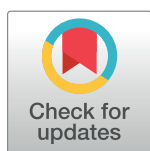


FORMAL COMMENT

Taxonomy based on science is necessary for global conservation

Scott A. Thomson^{1,2*}, Richard L. Pyle^{3,4*}, Shane T. Ah Yong^{5,6}, Miguel Alonso-Zarazaga^{4,7}, Joe Ammirati⁸, Juan Francisco Araya⁹, John S. Ascher¹⁰, Tracy Lynn Audisio¹¹, Valter M. Azevedo-Santos¹², Nicolas Bailly¹³, William J. Baker¹⁴, Michael Balke¹⁵, Maxwell V. L. Barclay¹⁶, Russell L. Barrett^{17,18}, Ricardo C. Benine¹², James R. M. Bickstaff¹⁹, Patrice Bouchard^{4,20}, Roger Bour²¹, Thierry Bourgoin^{4,21}, Christopher B. Boyko^{22,23}, Abraham S. H. Breure^{24,25}, Denis J. Brothers²⁶, James W. Byng^{24,27}, David Campbell²⁸, Luis M. P. Ceriaco²⁹, István Cernák³⁰, Pierfilippo Cerretti³¹, Chih-Han Chang^{32,33}, Soowon Cho³⁴, Joshua M. Copus³⁵, Mark J. Costello³⁶, Andras Cseh³⁷, Csaba Csuzdi³⁸, Alastair Culham³⁹, Guillermo D'Elia⁴⁰, Cédric d'Udekem d'Acoz²⁵, Mikhail E. Daneliya⁴¹, René Dekker²⁴, Edward C. Dickinson^{42a}, Timothy A. Dickinson⁴³, Peter Paul van Dijk^{44,45}, Klaas-Douwe B. Dijkstra²⁴, Bálint Dima^{46,47}, Dmitry A. Dmitriev^{4,48}, Leni Duistermaat²⁴, John P. Dumbacher⁴⁹, Wolf L. Eiserhardt⁵⁰, Torbjørn Ekrem⁵¹, Neal L. Evenhuis^{3,4}, Arnaud Faille⁵², José L. Fernández-Triana²⁰, Emile Fiesler⁵³, Mark Fishbein⁵⁴, Barry G. Fordham⁵⁵, André V. L. Freitas⁵⁶, Natália R. Friol¹, Uwe Fritz⁵⁷, Tobias Frøslev⁵⁸, Vicki A. Funk⁵⁹, Stephen D. Gaimari⁶⁰, Guilherme S. T. Garbino⁶¹, André R. S. Garraffoni⁵⁶, József Geml⁶², Anthony C. Gill⁶², Alan Gray⁶³, Felipe G. Grazziotin⁶⁴, Penelope Greenslade⁶⁵, Eliécer E. Gutiérrez^{66,67}, Mark S. Harvey^{4,68}, Cornelis J. Hazevoet⁶⁹, Kai He⁷⁰, Xiaolan He⁷¹, Stephan Helfer⁷², Kristofer M. Helgen⁷³, Anneke H. van Heteren¹⁵, Francisco Hita Garcia¹¹, Norbert Holstein⁷⁴, Margit K. Horváth⁷⁵, Peter H. Hovenkamp²⁴, Wei Song Hwang⁷⁶, Jaakko Hyvönen^{47,71}, Melissa B. Islam⁷⁷, John B. Iverson⁷⁸, Michael A. Ivie⁷⁹, Zeehan Jaafar¹⁰, Morgan D. Jackson⁸⁰, J. Pablo Jayat⁸¹, Norman F. Johnson⁸², Hinrich Kaiser⁸³, Bente B. Klitgård⁸⁴, Daniel G. Knapp⁴⁶, Jun-ichi Kojima^{4,85}, Urmas Köljal⁸⁶, Jenő Kontschán⁸⁷, Frank-Thorsten Krell^{4,88}, Irmgard Krisai-Greilhuber⁸⁹, Sven Kullander^{4,90}, Leonardo Latella⁹¹, John E. Latkic⁹², Valeria Lencioni⁹³, Gwilym P. Lewis¹⁴, Marcos G. Lhano⁹⁴, Nathan K. Lujan⁹⁵, Jolanda A. Luksenburg⁹⁶, Jean Mariaux^{97,98}, Jader Marinho-Filho⁹⁹, Christopher J. Marshall¹⁰⁰, Jason F. Mate¹⁰¹, Molly M. McDonough¹⁰², Ellinor Michel^{16,103}, Vitor F. O. Miranda¹⁰⁴, Mircea-Dan Mitroiu¹⁰⁵, Jesús Molinari¹⁰⁶, Scott Monks^{107,108}, Abigail J. Moore^{109,110}, Ricardo Moratelli¹¹¹, Dávid Murányi^{112,113}, Takafumi Nakano¹¹⁴, Svetlana Nikolaeva^{115,116}, John Noyes¹⁶, Michael Ohl¹¹⁷, Nora H. Oleas¹¹⁸, Thomas Orrell¹¹⁹, Barna Páll-Gergely³⁷, Thomas Pape^{4,120}, Viktor Papp¹²¹, Lynne R. Parenti¹⁰², David Patterson¹²², Igor Ya. Pavlinov¹²³, Ronald H. Pine¹²⁴, Péter Poczal¹²⁵, Jefferson Prado¹²⁶, Divakaran Prathapan¹²⁷, Richard K. Rabeler¹²⁸, John E. Randall³, Frank E. Rheindt^{4,10}, Anders G. J. Rhodin^{129,130}, Sara M. Rodríguez¹³¹, D. Christopher Rogers¹³², Fabio de O. Roque¹³³, Kevin C. Rowe¹³⁴, Luis A. Ruedas¹³⁵, Jorge Salazar-Bravo¹³⁶, Rodrigo B. Salvador¹³⁷, George Sangster¹³⁸, Carlos E. Sarmiento¹³⁹, Dmitry S. Schigel¹⁴⁰, Stefan Schmidt¹⁵, Frederick W. Schueler¹⁴¹, Hendrik Segers¹⁴², Neil Snow¹⁴³, Pedro G. B. Souza-Dias¹⁴⁴, Riaan Stals¹⁴⁵, Soili Stenroos⁷¹, R. Douglas Stone²⁶, Charles F. Sturm¹⁴⁶, Pavel Štys¹⁴⁷, Pablo Teta¹⁴⁸, Daniel C. Thomas¹⁴⁹, Robert M. Timm¹⁵⁰, Brian J. Tindall^{103,151}, Jonathan A. Todd¹¹⁵, Dagmar Triebel^{152,153}, Antonio G. Valdecasas¹⁵⁴, Alfredo Vizzini^{155,156}, Maria S. Vorontsova¹⁴, Jurriaan M. de Vos¹⁵⁷, Philipp Wagner¹⁵⁸, Les Watling¹⁵⁹, Alan Weakley¹⁶⁰, Francisco Welter-Schultes^{161,4}, Daniel Whitmore¹⁶, Nicholas Wilding¹⁶², Kipling Will¹⁶³, Jason Williams²³, Karen Wilson¹⁶⁴, Judith E. Winston^{4,165}, Wolfgang Wüster¹⁶⁶, Douglas Yanega^{4,167}, David K. Yeates¹⁶⁸, Hussam Zaher¹, Guanyang Zhang¹⁶⁹, Zhi-Qiang Zhang^{170,171}, Hong-Zhang Zhou^{4,172}

