Feral horses in the Australian Alps threaten the environment, forcing policy-makers to weigh humane conservation practices against less costly approaches.

PHOTO: © LANGRISH, BOB/ANIMALS ANIMALS

Edited by **Jennifer Sills**

Retraction

The supplementary materials (SM) for our Report "Proton transport enabled by a field-induced metallic state in a semiconductor heterostructure" (*1*) contained mistakes. Fig. S10 was incorrect. The image had been previously saved in an experimental database. The figure should have shown a schematic illustration. This mistake occurred when computer data was transferred from one student to another. Fig. S9B also raised questions. The image appears to be a copy of figure 8B in a 2018 paper in the *International Journal of Hydrogen Energy* (*2*). The tests producing the data for these two figures were performed during the same period of time. Because of the similarity between the *IV-IP* measurements of SN-120 and the Na_xCoO_2/CeO_2 (x = 0.55) measurements, these data were wrongly saved in the same folder. Therefore, the final plotted fig. S9B in *Science* erroneously contains data from the figure in the 2018 paper. We repeated the experiment to replicate the data and found that the new outputs of two Na_xCoO_2/CeO_2 (x < 0.6) cells are above 550 mW cm^{-2} at 520°C, consistent with the data in fig. S9.

These mistakes were related to recent location and personnel changes. Between June and September 2019, all laboratories of the Faculty of Materials Science and Chemistry, including ours, had to move to a new campus 30 km away. During the same time, author L. Liu graduated, but the ordinary data transfer to successors was temporarily discontinued. The manuscript was finalized between mid-December 2019 and March 2020, during the unprecedented lockdown of the city of Wuhan for coronavirus disease 2019. All authors who prepared the main manuscript and SM data were isolated in different cities and countries, without access to lab computers or database resources, which led to miscommunications.

We take full responsibility for the accidental mistakes in the SM. We stand by our experimental design, theoretical calculations, main data, and analysis of low-temperature proton ceramic fuel cells. However, given the mistakes in the SM, we have decided to retract the Report. All authors except for B. Zhu, M. Huang, M. Akbar, and J. S. Kim approved this Retraction.

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REFERENCES AND NOTES

1. Y. Wu, B. Zhu, M. Huang, L. Liu, Q. Shi, M. Akbar, C. Chen, J. Wei, J. F. Li, L. R. Zheng, J. S. Kim, H. B. Song, *Science* **369**, 184 (2020).
2. L. Liu *et al.*, *Int. J. Hydrogen Energ.* **43**, 12739 (2018).

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Hidden ethical costs of conservation

We agree with N. Sekar and D. Shillers ("Engage with animal welfare in conservation," Policy Forum, 7 August, p. 629) that welfare considerations are an important part of the myriad values in conservation. However, more humane conservation tactics are often costlier. The money and resources spent on humane conservation practices detract from the resources available for other conservation projects. This hidden ethical cost of humane conservation must be considered when proposing new approaches to conservation management.

Biodiversity conservation is associated with a variety of values that often vary implicitly between individuals and organizations (*1*, *2*). These values are rarely noticed until they conflict, such as when invasive-species culling is proposed. Compassionate conservationists have responded to this challenge with humane but more expensive animal management alternatives including fertility control and trapping and rehoming animals (*3*). Feral horse management in the Australian Alps with passive trapping costs approximately AU$1116 per horse, whereas aerial culling costs approximately AU$85 per horse (*4*). For the same cost, more culling could be carried out, resulting in a greater net area of biodiversity conserved. Alternatively, savings achieved by implementing aerial culling could be spent on

other conservation projects in the region. In addition to promoting biodiversity conservation, these projects could benefit the welfare of other animals by protecting threatened native species (*5*).

Considerations of what one could have done otherwise with a given resource is a foundational principle of the effective altruism movement, an evidence-based ethical framework (*6*). Emerging applications of this framework to conservation include considerations of animal welfare and offer promising solutions to complex cases of value conflict (*7*, *8*).

