Biodiversity Informatics, 20, 2026, pp. 111-117

CONSERVATION SCIENCE AND THE KNOWLEDGE SHORTFALLS

Jorge Soberon

Biodiversity Institute and Department of Ecology & Evolutionary Biology, University of Kansas, 1345 Jayhawk Blvd., Lawrence, Kansas 66045, USA

Abstract. There is much data publicly available on the biodiversity of the world. It would appear then that conserving biodiversity is just a matter of using the data. In this contribution I argue that conservation requires not only data availability, but also conversations about purpose, and present examples of how just being able to use large biodiversity databases is seldom enough to achieve successful conservation.

Introduction

In modern times (probably in the last four hundred years), the rate of impact that human activities have had on "biodiversity," i.e., on the local, regional and global elements, structures and processes of life (Noss 1990), has accelerated (McNeely et al. 1990; Ehrlich 1995; Butchart et al. 2010; Steffen 2015). Societies have moved away from acting mostly locally, with environmental impacts that were short-term and spatially concentrated (Turner et al. 2000) and towards a mode in which many societies today exert substantial and spatially very extended (maybe global) impacts on different components of biodiversity, sometimes in ways that have long-term, even irreversible effects (Steffen 2015).

Moreover, the governance (Bevir 2012) of economic and productive activities has also changed. Governance in small, traditional communities, historically has been socially encompassing, participatory, and including spiritual features (Gadgil et al. 1993; Von Der Porten 2012; Turner 2014), all of which encouraged sustainability (Johnson et al. 2016). On the other hand, governance of common-pool resources of global extent is challenging (Ostrom et al. 1999) and still being developed.

Since the spatiotemporal scales of biodiversity management and its governance have changed, we need to ask what is needed today. To many, it appears to be the case that what is needed is more biodiversity data, since (we are said) without data, management of global biodiversity would be very difficult or impossible (Sutherland et al. 2004; Balmford et al. 2005). This creates problems: (i) obtaining, (ii) sharing, and, (iii) using the required information.

One interesting fact of today's ecological science is the explosion of online databases. Today there are Terabytes of data online, although not necessarily all freely available. This is the question of "accessible digital data" (Sousa-Baena et al. 2014). There are now many databases of primary occurrence data, as shown in Table 1.

Although the number of databases is growing rapidly, and Table 1 is just an incomplete snapshot, there is a wealth of less available data [verbal, grey, traditional, and others. See Haddaway et al. (2015)]. Besides, today the Internet and new sensor technologies are creating an explosion of previously unavailable data of high-spatiotemporal resolution (Farley et al. 2018). Moreover, the pace of increase in text mining, natural language processing, and artificial intelligence will presumably allow all knowledge elements in the literature to become digitally available (Farrell et al. 2022). This will help to fill the gaps called the "shortfalls" (Hortal et al. 2015) of ecological knowledge by creating vast, and ever-growing repositories of data.

Will availability of databases solve all problems in conservation science? At first sight, the answer appears to be yes. Some time ago, optimists thought that by "putting biodiversity on the map" (Bibby 1992; Scott 1993; Reid 1998; Edwards et al. 2002) this would happen. Despite inconclusive evidence, there are still arguments favoring the view that more data means better conservation (Sutherland et al. 2004). Another popular argument suggests that what is needed is a set of "essential biodiversity variables" (Pereira et al. 2013), that mostly will allow monitoring of trends, hence allowing a better governance of global biodiversity.

However, biodiversity keeps being lost (Almond et al. 2020). Is this a simple problem of lack of data? Today, there have been claims that large data availability together with increasingly powerful artificial intelligence algorithms will make the need for conventional hypothesis-based science obsolete (Anderson 2008; Kelling et al. 2009; Kwok 2019), and by implication, conservation more successful. In this contribution, I intend to discuss this idea. I hope to argue that for conservation science: (i) blind data mining is an unfertile approach. One needs to

Table 1.

Topic	Taxonomic coverage	Geographic coverage	Organization	URL
Primary Ocurrences	All	Global	GBIF	https://www.gbif.org/
Primary Ocurrences	All	Global	IDigBio	https://www.idigbio.org/
Primary Ocurrences	All	Mostly Mexico	SNIB	https://www.snib.mx/
Primary Ocurrences	All	Mostly Australia	ALA	https://www.ala.org.au/
Primary Ocurrences	All	Mostly Brazil	CRIA	https://www.cria.org.br/
Demography	Plants	Global		https://compadre-db.org
	Animals	Global		https://onlinelibrary.wiley.com/doi/10.1111/ele.13898
Traits	Plants	Global		https://www.try-db.org/TryWeb/Home.php
	Butterflies	Global		https://www.nature.com/articles/s41597-022-01473-5
	Mammals	Global		https://esajournals.onlinelibrary.wiley.com/doi/10.1890/08-1494.1
	Birds	Global		https://onlinelibrary.wiley.com/doi/10.1111/ele.13898
Physiology	All	Global		https://datadryad.org/stash/dataset/doi:10.5061/dryad.1cv08
Ecological Interactions		Global		https://www.globalbioticinteractions.org/