1 Museu de Zoologia da Universidade de São Paulo, São Paulo, Brazil, 2 Chelonian Research Institute, Oviedo, Florida, United States of America, 3 Bernice Pauahi Bishop Museum, Hawai'i, United States of America, 4 International Commission on Zoological Nomenclature, Singapore, 5 Department of Marine Invertebrates, Australian Museum, New South Wales, Australia, 6 School of Biological, Earth & Environmental Sciences, University of New South Wales, New South Wales, Australia, 7 Departamento de Biodiversidad y Biología Evolutiva, Museo Nacional de Ciencias Naturales (CSIC), Madrid, Spain,



OPEN ACCESS

Citation: Thomson SA, Pyle RL, Ah Yong ST, Alonso-Zarazaga M, Ammirati J, Araya JF, et al. (2018) Taxonomy based on science is necessary for global conservation. *PLoS Biol* 16(3): e2005075. <https://doi.org/10.1371/journal.pbio.2005075>

Received: September 26, 2017

Accepted: February 8, 2018

Published: March 14, 2018

Copyright: This is an open access article, free of all copyright, and may be freely reproduced, distributed, transmitted, modified, built upon, or otherwise used by anyone for any lawful purpose. The work is made available under the [Creative Commons CC0](https://creativecommons.org/licenses/by/4.0/) public domain dedication.

Funding: The authors received no specific funding for this work.

Competing interests: The authors have declared that no competing interests exist.

Abbreviations: CITES, Convention on International Trade in Endangered Species; ICB, International Committee on Bionomenclature; IUBS, International Union of Biological Sciences; IUCN, International Union for Conservation of Nature.

Provenance: Not commissioned; externally peer reviewed

8 Department of Biology, University of Washington, Seattle, Washington, United States of America, **9** Universidad de Atacama, Copiapó, Chile, and Programa de Doctorado en Sistemática y Biodiversidad, Facultad de Ciencias Naturales y Oceanográficas, Universidad de Concepción, Concepción, Chile, **10** Department of Biological Sciences, National University of Singapore, Singapore, **11** Biodiversity and Biocomplexity Unit, Okinawa Institute of Science and Technology, Kunigami District, Okinawa Prefecture, Japan, **12** Laboratório de Ictiologia, Departamento de Zoologia, IBB-UNESP Campus de Botucatu, Botucatu, São Paulo, Brazil, **13** FishBase Information and Research Group, IRRI Campus, Los Baños, Laguna, Philippines, **14** Comparative Plant and Fungal Biology Department, Royal Botanic Gardens, Kew, London, United Kingdom, **15** Zoologische Staatssammlung München, Staatliche Naturwissenschaftliche Sammlungen Bayerns, München, Germany, **16** Department of Life Sciences, Natural History Museum, London, United Kingdom, **17** Australian National Herbarium, Centre for Australian National Biodiversity Research, CSIRO National Research Collections Australia, Australian Capital Territory, Australia, **18** College of Medicine, Biology and Environment, Research School of Biology, Australian National University, Australian Capital Territory, Australia, **19** Hawkesbury Institute for the Environment, Western Sydney University, Penrith, New South Wales, Australia, **20** Canadian National Collection of Insects, Arachnids and Nematodes, Agriculture and Agri-Food Canada, Ontario, Canada, **21** Institut de Systématique, Evolution, Biodiversité, Muséum National d'Histoire Naturelle, Sorbonne Universités, Paris, France, **22** Division of Invertebrate Zoology, American Museum of Natural History, New York, United States of America, **23** Department of Biology, Hofstra University, New York, United States of America, **24** Naturalis Biodiversity Center, Leiden, the Netherlands, **25** Royal Belgian Institute of Natural Sciences, Brussels, Belgium, **26** School of Life Sciences, University of KwaZulu-Natal, Scottsville, South Africa, **27** Plant Gateway Ltd., Yorkshire, United Kingdom, **28** Department of Natural Sciences, Gardner-Webb University, North Carolina, United States of America, **29** Department of Biology, Villanova University, Pennsylvania, United States of America, **30** Potato Research Center, Georgikon Faculty, University of Pannonia, Keszthely, Hungary, **31** Dipartimento di Biologia e Biotecnologia 'Charles Darwin', Sapienza Università di Roma, Rome, Italy, **32** Department of Earth and Planetary Sciences, Johns Hopkins University, Maryland, United States of America, **33** Department of Environmental Science and Technology, University of Maryland, Maryland, United States of America, **34** Department of Plant Medicine, Chungbuk National University, Cheongju, Korea, **35** Hawai'i Institute of Marine Biology, University of Hawai'i, Hawai'i, United States of America, **36** Institute of Marine Science, University of Auckland, Auckland, New Zealand, **37** Centre for Agricultural Research, Hungarian Academy of Sciences, Martonvásár, Hungary, **38** Department of Zoology, Eszterházy Károly University, Eger, Hungary, **39** Herbarium, School of Biological Sciences, University of Reading, Reading, United Kingdom, **40** Instituto de Ciencias Ambientales y Evolutivas, Facultad de Ciencias, Universidad Austral de Chile, Valdivia, Chile, **41** Department of Biosciences, University of Helsinki, Helsinki, Finland, **42** Ornithological Nomenclature Expert, **43** Green Plant Herbarium, Department of Natural History, Royal Ontario Museum, Toronto, Ontario, Canada, **44** Nomenclature Specialist, CITES Animals Committee; Turtle Conservancy, New York, United States of America, **45** Global Wildlife Conservation, Texas, United States of America, **46** Department of Plant Anatomy, Institute of Biology, Eötvös Loránd University, Budapest, Hungary, **47** Department of Biosciences (Plant Biology), Viikki Plant Science Centre, Helsinki, Finland, **48** Illinois Natural History Survey, Illinois, United States of America, **49** Institute of Biodiversity Science and Sustainability, California Academy of Sciences, San Francisco, California, United States of America, **50** Royal Botanic Gardens, Kew, London, United Kingdom, **51** NTNU University Museum, Norwegian University of Science and Technology, Trondheim, Norway, **52** Institut de Biologia Evolutiva, Universitat Pompeu Fabra, Barcelona, Spain, **53** Bioveya Biodiversity Inventories and Research, California, United States of America, **54** Department of Plant Biology, Ecology & Evolution and Herbarium, Oklahoma State University, Oklahoma, United States of America, **55** Research School of Earth Sciences, Australian National University, Australian Capital Territory, Australia, **56** Departamento de Biologia Animal, Instituto de Biologia, Universidade Estadual de Campinas, São Paulo, Brazil, **57** Senckenberg Naturhistorische Sammlungen, Dresden, Germany, **58** Department of Biology, University of Copenhagen, Copenhagen, Denmark, **59** Department of Botany, Smithsonian Institution, National Museum of Natural History, Washington, DC, United States of America, **60** Plant Pest Diagnostics Branch, California Department of Food and Agriculture, California, United States of America, **61** PPG Zoologia, Departamento de Zoologia, Instituto de Ciências Biológicas, Universidade Federal de Minas Gerais, Minas Gerais, Brazil, **62** Macleay Museum, University of Sydney, New South Wales, Australia, **63** Centre for Ecology and Hydrology, Edinburgh Research Station, Scotland, United Kingdom, **64** Laboratório de Coleções Zoológicas, Instituto Butantan, São Paulo, SP, Brazil, **65** Environmental Management, School of Applied and Biomedical Science, Federation University, Victoria, Australia, **66** PPG Biodiversidade Animal, Universidade Federal de Santa Maria, Rio Grande do Sul, Brazil, **67** National Museum of Natural History, Smithsonian Institution, Washington, DC, United States of America, **68** Department of Terrestrial Zoology, Western Australian Museum, Western Australia, Australia, **69** Museu Nacional da História Natural e da Ciência, Universidade de Lisboa, Lisboa, Portugal, **70** The Kyoto University Museum, Kyoto University, Kyoto, Japan, **71** Finnish Museum of Natural History (Botany), University of Helsinki, Helsinki, Finland, **72** Royal Botanic Garden Edinburgh, Scotland, United Kingdom, **73** School of Biological Sciences and Environment Institute, University of Adelaide, South Australia, Australia, **74** Nees