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REFERENCES AND NOTES

1. C. Gamborg *et al.*, *Nat. Educ. Knowl.* **3**, 8 (2012).
2. J. A. Newman *et al.*, *Defending Biodiversity: Environmental Science and Ethics* (Cambridge University Press, Cambridge, UK, 2017).
3. A. Wallach *et al.*, *Conserv. Biol.* **32**, 1255 (2018).
4. N. J. Beeton, C. N. Johnson, *Ecol. Manage. Restor.* **20**, 57 (2019).
5. D. A. Driscoll *et al.*, *Ecol. Manage. Restor.* **20**, 63 (2019).
6. W. McAskill, *Doing Good Better: How Effective Altruism Can Help You Make a Difference* (Penguin Random House, 2015).
7. K. E. Lynch, D. T. Blumstein, *TREE* **35**, 857 (2020).
8. B. S. Freeling, S. D. Connell, *TREE* **35**, 3 (2020).

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Pragmatic animal welfare is independent of feelings

In their Policy Forum "Engage with animal welfare in conservation" (7 August, p. 629), N. Sekar and D. Shiller state that the "overwhelming evidence that animals think and feel" is the basis for their call to include animal welfare in conservation practices. This feelings-based approach is problematic because there is substantial scientific uncertainty about whether taxa such as fish are sentient and, therefore, able to feel pain and suffer (*1*, *2*).

In recreational fishing, animal welfare concepts are embedded in global international conservation policies (*3*, *4*) and in local welfare actions (*5*), despite the uncertainty about fish sentience. These activities are motivated by the reality that fish populations are composed of individuals whose well-being is important to the conservation of populations and fisheries, regardless of whether the animal is able to think and feel. Moreover, many users of fish respect the life, function, and welfare of individual fish and act accordingly, independent of whether they think that the animal can feel pain (*5*, *6*).

Recreational fishing policies recognize the importance of animal welfare regardless of whether fish are sentient.

An effective application of animal welfare in conservation is possible—and is perhaps more effective and convincing to stakeholders—without invoking or relying on concepts such as consciousness, sentience, or pain (*5*, *7*). A pragmatic approach to animal welfare that relies on objective and measurable endpoints of animal well-being is more likely to gain support among stakeholders and be implemented in practice than a feelings-based framework that is based on concepts that are difficult to define and cannot be readily measured in many taxa (*5*, *7*).

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REFERENCES AND NOTES

1. J. D. Rose *et al.*, *Fish Fish.* **15**, 97 (2014).
2. B. Key, *Biol. Phil.* **30**, 149 (2015).
3. Food and Agriculture Organization of the United Nations (FAO), "FAO technical guidelines for responsible fisheries recreational fisheries" (2012).
4. European Inland Fisheries Advisory Commission (EIFAC), "EIFAC code of practice for recreational fisheries" (FAO, 2008).
5. R. Arlinghaus *et al.*, *J. Fish Biol.* **75**, 2448 (2009).
6. J. C. Evans, *With Respect for Nature: Living as Part of the Natural World* (Sunypress, 2015).
7. M. S. Dawkins, *J. Zool.* **301**, 1 (2017).

COMPETING INTERESTS

This piece reflects the views of the authors and not those of their organizations or relevant funding sources.

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Animal welfare science aids conservation

In their Policy Forum "Engage with animal welfare in conservation" (7 August, p. 629), N. Sekar and D. Shiller overlooked a long history of conservation-related animal welfare science. The integration of animal welfare science and conservation spans at least 60 years (*1*) and has been applied to a broad range of wildlife management activities (*2*) and interdisciplinary research (*3*–*5*). Understanding and incorporating animal welfare science can benefit conservation efforts.

