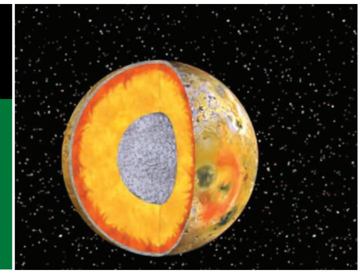
COMMENTARY



LETTERS

edited by Jennifer Sills

Editor's Note

THE RESEARCH ARTICLE "A BACTERIUM THAT CAN GROW BY USING arsenic instead of phosphorus" by F. Wolfe-Simon *et al*. [p. 1163, (*1*)] was the subject of extensive discussion and criticism following its online publication. *Science* received a wide range of correspondence that raised specific concerns about the Research Article's methods and interpretations. Eight Technical Comments that represent the main concerns, as well as a Technical Response by Wolfe-Simon *et al*., are published online with this issue at the addresses listed below (all were previously published in *Science* Express on 27 May). They have been peer-reviewed and revised according to *Science's* standard procedure.

The print version of the Wolfe-Simon *et al*. paper reflects minor clarifications and copyediting of the *Science* Express version. We hope that publication of this collection will allow readers to better assess the Research Article's original claims and the criticisms of them. Our procedures for Technical Comments and Responses are such that the original authors are given the last word, and we recognize that some issues remain unresolved. However, the discussion published today is only a step in a much longer process. Wolfe-Simon *et al*. are making bacterial strain GFAJ-1 available for others (*2*) to test their hypotheses in the usual way that science progresses.

BRUCE ALBERTS
Editor-in-Chief

References and Notes

1. F. Wolfe-Simon, J. S. Blum, T. R. Kulp, G. W. Gordon, S. E. Hoeft, J. Pett-Ridge, J. F. Stolz, S. M. Webb, P. K. Weber, P. C. W. Davies, A. D. Anbar, R. S. Oremland, *Science* **332**, 1163 (2011); published online 2 December 2010 (10.1126/science.1197258).
2. Cultures of GFAJ-1 were submitted to the American Type Culture Collection and Deutsche Sammlung von Mikroorganismen und Zellkulturen on 21 March 2011 and will be available from these sources within several months. Until then, samples of GFAJ-1 are available to the community from the Oremland lab upon completion of a materials transfer agreement, which is required by the U.S. Geological Survey for the transfer of bacterial cultures.

TECHNICAL COMMENTS

Comment on "A Bacterium That Can Grow by Using Arsenic Instead of Phosphorus"
István Csabai and Eörs Szathmáry
www.sciencemag.org/cgi/content/full/332/6034/1149-b

Comment on "A Bacterium That Can Grow by Using Arsenic Instead of Phosphorus"
Steven A. Benner
www.sciencemag.org/cgi/content/full/332/6034/1149-c

Comment on "A Bacterium That Can Grow by Using Arsenic Instead of Phosphorus"
B. Schoepp-Cothenet, W. Nitschke, L. M. Barge, A. Ponce, M. J. Russell, A. I. Tsapin
www.sciencemag.org/cgi/content/full/332/6034/1149-d

Comment on "A Bacterium That Can Grow by Using Arsenic Instead of Phosphorus"
David W. Borhani
www.sciencemag.org/cgi/content/full/332/6034/1149-e

Comment on "A Bacterium That Can Grow by Using Arsenic Instead of Phosphorus"
James B. Cotner and Edward K. Hall
www.sciencemag.org/cgi/content/full/332/6034/1149-f

Comment on "A Bacterium That Can Grow by Using Arsenic Instead of Phosphorus"
Stefan Oehler
www.sciencemag.org/cgi/content/full/332/6034/1149-g

Comment on "A Bacterium That Can Grow by Using Arsenic Instead of Phosphorus"
Rosemary J. Redfield
www.sciencemag.org/cgi/content/full/332/6034/1149-h

Comment on "A Bacterium That Can Grow by Using Arsenic Instead of Phosphorus"
Patricia L. Foster
www.sciencemag.org/cgi/content/full/332/6034/1149-i

Response to Comments on "A Bacterium That Can Grow by Using Arsenic Instead of Phosphorus"
Felisa Wolfe-Simon, Jodi Switzer Blum, Thomas R. Kulp, Gwyneth W. Gordon, Shelley E. Hoeft, Jennifer Pett-Ridge, John F. Stolz, Samuel M. Webb, Peter K. Weber, Paul C. W. Davies, Ariel D. Anbar, Ronald S. Oremland
www.sciencemag.org/cgi/content/full/332/6034/1149-j

Zoos and Captive Breeding

D. A. CONDE AND COLLEAGUES' POLICY FORUM "An emerging role of zoos to conserve biodiversity" (18 March, p. 1390) presents an inspiring view of zoos' potential contributions to conservation through captive breeding and reintroduction. However, their analysis overlooks two key issues.