Institut für Biodiversität der Pflanzen, Universität Bonn, Bonn, Germany, **75** Department of Plant Science and Biotechnology, University of Pannonia, Keszthely, Hungary, **76** Lee Kong Chian Natural History Museum, National University of Singapore, Singapore, **77** Denver Botanic Gardens, Denver, Colorado, United States of America, **78** Department of Biology, Earlham College, Indiana, United States of America, **79** Montana Entomology Collection, Montana State University, Montana, United States of America, **80** School of Environmental Sciences, University of Guelph, Ontario, Canada, **81** Instituto de Ambiente de Montaña y Regiones Áridas, Universidad Nacional de Chilecito, La Rioja, Argentina, **82** Martha N. and John C. Moser Chair in Arthropod Systematics and Biological Diversity, The Ohio State University, Ohio, United States of America, **83** Department of Biology, Victor Valley College, Victorville, California, United States of America, **84** Identification and Naming Department, Royal Botanic Gardens, Kew, London, United Kingdom, **85** Natural History Laboratory, Faculty of Science, Ibaraki University, Mito, Japan, **86** Natural History Museum and Botanical Garden, University of Tartu, Tartu, Estonia, **87** Plant Protection Institute, Centre for Agricultural Research, Hungarian Academy of Sciences, Budapest, Hungary, **88** Department of Zoology, Denver Museum of Nature & Science, Denver, Colorado, United States of America, **89** Department of Systematic and Evolutionary Botany, Universität Wien, Wien, Austria, **90** FishBase, Department of Zoology, Swedish Museum of Natural History, Stockholm, Sweden, **91** Department of Zoology, Museo Civico di Storia Naturale di Verona, Verona, Italy, **92** Departamento de Zoología, Universidade Federal do Paraná, Paraná, Brazil, **93** Sezione di Zoologia degli Invertebrati e Idrobiologia, MUSE-Museo delle Scienze di Trento, Trento, Italy, **94** Centro de Ciências Agrárias, Ambientais e Biológicas, Universidade Federal do Recôncavo da Bahia, Bahia, Brazil, **95** Department of Biological Sciences, University of Toronto Scarborough, Ontario, Canada, **96** Department of Environmental Science and Policy, George Mason University, Virginia, United States of America, **97** Natural History Museum of Geneva, Geneva, Switzerland, **98** Department of Genetics and Evolution, University of Geneva, Geneva, Switzerland, **99** Departamento de Zoologia, Universidade de Brasília, Distrito Federal, Brazil, **100** Department of Integrative Biology, Oregon State Arthropod Collection, Oregon State University, Oregon, United States of America, **101** Henares 16, Velilla de San Antonio, Madrid, Spain, **102** Department of Vertebrate Zoology, National Museum of Natural History, Smithsonian Institution, Washington, DC, United States of America, **103** International Committee on Nomenclature, Braunschweig, Germany, **104** Universidade Estadual Paulista (Unesp), Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal, Departamento de Biologia Aplicada à Agropecuária, São Paulo, Brazil, **105** Faculty of Biology, Alexandru Ioan Cuza University of Iași, Iași, Romania, **106** Departamento de Biología, Universidad de Los Andes, Mérida, Venezuela, **107** Laboratorio de Morfología Animal, Universidad Autónoma del Estado de Hidalgo, Hidalgo, México, **108** H.W. Manter Laboratory of Parasitology, University of Nebraska-Lincoln, Lincoln, Nebraska, United States of America, **109** Robert Bebb Herbarium (OKL), University of Oklahoma, Oklahoma Biological Survey, Norman, Oklahoma, United States of America, **110** Department of Microbiology and Plant Biology, Norman, Oklahoma, United States of America, **111** Fiocruz Mata Atlântica, Fundação Oswaldo Cruz, Rio de Janeiro, Brazil, **112** Department of Civil and Environmental Engineering, Ehime University, Matsuyama, Japan, **113** Department of Zoology, Hungarian Natural History Museum, Budapest, Hungary, **114** Department of Science Education, Hiroshima University, Higashihiroshima, Japan, **115** Department of Earth Sciences, Natural History Museum, London, United Kingdom, **116** Kazan Federal University, Kremlyovskaya, Russia, **117** Museum für Naturkunde, Leibniz-Institut für Evolutions- und Biodiversitätsforschung, Berlin, Germany, **118** Centro de Investigación de la Biodiversidad y Cambio Climático (BioCamb) e Ingeniería en Biodiversidad y Recursos Genéticos, Universidad Tecnológica Indoamérica, Quito, Ecuador, **119** Integrated Taxonomic Information System, National Museum of Natural History, Smithsonian Institution, Washington, DC, United States of America, **120** Natural History Museum of Denmark, Copenhagen, Denmark, **121** Department of Botany, Szent István University, Budapest, Hungary, **122** University of Sydney, New South Wales, Australia, **123** Zoological Museum of Lomonosov Moscow State University, Moscow, Russia, **124** Biodiversity Institute, University of Kansas, Kansas, United States of America, **125** CITES Scientific Authority, Finnish Museum of Natural History (Botany), University of Helsinki, Helsinki, Finland, **126** Instituto de Botânica, São Paulo, Brazil, **127** Department of Entomology, Kerala Agricultural University, Kerala, India, **128** University of Michigan Herbarium EEB, Ann Arbor, Michigan, United States of America, **129** Chelonian Research Foundation, Massachusetts, United States of America, **130** Turtle Conservancy, New York, United States of America, **131** Instituto de Ciencias Marinas y Limnológicas, Facultad de Ciencias, Universidad Austral de Chile, Valdivia, Chile, **132** Kansas Biological Survey and the Biodiversity Institute, University of Kansas, Kansas, United States of America, **133** Laboratório de Ecologia e Conservação, Universidade Federal do Mato Grosso do Sul, Mato Grosso do Sul, Brazil, **134** Sciences Department, Museums Victoria, Victoria, Australia, **135** Department of Biology and Museum of Vertebrate Biology, Portland State University, Oregon, United States of America, **136** Department of Biological Sciences, Texas Tech University, Texas, United States of America, **137** Staatliches Museum für Naturkunde Stuttgart, Stuttgart, Germany, **138** Department of Bioinformatics and Genetics, Swedish Museum of Natural History, Stockholm, Sweden, **139** Laboratorio de Sistemática y Biología Comparada de Insectos, Instituto de Ciencias Naturales, Universidad Nacional de Colombia, Bogotá, Colombia, **140** Global Biodiversity Information Facility, Copenhagen, Denmark, **141** Fragile Inheritance Natural History, Ontario, Canada, **142** National Focal Point to the Convention on