Animal welfare science is not synonymous with opposition to intentional killing of wildlife (compassionate conservation) (*6*, *7*). Rather, animal welfare science uses quantitative measurements to assess harmful and positive impacts of human activities on animals (*8*). Traditionally, the harms are weighed against conservation benefits to justify (or rule out) a management action. Approaches such as compassionate conservation may, perhaps counterintuitively, worsen animal welfare outcomes and make biodiversity conservation more difficult (*9*).

Sekar and Shiller use prescriptive advocacy framing that does not represent animal welfare science. Stipulating that conservation agencies should avoid factory farming products does not reflect scientific quantification and comparison of harms posed by this and other human activities. Processes such as land clearing (*10*) may pose greater animal welfare impacts when all wild sentient species and types of harm (*11*) are considered.

We agree that increased animal welfare focus is warranted in conservation. Progress will be expedited by wider collaboration with animal welfare scientists. Decades-old

PHOTO: FLORIAN MÖLLERS

scientific tradition in this space teaches us to prioritize objective assessment of harms rather than deferring to advocacy.

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REFERENCES AND NOTES

1. B. Warburton, J. Hall, *New Zealand J. Zool.* **22**, 39 (1995).
2. S. E. Baker *et al.*, *BioScience* **63**, 928 (2013).
3. D. Fraser, *Anim. Welfare* **19**, 121 (2010).
4. B. Warburton, B. Norton, *J. Wildl. Manag.* **73**, 158 (2009).
5. A. M. Harvey *et al.*, *Animals* **10**, 148 (2020).
6. A. D. Wallach *et al.*, *Conserv. Biol.* **32**, 1255 (2018).
7. N. J. Beausoleil, *Animals* **10**, 257 (2020).
8. C. R. McMahon *et al.*, *Wildl. Res.* **39**, 375 (2012).
9. A. Callen *et al.*, *Biol. Conserv.* **241**, 108365 (2020).
10. H. Finn, N. Stephens, *Wildl. Res.* **44**, 377 (2017).
11. D. Fraser, A. M. MacRae, *Anim. Welfare* **20**, 581 (2011).

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Response

We agree with Lynch and Blumstein that decision-makers must consider the opportunity costs—financial and ethical—of conservation programming. Making decisions in the face of such trade-offs will inevitably require value judgments. Decision-makers will likely continue to conclude that interventions that harm individual animals, such as culling, are sometimes merited by the benefits and necessitated by financial constraints.

Even so, explicit consideration of animal welfare could lead to affordable improvements when ideal alternatives are unworkable. For instance, evidence suggests that aerial culling operations might entail acceptable levels of duress for feral horses if done properly (*1*). For a marginal increase in cost, conservation organizations could promote oversight by independent animal welfare experts to ensure adherence to best practices during unavoidable culling operations.

Focusing too much on the current financial costs of humane alternatives could cause the conservation community to discount the value of prioritizing animal welfare. We hope that recognition of the moral relevance of individual animals' life experiences could lead to innovations that circumvent difficult trade-offs. For instance, conservationists have already demonstrated the promise of contraceptives to address population control for horses (*2*). Giving animal welfare the appropriate weight could motivate efforts to reduce the costs of contraceptive programs. Prioritization drives innovation.

Arlinghaus *et al.* are likely correct that an instrumental approach, which sets aside the issue of suffering, eases the introduction of some safeguards for animal welfare in recreational fishing. However, experts remain divided on the capacity for consciousness in fish (*3*, *4*). If fish can suffer, protections based solely on instrumental considerations would be inadequate. Conservation organizations should, wherever practical, establish policies that reflect the diversity of evidence on suffering in fish. The uncertainty about what fish can experience—in contrast to the expert consensus about the capacity for mammals and birds to suffer—highlights how animal welfare institutions in conservation must navigate diverse challenges across taxa. Formal concern for animal welfare could not only shape conservation practice but also influence the direction of fundamental research on the quality of animal life.