First, zoos currently devote only a small proportion of their capacity to conserving the most threatened species. Although zoos house ~15% of threatened tetrapods, Conde *et al*.'s histograms reveal that this includes proportionally fewer species in more-threatened categories, and hardly any amphibians—the group that is most threatened and probably best suited to captive breeding (*1*). More important, most (185 of 344; 54%) of the most highly threatened tetrapod species in zoos are held in populations that are too small to be viable (*2*) because they comprise 50 or fewer individuals, and those are often spread across separately managed subpopulations (*3*). These small population sizes have not improved in the past two decades, at least for mammals (*4*). Furthermore, many species perform more poorly in captivity than when protected in the wild, with lower reproductive rates and higher offspring losses (*5*); this exacerbates the problem of small populations in zoos by reducing these species' effective population sizes even further.

Second, Conde *et al*.'s analysis pays little attention to other effects of captivity, such as abnormal behavior, insufficient fear of humans, and exposure to novel diseases, which often limit the success of subsequent reintroduction attempts (*6*). This may be why releasing zoo-bred animals has had only limited impact on the status of wild populations. Conde *et al*. state that captive-breeding has played a major role in reducing the threat level of 17 tetrapod species [26% of the 64 whose status has been improved by conservation action (*7*)], but this total involves a miscount and erroneously includes the Seychelles magpie-robin (*Copsychus sechellarum*), the Marquesan Imperial-pigeon (*Ducula galeata*), and the Polynesian megapode (*Megapodius pritchardii*), which were never held in captive breeding programs (*8*). In reality, zoos have directly provided most of the stock for reintroduction in a much smaller number of cases.

Given the scale of the biodiversity crisis, we therefore recommend that zoos increase the contribution that their captive breeding efforts make to conservation in the wild by focusing efforts more closely on those species with good captive health, welfare, and population viability (*5*, *9*, *10*).

ANDREW BALMFORD,[1] JEANETTE KROSHKO,[2] NIGEL LEADER-WILLIAMS,[3] GEORGIA MASON[2]*

[1]Department of Zoology, University of Cambridge, Cambridge, CB2 3EJ, UK. [2]Department of Animal and Poultry Sciences, University of Guelph, Guelph, Ontario, N1G 2W1, Canada. [3]Department of Geography, University of Cambridge, Cambridge, CB2 3EN, UK.

*To whom correspondence should be addressed. E-mail: gmason@uoguelph.ca

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2. I. R. Franklin, in *Conservation Biology, An Evolutionary-Ecological Perspective*, M. E. Soulé, B. A. Wilcox, Eds. (Sinauer, Sunderland, MA, 1980), pp. 135–149.
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4. C. D. Magin *et al*., in *Creative Conservation: Interactive Management of Wild and Captive Animals*, P. S. Olney, G. M. Mace, A. T. C. Feistner, Eds. (Chapman & Hall, London, 1993), pp. 3–31.
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10. N. Leader-Williams *et al*., in *Zoos in the 21st Century: Catalysts for Conservation?* A. Zimmermann, M. Hatchwell, L. Dickie, C. West, Eds. (Cambridge Univ. Press, Cambridge, 2007), pp. 236–254.

Response

BALMFORD *ET AL.* SUGGEST THAT OUR ANALYSIS has embellished the potential of zoos to conserve endangered species, and they state that zoos devote only a small proportion of their capacity to threatened species. Although zoos devote only 8% of their capacity to threatened bird species, 23% of amphibians, 27% of mammals, and 40% of reptiles within zoo collections are threatened (see table 1 in the Policy Forum supporting online material). A comparison of our data and the data by Magin *et al*. that Balmford *et al*. cite (*1*) shows that the number of threatened species in ISIS zoos has markedly increased over the past 20 years. The most substantial increase has been for threatened amphibians, from just 5 species in 1990 to 56 species in 2009 (an increase of 1020%), followed by birds (509% increase) and reptiles (424% increase). These absolute gains are obscured because, although the number of threatened species in zoos has increased substantially, the number of species classified as threatened has increased relatively more. For example, in 1990 the IUCN listed just 57 threatened amphibians (*1*), but by 2009 this figure had jumped to 1895 (*2*). Thus, the number of species of threatened amphibians held in zoos increased by 1020%, while the number listed as threatened increased by 3300%, outpacing the zoos' response to the amphibian crisis. The percentage of all then-threatened species kept in captivity, comparing the 1990 and 2009 figures, declined for amphibians and mammals, and increased for birds and reptiles.