Biological Diversity, Royal Belgian Institute of Natural Sciences, Brussels, Belgium, **143** Department of Biology, Pittsburg State University, Kansas, United States of America, **144** Departamento de Zoologia, Instituto de Biociências, Universidade de São Paulo, São Paulo, Brazil, **145** Agricultural Research Council, Plant Protection Research Institute, South African National Collection of Insects, Queenswood, South Africa, **146** Section of Mollusks, Carnegie Museum of Natural History, Pennsylvania, United States of America, **147** Department of Zoology, Faculty of Science, Charles University, Prague, Czech Republic, **148** Museo Argentino de Ciencias Naturales 'Bernardino Rivadavia', Buenos Aires, Argentina, **149** National Parks Board, Singapore Botanic Gardens, Singapore, **150** Department of Ecology and Evolutionary Biology, University of Kansas, Kansas, United States of America, **151** Judicial Commission on Prokaryote Nomenclature, London, United Kingdom, **152** Botanische Staatssammlung München and SNSB IT Center, Staatliche Naturwissenschaftliche Sammlungen Bayerns, München, Germany, **153** Permanent ICN Nomenclature Committee for Fungi, International Mycological Association, **154** Museo Nacional de Ciencias Naturales (CSIC), Madrid, Spain, **155** Dipartimento di Scienze della Vita e Biologia dei Sistemi, Università di Torino, Torino, Italy, **156** Istituto per la Protezione Sostenibile delle Piante sez. di Torino, CNR, Torino, Italy, **157** Department of Environmental Sciences, University of Basel, Basel, Switzerland, **158** Allwetterzoo Münster, Münster, Germany, **159** Department of Biology, University of Hawai'i at Manoa, Hawai'i, United States of America, **160** UNC Herbarium (NCU), North Carolina Botanical Garden, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, United States of America, **161** Abteilung Morphologie und Systematik der Tiere und Zoologisches Museum, Universität Göttingen, Göttingen, Germany, **162** Unité Mixte de Recherche, Peuplements Végétaux et Bioagresseurs en Milieu Tropical, Université de La Réunion, Ile de La Réunion, France, **163** Essig Museum of Entomology, University of California, Berkeley, Berkeley, California, United States of America, **164** General Committee for Nomenclature [for algae, fungi and plants], Royal Botanic Gardens and Domain Trust, New South Wales, Australia, **165** Smithsonian Marine Station, Florida, United States of America, **166** Molecular Ecology and Fisheries Genetics Lab, School of Biological Sciences, Bangor University, Bangor, United Kingdom, **167** Department of Entomology, Entomology Research Museum, University of California, Riverside, California, United States of America, **168** Australian National Insect Collection, CSIRO National Research Collections Australia, Australian Capital Territory, Australia, **169** School of Life Sciences, Biodiversity Knowledge Integration Center, Hasbrouck Insect Collection, Arizona State University, Arizona, United States of America, **170** Landcare Research, Auckland, New Zealand, **171** School of Biological Sciences, University of Auckland, Auckland, New Zealand, **172** Institute of Zoology, Chinese Academy of Sciences, Chaoyang District, P. R. China

✉ Current address: 19 Marlborough Court, East Sussex, United Kingdom

* scott.thomson321@gmail.com (SAT); deepreef@bishopmuseum.org (RLP)

Taxonomy is a scientific discipline that has provided the universal naming and classification system of biodiversity for centuries and continues effectively to accommodate new knowledge. A recent publication by Garnett and Christidis [1] expressed concerns regarding the difficulty that taxonomic changes represent for conservation efforts and proposed the establishment of a system to govern taxonomic changes. Their proposal to “restrict the freedom of taxonomic action” through governing subcommittees that would “review taxonomic papers for compliance” and their assertion that “the scientific community’s failure to govern taxonomy threatens the effectiveness of global efforts to halt biodiversity loss, damages the credibility of science, and is expensive to society” are flawed in many respects. They also assert that the lack of governance of taxonomy damages conservation efforts, harms the credibility of science, and is costly to society. Despite its fairly recent release, Garnett and Christidis’ proposition has already been rejected by a number of colleagues [2,3,4,5,6,7,8]. Herein, we contribute to the conversation between taxonomists and conservation biologists aiming to clarify some misunderstandings and issues in the proposition by Garnett and Christidis.

Placing governance over the science of taxonomy blurs the distinction between taxonomy and nomenclature. Garnett and Christidis’s proposal is far-reaching but represents a narrow perspective of taxonomy, as utilized by conservation, and reflects an increasingly broad misunderstanding throughout biology of the scientific basis of taxonomy, formalized nomenclature, and the relationship between them. This trend may have resulted from the attenuation of instruction in taxonomic principles and, in particular, nomenclature at many universities, in part because of a shift in research priorities away from taxonomy.

Garnett and Christidis assert that an “assumption that species are fixed entities underpins every international agreement on biodiversity conservation.” This assumption demonstrates a fundamental misunderstanding of taxonomy and the evolving view of what species represent. The essential features of science include documenting natural patterns and processes, developing and testing hypotheses, and refining existing ideas and descriptions of nature based on new data and insights. Taxonomy, the science of recognizing and delimiting species, adheres to these fundamental principles. Discoveries of new organisms together with advances in methodology continue unabated, leading to a constant reevaluation of the boundaries between taxonomic entities. Species (and higher taxa) comprise related organisms that may be clustered together differently depending on which sets of criteria are emphasized. Hey et al. [9] acknowledge “the inherent ambiguity of species in nature” but point out that “species-related research and conservation efforts can proceed without suffering from, and without fear of, the ambiguity of species.” Through taxonomic research, our understanding of biodiversity and classifications of living organisms will continue to progress. Any system that restricts such progress runs counter to basic scientific principles, which rely on peer review and subsequent acceptance or rejection by the community, rather than third-party regulation. Thiele and Yeates [10] cautioned that such a system “could lead to authoritarianism and a stifling of innovative taxonomic viewpoints. No other hypothesis-driven field of science would accept such a straitjacket”.

