creating ballistic tables, cracking ciphers, collecting laboratory data, etc., by carrying out a set of instructions from start to finish. Starting with DENDRAL in the 1960s (1), artificial intelligence programs such as Prospector (2), Bacon (3), and Fahrenheit (4) automated some of the planning, analysis, and discovery portions of the scientific enterprise. However, most of these programs were still designed to run a calculation to completion, produce an answer, and then stop. They did not fully “close the loop” in the sense of examining the results of their actions, deciding what to try next, potentially cycling forever.

Two reports on pages 85 and 81 of this issue push the boundaries of automatic scientific experimentation and discovery. King et al. (5) describe a robotic system for running biological experiments, evaluating their results, and deciding what experiments to try next. Schmidt and Lipson (6) describe their work on discovering complex equations that characterize complex nonlinear dynamical systems, derived from visual observation of such systems. As these reports show, it is possible for one computer program to step through the activities needed to conduct a continuously looping procedure that starts with a question, carries out experiments to answer the question, evaluates the results, and reformulates new questions.

The main goals of automation in science have been to increase productivity by increasing efficiency (e.g., with rapid throughput), to improve quality (e.g., by reducing error), and to cope with scale, allowing scientific treatment of topics that were previously impossible to address. Tycho Brahe spent a lifetime recording observations that allowed Johannes Kepler to formulate Kepler’s laws of planetary motion; today, computer-controlled data collection is commonplace and necessary for both experimental and observational science. Automating many activities beyond data collection offers even more benefits.

In the near term, a useful metaphor is to consider computers as intelligent assistants. Some assistants gather data and attend to such tasks as noise filtering, data smoothing, outlier rejection, and data storage. Other assistants are specialists at statistical analysis, still others at bench work. This metaphor has driven many research projects over the past several decades and has led to many of the most successful applications of computers.

An early articulation of this metaphor is Joshua Lederberg’s effort at Stanford University School of Medicine to develop an automated biomedical laboratory to examine the soil of Mars for traces of life, as part of the 1975 Viking mission deployed by the U.S. National Aeronautics and Space Administration. The robot assistant Lederberg designed, with engineer Elliott Levinthal, consisted of a conveyor belt that scooped up soil of Mars for traces of life, as part of the 1975 Viking mission deployed by the U.S. National Aeronautics and Space Administration. The robot assistant Lederberg designed, with engineer Elliott Levinthal, consisted of a conveyor belt that scooped up samples of Martian soil and deposited them within a computer-controlled mass spectrometer. Each soil sample was bombarded with electrons, producing a fragmentation pattern that sorted the charged particles (ions) according to their mass. This pattern was transmitted to Earth, where scientists could analyze it for

REFERENCES


Supporting Online Material

www.sciencemag.org/cgi/content/full/324/5923/42/DC1

Fig. S1

Table S1

References

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This PDF file includes:

Fig. S1
Table S1
References
Figure S1. Current and projected ecological shrinkage in seed dispersal interactions on continents, continental islands, and oceanic islands, illustrated by declines in frugivore body mass. Arrows span declines from the largest recently extinct frugivore to the largest extant frugivore (red arrows), as well as maximum projected future decline if all currently threatened frugivores went extinct (IUCN status of VU, EN or CR; yellow arrows). Regions: Africa [AF], South America [SA], Australia [AU], Southeast Asia [AS]; Cuba [CU], Madagascar [MA], New Caledonia [NC]; Tonga [TO], Mauritius [MR], Fiji [FI].
Table S1. Largest extinct and extant frugivores in selected continents, continental islands and oceanic islands. Body mass in kg. IUCN status, from least concern to critically endangered: LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered, CR = Critically Endangered.

<table>
<thead>
<tr>
<th>Region</th>
<th>Largest extinct</th>
<th>Body mass</th>
<th>Largest extant</th>
<th>Body mass</th>
<th>IUCN status (1)</th>
<th>Largest extant non-threatened</th>
<th>Body mass</th>
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<tr>
<td>Africa</td>
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<td>3940</td>
<td>NT</td>
<td>African bush elephant</td>
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<td>300</td>
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<td>Red howler monkey</td>
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<td>Dromaius novaehollandiae (8)</td>
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<td>SE Asia</td>
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<td>10000</td>
<td>Asian elephant</td>
<td>3000</td>
<td>VU</td>
<td>Tibetan macaque</td>
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References:
1. IUCN Redlist online: http://www.iucnredlist.org (accessed February 01, 2009).
6. No published body mass estimates exist for these species; we estimated the body masses based on known carapace length/body mass relations for the giant Aldabran tortoise, Aldabrachelys gigantea, from M. J. Coe, D. Bourn, I. R. Swingland, Phil. Trans. R. Soc. Lond. B. 286, 163 (1979).