Balmford *et al*. mention that the number of individuals of highly threatened species in zoos is low and has not increased in the past two decades. Magin *et al*. only provide this information for mammals, but they show that, although many zoo populations do remain small, there is an encouraging trend: From 1990 to 2009, there has been a 21.2% increase in the number of threatened mammal species with a zoo metapopulation size exceeding 50 individuals, and a 48.6% increase in the number of species with a metapopulation size exceeding 250 individuals. We argue that, although the zoo community is not keeping up with the rapidly accelerating scale of the species conservation challenge, it is doing much better than Balmford *et al*. suggest. Moreover, despite small population sizes, zoos' intervention has prevented the extinction of a number of species, such as the California condor (*Gymnogyps californianus*) (*3*), the European bison (*Bison bonasus*) (*4*), and the Przewalski's horse (*Equus ferus przewalskii)* (*5*)*.* It is true that 53% of zoos' highly threatened species are represented by fewer than 50 individuals and that many are managed across separate subpopulations, but some zoos are aware of this problem and are linking several species in cooperative breeding programs (*6*).

Balmford *et al*. also reiterated that the effects of captivity can affect further reintroductions. Although we agree that this could be a serious issue, given the biodiversity crisis it is important to recognize that these effects can often be overcome, as exemplified by reintroduction programs for species such as the whooping crane (*7*). Balmford *et al*. rightly point out errors in Hoffmann *et al*.'s (*8*) calculation for the number of species for which captive breeding played an important con-

Captive breeding.

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Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the past 3 months or matters of general interest. Letters are not acknowledged upon receipt. Whether published in full or in part, Letters are subject to editing for clarity and space. Letters submitted, published, or posted elsewhere, in print or online, will be disqualified. To submit a Letter, go to www.submit2science.org.

servation role. The correct figure is 13 species [Hoffman *et al.* omitted the Californian condor, in addition to the erroneous inclusion of the three species Balmford *et al.* mention together with *Dendrobates azureus* (*2*)].

Balmford *et al.* further claim that zoos have only contributed stock from captive breeding in a small number of these reintroductions. However, it is important to stress that zoos provided substantial logistical, technical, and/or financial support for at least 9 of these 13 species (*9*).

These points notwithstanding, we agree with Balmford *et al.*'s closing argument that zoos should continue to increase their captive conservation efforts in a scientifically informed manner.

D. A. CONDE,[1]* N. FLESNESS,[2] F. COLCHERO,[1] O. R. JONES,[1] A. SCHEUERLEIN[1]

[1]Max Planck Institute for Demographic Research, 18057 Rostock, Germany. [2]International Species Information System, Eagan, MN 55121, USA.

References and Notes

1. C. D. Magin *et al.*, in *Creative Conservation: Interactive Management of Wild and Captive Animals*, P. S. Olney, G. M. Mace, A. T. C. Feistner, Eds. (Chapman & Hall, London, 1993), pp. 3–31.
2. IUCN, IUCN Red List of Threatened Species (www.iucnredlist.org).
3. IUCN, *Gymnogyps californianus* in "IUCN 2010: IUCN Red List of Threatened Species, Version 2010.4" (2008).
4. Z. Pucek *et al.*, "Status survey and conservation action plan: European bison" (IUCN Bison Specialist Group, Gland, Switzerland, 2004).
5. L. Boyd *et al.*, in "IUCN 2010: IUCN Red List of Threatened Species, Version 2010.4" (2008).
6. W. G. Conway, *Zoo Biol.* **30**, 1 (2011).
7. U.S. Fish and Wildlife Service, Reintroduction of a Migratory Flock of Whooping Cranes in the Eastern United States (www.fws.gov/midwest/whoopingcrane).
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9. Species that reduced their threat status by captive breeding actions with substantial logistical, technical and/or financial support from zoos include *Gymnogyps californianus* (*3*), *Bison bonasus (4), Equus ferus przewaskii (5), Leontopithecus rosalia* (*10*), *Nesoenas mayeri* (*11*), *Falco punctatus* (*12*), *Mustela nigripes* (*13*), *Leporillus conditor* (*14*), and *Alytes muletensis* (*15*).
10. M. C. M. Kierulff *et al.*, in "IUCN 2010: IUCN Red List of Threatened Species, Version 2010.4" (2008).
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CORRECTIONS AND CLARIFICATIONS

News & Analysis: "Spate of suicides roils university, jeopardizing academic reforms" by D. Normile (22 April, p. 410). The article stated that "local media reported that the education ministry found evidence of administrative and financial irregularities, including improperly vetted bonus payments to [KAIST President Suh Nam Pyo]." KAIST contests the ministry's finding; it says that the total amount of the yearly compensation for the president is specified in the employment contract with KAIST and that Suh did not receive any additional compensation other than the specified amount.