Taxonomy and associated nomenclature are not without problems. Even with a common set of facts, alternative interpretations of how to classify organisms can lead to differing classifications. However, the science of taxonomy is increasingly rigorous, which can improve the foundation for targeted legislative action regarding species [11,12]. Taxonomic instability does not affect all taxonomic groups equally. Garnett and Christidis provide examples from mammals and birds, which collectively represent a small fraction (<1%) of known biodiversity [13]. These groups tend to be the subject of greater levels of taxonomic “fine-tuning”—but less so in bats and rodents, groups in which basic species discoveries frequently take place—leading to disproportionately more lumping, splitting, and nomenclatural issues. In contrast, taxonomists working on most other groups of organisms, with vastly greater diversity, are focused on the basic tasks of discovering, delimiting, and describing species, rather than rearranging classifications of taxa already described. In extreme cases, taxonomic instability results in what has become known as “taxonomic vandalism” [14,15], which usually involves self-published or non-peer-reviewed taxonomic works that unnecessarily disrupt taxonomy without a solid scientific foundation. Academic freedom, needed for scientific progress, may yield undesirable results. However, over some 250 years of taxonomy, the number of authors that would be considered taxonomic vandals is very small, and further improvements to the Codes of nomenclature may reduce the harm they do without impinging on science. Scientists have long worked to achieve a universal species concept and an accompanying set of operational criteria that could serve to define species limits across most, if not all, groups of organisms; however, this task remains incomplete for a number of legitimate reasons [16,17,18,19]. Rather than promoting the establishment of a system that would arbitrarily bias community acceptance or rejections of species-level taxonomic hypotheses, many avenues of work seem more likely to improve taxonomy and the sciences that depend on it, including the following: efforts to improve our definitions of what a species is, incorporating more taxonomists into committees of conservation organizations, and providing aid in campaigns aiming to secure funding for education and research in taxonomy, among others.

Does taxonomy hamper conservation?

Garnett and Christidis “contend that the scientific community’s failure to govern taxonomy threatens the effectiveness of global efforts to halt biodiversity loss, damages the credibility of science, and is expensive to society.” We disagree.

The authors claim that species-splitting provides an incentive to trophy hunters to target small populations, affects biodiversity tallies in ways that negatively impact conservation, and results in inordinately higher funding to oversplit taxonomic groups; but they provide no evidence to support these claims. If hunters target endangered species, then such societal developments should be challenged, rather than used as justification for changing the way in which science is conducted. They cite data in Evans et al. [20] to imply that different taxonomic approaches between birds and mammals could lead to disproportionate funding relative to genetic diversity, when in fact those data (Figure 6 therein) show that the number of species in a group is not correlated with funding (e.g., fishes comprise 11% of species protected under the United States Endangered Species Act but receive 61% of government funding).

How does taxonomic instability affect conservation? Morrison et al. [21] “found that changes in taxonomy do not have consistent and predictable impacts on conservation”; they also found that “splitting taxa may tend to increase protection, and name changes may have the least effect where they concern charismatic organisms.” In African ungulates, Gippoliti et al. [22] describe cases where conservation management based on the Biological Species Concept overlooks evolutionarily significant units (recognized with the Phylogenetic Species Concept), with negative consequences. The splitting of legally protected taxa may result in species not being included by name in conservation legislation or regulations, thereby losing legal protection. However, well-crafted legislation includes mechanisms to extend protection despite taxonomic changes; initiatives such as Convention on International Trade in Endangered Species (CITES) and the International Union for Conservation of Nature (IUCN) specialist groups already link taxonomy and its changes with conservation [23]. Garnett and Christidis assert that taxonomic instability negatively affects conservation. However, artificial stability arising from insufficient taxonomic work can be particularly detrimental to conservation, causing mistargeting of conservation funding by misrepresentation of population size and distribution with the flow-on effects to conservation status [11,24,25].

More bureaucracy is not the answer

The proposal by Garnett and Christidis for the International Union of Biological Sciences (IUBS) to create a process that “restrict[s] the freedom of taxonomic action” is not only flawed in terms of scientific integrity (as outlined above) but is also untenable in practice. Nomenclature regulates how names are used to communicate taxonomic hypotheses and is governed by rules (Codes) to ensure the least possible degree of ambiguity in the application of names. The relationship between taxonomy and nomenclature is illustrated in Fig 1. These Codes have been and continue to be refined into complex and intricate legal systems (the *International Code of Zoological Nomenclature* consists of 90 articles with more than 600 subsections). A system that endeavors to impose similar controls over taxon concepts would likely be vastly more complex than, and in conflict with, the Codes. It is for good reason that the major Codes explicitly avoid interfering with taxonomic freedom.

In addition, such a system raises many questions. Would it limit the kinds of characters used to assert taxonomically important distinctions, or be biased in favor of one class of characters (e.g., molecular versus morphological), when these cannot be equated across different taxa? How would new knowledge be incorporated? Would it favor one particular species concept for all organisms (and if so, which one)? Would newly discovered species automatically

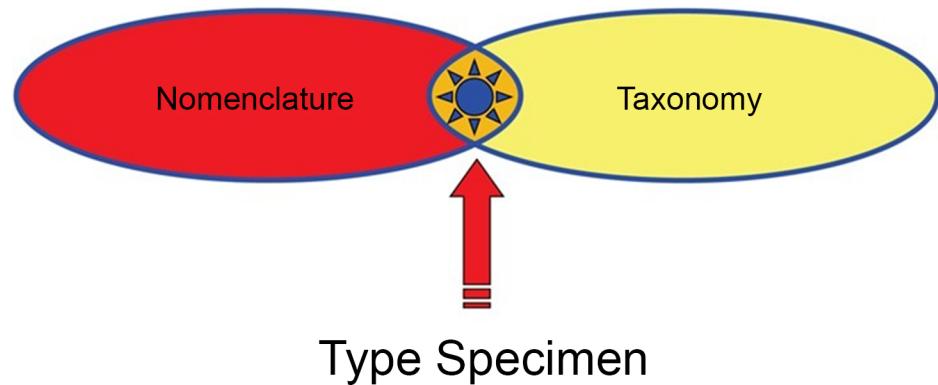


Fig 1. Nomenclature and taxonomy intersect objectively only at the type specimen, as designated through rules established by nomenclatural codes to anchor scientific names to the biological world.

<https://doi.org/10.1371/journal.pbio.2005075.g001>

be acknowledged as legitimate new taxa or would they need to be approved before being considered valid? How often would the approved species lists be updated? Taking into account the vanishing taxonomic expertise, who would do this, and who would fund it? Can we afford to draw limited resources away from vital efforts to describe and catalogue biodiversity? There is already a scientific process to deal with updating taxonomy; “taxonomic revisions” carefully review all knowledge on a taxonomic group and may propose alternative classifications and relationships to accommodate new knowledge. These are peer-reviewed, published, and up to the community to accept or reject with further research. Furthermore, given that hundreds of thousands of species remain to be discovered, and that about 18,000 new species are described and named every year [26], adding layers of bureaucracy to this process would be both impractical and expensive. The governing structure proposed by Garnett and Christidis would need to include this peer review, consultation, and publication process regularly to reflect new knowledge. Therefore, it would add, and possibly duplicate, existing practice.