Hampton *et al.* describe the work done by animal welfare scientists in conservation. Our Policy Forum did not claim that animal welfare science in conservation would be novel but rather that it deserves more attention and institutional support. The public looks to conservation organizations for leadership in how to ethically engage with other species. As such, institutional safeguards for animal welfare should be at least as much a priority in conservation as in academic research. The small minority of conservation organizations that do explicitly recognize animal welfare concerns [e.g., (*5*, *6*)] have demonstrated that policies promoting animal welfare in conservation are practicable.

We agree with Hampton *et al.* that animal welfare science should not be biased by unsubstantiated pre-existing beliefs. However, once enough evidence has accumulated, evidence-driven advocacy can be crucial for translating science into societal improvement. The harms from factory farming to billions of domestic animals [e.g., (*7*, *8*)], the climate, and biodiversity (*9*, *10*) merit decisive action from conservation organizations. Whereas some substitutes for factory farming might have negative biodiversity consequences, other alternatives—such as diets that largely exclude animal products—can offer a clear net win for both animal welfare and biodiversity (*9*, *10*).

Conservation organizations frequently engage in advocacy to build a better planet for animals, including efforts to shape the cultural and consumptive practices of people around the world (*11*, *12*). When presented with evidence-based opportunities to improve the quality of animal life, conservation organizations must be receptive to altering their own practices as well.

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REFERENCES AND NOTES

1. J. O. Hampton *et al.*, *Wildl. Res.* **44**, 97 (2017).
2. C. M. V. Nuñez *et al.*, *Conserv. Physiol.* **5**, 1 (2017).
3. V. Braithwaite, *Do fish feel pain?* (OUP, Oxford, 2010).
4. J. D. Rose *et al.*, *Fish Fish.* **15**, 97 (2014).
5. International Fund for Animal Welfare, Guiding Principles (2020); www.ifaw.org/about/guiding-principles.
6. Sierra Club Board of Directors, "Policy on trapping of wildlife" (2012); www.sierraclub.org/sites/www.sierraclub.org/files/uploads-wysiwig/Trapping-Wildlife.pdf.
7. R. J. Julian, *Poult. Sci.* **77**, 1773 (1998).
8. M. R. N. Bruijnis *et al.*, *Animal* **7**, 167 (2013).
9. J. Poore, T. Nemecek, *Science* **360**, 987 (2018).
10. B. Machovina *et al.*, *Sci. Total Environ.* **536**, 419 (2015).
11. Global Wildlife Conservation, #endthetrade (2020); https://endthetrade.com/.
12. R. Fobar, "Shark fin is banned in 12 U.S. states—but it's still on the menu," *National Geographic* (2019).

COMPETING INTERESTS

This piece reflects the views of the authors and not the official positions of their organizations.

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TECHNICAL COMMENT ABSTRACTS

Comment on "Female toads engaging in adaptive hybridization prefer high-quality heterospecifics as mates"

Michael J. Braun, Gerald S. Wilkinson, Brian S. Cade

Chen and Pfennig (Reports, 20 March 2020, p. 1377) analyze the fitness consequences of hybridization in toads but do not account for differences in survival among progeny. Apparent fitness effects depend on families with anomalously low survival, yet survival is crucial to evolutionary fitness. This and other analytical shortcomings demonstrate that a conclusion of adaptive mate choice is not yet justified.

Full text: dx.doi.org/10.1126/science.abd3905

Response to Comment on "Female toads engaging in adaptive hybridization prefer high-quality heterospecifics as mates"

Catherine Chen and Karin S. Pfennig

Braun *et al.* contend that we did not account for survival, but we did. Differential survival does not alter our conclusions, which were also robust to removing anomalous families. They ignore the study system's natural history justifying our fitness measures, while failing to account for our behavioral data. We stand by our conclusion that females adaptively choose among heterospecific males.

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Pragmatic animal welfare is independent of feelings

Robert Arlinghaus, Ian G. Cowx, Brian Key, Ben K. Diggles, Alexander Schwab, Steven J. Cooke, Anne Berit Skiftesvik and Howard I. Browman

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