The products of taxonomic research underpin all biological research, but the proposal by Garnett and Christidis would regulate taxonomy primarily in the context of conservation. This has important potential ramifications because any supervisory body would implicitly have the power to direct, through its actions and judgments, the lumping or splitting of taxa according to conservation, economic significance, or political agendas to affect resource streams directed to those taxa. The process would also be vulnerable to conflicting pressures from advocacy groups in many areas, including conservation, trade, bioprospecting, and particularly politics. Even within birds, one of the groups that exemplify the problem that the proposal seeks to solve, taxonomic committees for managing taxa have had a mixed track record [27].

Certainly, there are many ways taxonomists can improve the value and impact of their research to conservation biology and other biological disciplines, such as explicitly citing the species concept employed in new taxonomic descriptions and including information on distributions, ecology, conservation status, and potential threats. Better and more modern approaches to organizing scientific names of organisms could also be expanded. In addition to overseeing the Codes of nomenclature, IUBS supports the International Committee on Bionomenclature (ICB) to promote harmony among the different Codes as nomenclature becomes increasingly digital. The development of online nomenclatural registration and indexing systems (e.g., the International Plant Names Index, ZooBank, various mycological registries, List of Prokaryotic Names with Standing in Nomenclature) offer improved access to nomenclatural information. These help avoid perpetuation of errors in the literature and thus increase stability and decrease ambiguity of taxon names.

Improvements are not limited to the Codes. Efforts such as the Catalogue of Life, with its numerous contributors and broad spectrum of users, already provide a valuable service for many taxonomic groups in asserting a reference classification and set of species concepts covering all life. This illustrates the potential for building a robust framework for a stable taxonomy to serve those initiatives that benefit from such stability, including conservation. These efforts can be improved by filling the existing gaps in taxa, training new taxonomists, improving the quality of information included for certain groups (e.g., distribution, conservation status), and by incorporating systems that track changes in both taxon names and circumscriptions through mapping of taxonomic concepts [28].

Dynamic taxonomy reflects the scientific nature and progress of the discipline. Artificially and arbitrarily constraining taxonomy through the system proposed by Garnett and Christidis would damage scientific credibility far more severely than misperceptions about the taxonomic process. “Absolute stability of taxonomic concepts—and nomenclature—would hinder scientific progress rather than promote it” [29].

Conservation is crucial

The dynamic nature of taxonomic progress may be at odds with some aspects of conservation legislation, resulting, in part, from a mutual misunderstanding of the fundamental processes involved with both taxonomy and conservation. We advocate a solution that allows input, collaboration, and cooperation, from both conservation biologists and taxonomists, with a multidisciplinary approach towards a new framework for legislation that does not rely on the false premise that species are “fixed entities”. The development of “best practices” by both conservation biologists and taxonomists working together could avoid many unnecessary problems when using taxon names to represent vulnerable biological units in nature, thereby improving the effectiveness of their protection without impeding scientific progress.

Rather than redefine how one of the core disciplines of biological sciences is conducted, a more effective approach is to redefine how conservation legislation is enacted and implemented. The process of changing legislation requires acts of governments, which can take years to accomplish. However, fundamentally altering a system of classifying nature that has successfully endured more than two and a half centuries would have many detrimental consequences. Most of the problems for conservation resulting from the dynamic taxonomic process could be avoided entirely if future conservation legislation followed the lead of existing international conventions by explicitly referencing the specific taxon concept implied by a name, that is, by citing the original species description or a recent scholarly taxonomic treatment. Taxonomists and conservation biologists should join forces to promote effective legislative mechanisms to deal with a changing taxonomy rather than engage in infighting about the proper way to do taxonomy. This is exemplified by CITES, which adopts standard nomenclatural references [23] to define species or taxonomic groups and which periodically revises the adopted standards in response to evolving taxonomic consensus.

Many have argued that conservation legislation should focus on protecting entire ecosystems rather than rely on enumerated lists of species (e.g., [30]). While this approach requires a solid taxonomic foundation to characterize the ecosystems in question, the legislation itself would be insulated from specific changes to taxon names and concepts. In cases in which legislation includes specific taxa by name, such as harvesting or endangered species regulations, it should make the intended taxonomic concepts clear with reference to published treatments. That will allow unambiguous understanding even if the nomenclature and classification change because of taxonomic advances.

The critical importance of taxonomy and the taxonomic process in the global quest to mitigate biodiversity loss cannot be overemphasized. Without a robust taxonomic paradigm that is based on science and unconstrained by unnecessary and counterproductive bureaucracy, conservation efforts will ultimately suffer, potentially leading to devastating and irreversible impacts on global biodiversity.

Author Contributions

Conceptualization: Scott A. Thomson, Richard L. Pyle, Denis J. Brothers, Hussam Zaher.

Formal analysis: Douglas Yanega.

Methodology: Scott A. Thomson, Richard L. Pyle.

Project administration: Scott A. Thomson, Richard L. Pyle.

Resources: Richard L. Pyle, Peter Paul van Dijk, Ellinor Michel.

Validation: Mark J. Costello, Eliécer E. Gutiérrez, Riaan Stals, Hussam Zaher.

Visualization: Hussam Zaher.

Writing – original draft: Scott A. Thomson, Richard L. Pyle, Shane T. Ah Yong, Miguel Alonso-Zarazaga, Joe Ammirati, Juan Francisco Araya, John S. Ascher, Tracy Lynn Audisio, Valter M. Azevedo-Santos, Nicolas Bailly, William J. Baker, Michael Balke, Maxwell V. L. Barclay, Russell L. Barrett, Ricardo C. Benine, James R. M. Bickerstaff, Patrice Bouchard, Roger Bour, Thierry Bourgoin, Christopher B. Boyko, Abraham S. H. Breure, Denis J. Brothers, James W. Byng, David Campbell, Luis M. P. Ceriaco, István Cernák, Pierfilippo Cerretti, Chih-Han Chang, Soowon Cho, Joshua M. Copus, Mark J. Costello, Andras Cseh, Csaba Csuzdi, Alastair Culham, Guillermo D'Elia, Cédric d'Udekem d'Acoz, Mikhail E. Daneliya, René Dekker, Edward C. Dickinson, Timothy A. Dickinson, Peter Paul van Dijk, Klaas-Douwe B. Dijkstra, Bálint Dima, Dmitry A. Dmitriev, Leni Duistermaat, John P. Dumbacher, Wolf L. Eiserhardt, Torbjørn Ekrem, Neal L. Evenhuis, Arnaud Faille, José L. Fernández-Triana, Emile Fiesler, Mark Fishbein, Barry G. Fordham, André V. L. Freitas, Natália R. Friol, Uwe Fritz, Tobias Frøslev, Vicki A. Funk, Stephen D. Gaimari, Guilherme S. T. Garbino, André R. S. Garraffoni, József Geml, Anthony C. Gill, Alan Gray, Felipe G. Grazziotin, Penelope Greenslade, Eliécer E. Gutiérrez, Mark S. Harvey, Cornelis J. Hazevoet, Kai He, Xiaolan He, Stephan Helfer, Kristofer M. Helgen, Anneke H. van Heteren, Francisco Hita Garcia, Norbert Holstein, Margit K. Horváth, Peter H. Hovenkamp, Wei Song Hwang, Jaakko Hyvönen, Melissa B. Islam, John B. Iverson, Michael A. Ivie, Zeehan Jaafar, Morgan D. Jackson, J. Pablo Jayat, Norman F. Johnson, Hinrich Kaiser, Bente B. Klitgård, Dániel G. Knapp, Jun-ichi Kojima, Urmas Köljal, Jenő Kontschán, Frank-Thorsten Krell, Irmgard Krisai-Greilhuber, Sven Kullander, Leonardo Latella, John E. Lattke, Valeria Lencioni, Gwilym P. Lewis, Marcos G. Lhano, Nathan K. Lujan, Jolanda A. Luksenburg, Jean Mariaux, Jader Marinho-Filho, Christopher J. Marshall, Jason F. Mate, Molly M. McDonough, Ellinor Michel, Vitor F. O. Miranda, Mircea-Dan Mitroiu, Jesús Molinari, Scott Monks, Abigail J. Moore, Ricardo Moratelli, Dávid Murányi, Takafumi Nakano, Svetlana Nikolaeva, John Noyes, Michael Ohl, Nora H. Oleas, Thomas Orrell, Barna Páll-Gergely, Thomas Pape, Viktor Papp, Lynne R. Parenti, David Patterson, Igor Ya. Pavlinov, Ronald H. Pine, Péter Poczai, Jefferson Prado, Divakaran Prathapan, Richard K. Rabeler, John E. Randall, Frank E. Rheindt, Anders G. J. Rhodin, Sara M. Rodríguez, D. Christopher Rogers, Fabio de O. Roque, Kevin C. Rowe, Luis A. Ruedas, Jorge Salazar-Bravo, Rodrigo B. Salvador, George Sangster, Carlos E. Sarmiento, Dmitry S. Schigel, Stefan Schmidt,

Frederick W. Schueler, Hendrik Segers, Neil Snow, Pedro G. B. Souza-Dias, Riaan Stals, Soili Stenroos, R. Douglas Stone, Charles F. Sturm, Pavel Štys, Pablo Teta, Daniel C. Thomas, Robert M. Timm, Brian J. Tindall, Jonathan A. Todd, Dagmar Triebel, Antonio G. Valdecasas, Alfredo Vizzini, Maria S. Vorontsova, Jurriaan M. de Vos, Philipp Wagner, Les Watling, Alan Weakley, Francisco Welter-Schultes, Daniel Whitmore, Nicholas Wilding, Kipling Will, Jason Williams, Karen Wilson, Judith E. Winston, Wolfgang Wüster, Douglas Yanega, David K. Yeates, Guanyang Zhang, Zhi-Qiang Zhang, Hong-Zhang Zhou.

Writing – review & editing: Scott A. Thomson, Richard L. Pyle, Shane T. Ah Yong, Miguel Alonso-Zarazaga, Joe Ammirati, Juan Francisco Araya, John S. Ascher, Tracy Lynn Audisio, Valter M. Azevedo-Santos, Nicolas Bailly, William J. Baker, Michael Balke, Maxwell V. L. Barclay, Russell L. Barrett, Ricardo C. Benine, James R. M. Bickelstaff, Patrice Bouchard, Roger Bour, Thierry Bourgoin, Christopher B. Boyko, Abraham S. H. Breure, Denis J. Brothers, James W. Byng, David Campbell, Luis M. P. Ceriaco, István Cernák, Pierfilippo Cerretti, Chih-Han Chang, Soowon Cho, Joshua M. Copus, Mark J. Costello, Andras Cseh, Csaba Csuzdi, Alastair Culham, Guillermo D’Elia, Cédric d’Udekem d’Acoz, Mikhail E. Daneliya, René Dekker, Edward C. Dickinson, Timothy A. Dickinson, Peter Paul van Dijk, Klaas-Douwe B. Dijkstra, Bálint Dima, Dmitry A. Dmitriev, Leni Duistermaat, John P. Dumbacher, Wolf L. Eiserhardt, Torbjørn Ekrem, Neal L. Evenhuis, Arnaud Faille, José L. Fernández-Triana, Emile Fiesler, Mark Fishbein, Barry G. Fordham, André V. L. Freitas, Natália R. Friol, Uwe Fritz, Tobias Frøslev, Vicki A. Funk, Stephen D. Gaimari, Guilherme S. T. Garbino, André R. S. Garraffoni, József Geml, Anthony C. Gill, Alan Gray, Felipe G. Grazziotin, Penelope Greenslade, Eliécer E. Gutiérrez, Mark S. Harvey, Cornelis J. Hazevoet, Kai He, Xiaolan He, Stephan Helfer, Kristofer M. Helgen, Anneke H. van Heteren, Francisco Hita Garcia, Norbert Holstein, Margit K. Horváth, Peter H. Hovenkamp, Wei Song Hwang, Jaakko Hyvönen, Melissa B. Islam, John B. Iverson, Michael A. Ivie, Zeehan Jaafar, Morgan D. Jackson, J. Pablo Jayat, Norman F. Johnson, Hinrich Kaiser, Bente B. Klitgård, Dániel G. Knapp, Jun-ichi Kojima, Urmas Kõljalg, Jenő Kontschán, Frank-Thorsten Krell, Irmgard Krisai-Greilhuber, Sven Kullander, Leonardo Latella, John E. Latte, Valeria Lencioni, Gwilym P. Lewis, Marcos G. Lhano, Nathan K. Lujan, Jolanda A. Luksenburg, Jean Mariaux, Jader Marinho-Filho, Christopher J. Marshall, Jason F. Mate, Molly M. McDonough, Ellinor Michel, Vitor F. O. Miranda, Mircea-Dan Mitroiu, Jesús Molinari, Scott Monks, Abigail J. Moore, Ricardo Moratelli, Dávid Murányi, Takafumi Nakano, Svetlana Nikolaeva, John Noyes, Michael Ohl, Nora H. Oleas, Thomas Orrell, Barna Páll-Gergely, Thomas Pape, Viktor Papp, Lynne R. Parenti, David Patterson, Igor Ya. Pavlinov, Ronald H. Pine, Péter Poczai, Jefferson Prado, Divakaran Prathapan, Richard K. Rabeler, John E. Randall, Frank E. Rheindt, Anders G. J. Rhodin, Sara M. Rodríguez, D. Christopher Rogers, Fabio de O. Roque, Kevin C. Rowe, Luis A. Ruedas, Jorge Salazar-Bravo, Rodrigo B. Salvador, George Sangster, Carlos E. Sarmiento, Dmitry S. Schigel, Stefan Schmidt, Frederick W. Schueler, Hendrik Segers, Neil Snow, Pedro G. B. Souza-Dias, Riaan Stals, Soili Stenroos, R. Douglas Stone, Charles F. Sturm, Pavel Štys, Pablo Teta, Daniel C. Thomas, Robert M. Timm, Brian J. Tindall, Jonathan A. Todd, Dagmar Triebel, Antonio G. Valdecasas, Alfredo Vizzini, Maria S. Vorontsova, Jurriaan M. de Vos, Philipp Wagner, Les Watling, Alan Weakley, Francisco Welter-Schultes, Daniel Whitmore, Nicholas Wilding, Kipling Will, Jason Williams, Karen Wilson, Judith E. Winston, Wolfgang Wüster, Douglas Yanega, David K. Yeates, Hussam Zaher, Guanyang Zhang, Zhi-Qiang Zhang, Hong-Zhang Zhou.

References

1. Garnett ST, Christidis L. Taxonomy anarchy hampers conservation. *Nature*. 2017; 546(7656):25–27. <https://doi.org/10.1038/546025a> PMID: 28569833
2. Raposo MA, Stopiglia R, Brito GRR, Bockmann FA, Kirwan GM, Gayon J, Dubois A. What really hampers taxonomy and conservation? A riposte to Garnett and Christidis (2017). *Zootaxa*, 2017; 4317 (1), pp.179–184.
3. Holstein N. and Luebert F., 2017. Taxonomy: stable taxon boundaries. *Nature*, 548(7666), pp.158–158.
4. Cotterill FP., Groves CP., Taylor PJ., 2017. Taxonomy: refine rather than stabilize. *Nature*, 547 (7662), pp.162–162.
5. Jackson MD, Scherz MD, Zona S. 2017. Taxonomy is not beholden to its dependencies: a rebuttal to Garnett and Christidis (2017) *PeerJ Preprints* 5:e3060v1 <https://doi.org/10.7287/peerj.preprints.3060v1>
6. Hollingsworth PM, 2017. Taxonomy: avoid extra bureaucracy. *Nature*, 546(7660), pp.600–600.
7. Lambert M., 2017. Taxonomy: retain scientific autonomy. *Nature*, 546(7660), pp.600–600.
8. Funk VA, Herendeen P, Knapp S., 2017. Taxonomy: naming algae, fungi, plants. *Nature*, 546 (7660), pp.599–599.
9. Hey J, Waples RS, Arnold ML, Butlin RK, Harrison RG. Understanding and confronting species uncertainty in biology and conservation. *Trends Ecol Evol*. 2003; 18(11):597–603. <https://doi.org/10.1016/j.tree.2003.08.014>
10. Thiele K, Yeates D. Tension arises from duality at the heart of taxonomy. *Nature*. 2002; 419(6905):337. <https://doi.org/10.1038/419337a> PMID: 12353005
11. Thomson S. Management implications of poor alpha taxonomy. *Aust. Wildl. Mgmt Soc. Newsl.* 1997 March;14–16.
12. Sangster G, Luksenburg JA. Declining rates of species described per taxonomist: slowdown of progress or a side-effect of improved quality in taxonomy? *Syst Biol*. 2014; 64(1):144–151. <https://doi.org/10.1093/sysbio/syu069> PMID: 25190593
13. Chapman AD. Numbers of living species in Australia and the World. 2nd ed. Canberra: Australian Biological Resources Study; 2009.
14. Kaiser H, Crother BI, Kelly CMR, Luiselli L, O'Shea M, Ota H, et al. Best practices: in the 21st century, taxonomic decisions in herpetology are acceptable only when supported by a body of evidence and published via peer-review. *Herpetol Rev*. 2013; 44(1):8–23.
15. Rhodin AGJ, Kaiser H, van Dijk PP, Wüster W, O'Shea M, Archer M, et al. Comment on *Spracklandus* Hoser, 2009 (Reptilia, Serpentes, ELAPIDAE): request for confirmation of availability of the generic name and for the nomenclatural validation of the journal in which it was published. *Bull Zool Nomencl.* 2015; 72(1):65–78. <https://doi.org/10.21805/bzn.v72i1.a12>
16. De Queiroz K. 2007. Species Concepts and Species Delimitation. *Systematic Biology*, 56 (6): 879–886, <https://doi.org/10.1080/10635150701701083> <https://doi.org/10.1080/10635150701701083> PMID: 18027281
17. Mayden R. L. 1997. A hierarchy of species concepts: the denouement in the saga of the species problem. In Claridge M. F., Dawah H. A. & Wilson M. R. (eds.), *Species: The units of diversity*, Chapman & Hall. pp. 381–423
18. Wheeler QD, Meier R. 2000. *Species concepts and phylogenetic theory: a debate*. Columbia University Press, New York
19. Zachos FE. 2016. *Species concepts in biology. Historical development, theoretical foundations and practical relevance*. Springer, Cham
20. Evans DM, Che-Castaldo JP, Crouse D, Davis FW, Epanchin-Niell R, Flather CH, et al. Species recovery in the United States: increasing the effectiveness of the Endangered Species Act. *Issues in Ecology*. 2016; 20:1–28.
21. Morrison WR, Lohr JL, Duchon P, Wilches R, Trujillo D, Mair M, Renner SS. The impact of taxonomic change on conservation: Does it kill, can it save, or is it just irrelevant?. *Biol Conserv*. 2009; 142 (12):3201–3206. <https://doi.org/10.1016/j.biocon.2009.07.019>
22. Gippoliti S, Cotterill FPD, Zinner D, Groves CP. Impacts of taxonomic inertia for the conservation of African ungulate diversity: an overview. *Biol Rev Camb Philos Soc*. <https://doi.org/10.1111/brv.12335> PMID: 28429851
23. CITES. Standard nomenclature. Resolution Conf. 12.11 (Rev. CoP17). [Cited 11 May 2017]. Available from: <https://cites.org/eng/res/12/12-11R17.php>.

24. Hazevoet CJ. Conservation and species lists: taxonomic neglect promotes the extinction of endemic birds, as exemplified by taxa from eastern Atlantic islands. *Bird Conserv Int.* 1996; 6(2):181–196. <https://doi.org/10.1017/S0959270900003063>
25. Gutiérrez EE, Helgen KM. 2013. Outdated taxonomy blocks conservation. *Nature*, 495: 314. <https://doi.org/10.1038/495314e> PMID: 23518556
26. Costello MJ, May RM, Stork NE 2013. Response to Comments on “Can we name Earth’s species before they go extinct?” *Science* 341, 237.
27. Donegan T, Quevedo A, Verhelst JC, Cortés-Herrera O, Ellery T, Salaman P. Revision of the status of bird species occurring or reported in Colombia 2015, with discussion of BirdLife International’s new taxonomy. *Conservación Colombiana*. 2015; 23:3–48.
28. Franz N, Gilbert E, Ludäscher B, Weakley A. Controlling the taxonomic variable: taxonomic concept resolution for a southeastern United States herbarium portal. *Research Ideas and Outcomes*. 2016; 2: e10610. <https://doi.org/10.3897/rio.2.e10610>
29. Schuh RT. The Linnaean system and its 250-year persistence. *Bot Rev.* 2003; 69(1):59–78. [https://doi.org/10.1663/0006-8101\(2003\)069\[0059:TLSEIY\]2.0.CO;2](https://doi.org/10.1663/0006-8101(2003)069[0059:TLSEIY]2.0.CO;2)
30. Pickett STA, Ostfeld RS, Shachak M, Likens GE (eds). *The ecological basis of conservation. Heterogeneity, ecosystems, and biodiversity.* Dordrecht: Springer; 1997. <https://doi.org/10.1007/978-1-4615-6003-6>