have explanations to assess the limits of predictions, and to share knowledge. (ii) The multiplicity of perspectives about biodiversity, and the complexity of social issues underlying conservation preclude an algorithmic approach to conservation, even if based on sophisticated Artificial Intelligence methods. In brief, solutions need to **be negotiated** among actors, not simply **provided** by experts because solutions are not only about *what is* (based on knowledge), but what *must be done* (depending on the values of different stakeholders). Besides, scientific explanations need to be understood, and often co-generated by communities of interested parties. And (iii), data and methods need to be available in equitable ways. This means not only "to have access" to knowledge, but "to contribute" to it. I will illustrate these ideas with examples of CONABIO in Mexico.

Prediction and explanation in science

In general, the sciences (so called "western"), are dedicated to describe, explain and predict natural phenomena (Griesmaier and Lockwood 2022), with "explanation" often, but by no means always, given a priority role (McCain 2015). However, as described above, some ecologists ask for a "data driven" model of research where patterns are discovered (perhaps by Artificial Intelligence engines) in complex multivariate data (Kelling et al. 2009), avoiding the need to have *a priory* hypothesis. In fact, this perspective implies that pattern identification (description) is the most important objective of science. There is no doubt that pattern identification is very important in conservation science. For instance, identifying geographic areas of high numbers of species, or high proportion of endemism, is the first step many government take towards planning of conservation (Kress et al. 1998), often with the help of modeling techniques (Pawar et al. 2007). However, simply identifying regions is not enough, as I hope to illustrate with an example.

About 20 years ago, the Mexican National Commission on Biodiversity (CONABIO) launched a program to prioritize areas for conservation in Mexico. To do that, a massive exercise of modelling distributions, based on a years-long process of computerizing museum data (Soberón and Koleff 2000; Sarukhán et al. 2014) began. The results were based on practically all the available (to biologists) data about the vertebrates of Mexico, and it was the result of the participation of hundreds of experts (Sarukhán and Jiménez 2016). These results were based, at first sight, on a simple description of the pattern of biodiversity. But this description was in turn based on a number of biodiversity informatics algorithms (Pressey et al. 1993; Franklin 2009). The extremely useful results (based on large databases) required a substantial amount of interpretation, much of which was based on concepts and perspectives, and thus it was more than the simple "pattern recognition" approach of artificial intelligence. The fitting part of a "distribution modelling" (SDM) exercise can indeed be performed in an unsupervised mode, algorithmically, without human intervention (Stockwell et al. 2006) and using very non-transparent methods like neural networks, generalized additive models, or random regression trees (Franklin 2009; Guisan et al. 2017). However, the actual interpretation and creation of proper distribution models (rather than simply fitted shapes) requires human intervention. In the CONABIO exercise, experts "clipped" the computer predictions using their expertise and knowledge of the species, performing thus the final part of the modeling. Most importantly, both the algorithm and its interpretation could be explained to non-experts and thus understood by a community.

After getting sets of thousands of modelled species distributions, CONABIO used them to perform a prioritization exercise. Prioritization algorithms cannot be run in an unsupervised mode. There are always based on some concept of what is a "priority." Priorities change among different stakeholders and require some sort of negotiation to be agreed upon (see next section).

This problem is even worse when the conservation exercise is not focused on describing a pattern but, for instance, on managing a population (Simberloff 1988; Liebhold and Tobin 2008). For these kinds of problems, where one needs to go beyond pattern descriptions, blind data mining may provide answers, but these answers are not convincing (at least today. Maybe in the future people will simply trust algorithms) because they do not create a shared understanding, provide no insights about mechanisms, and their usefulness to assess the scope and limits of validity of a research result is very restricted, even with last generation "explanatory artificial intelligence" (Gilpin et al. 2018).

The key issue is that science is not only about describing patterns, but (1) *explaining* them, which means providing a logical description of the observations and its causes (Hempel and Oppenheim 1948) and, (2) *understanding* them, which is the psychological and social process of sharing the explanation (De Regt et al. 2009). These features are not well addressed by simple pattern recognition, and they become crucial in conservation science.

In conservation science, explaining, and thus understanding, is a key objective. Blind data fitting may lead to predictions, even "good" (i.e., empirically verified) predictions, but without theory we never know how much to trust these predictions, or their scope of applicability. Besides, it is known that in order to be accepted as "legitimate," knowledge requires participation of stakeholders (Cash et al. 2003). This led us to the next section.

Participatory conservation

To be successfully translated to "policy" (using a singular is misleading since there are many levels of policies), scientific knowledge needs much more than just to exist, even if it exists in Internet public-access databases. In conservation science, a "crisis" discipline (Soulé 1985), a multiplicity of interested parties need to be included (Agrawal 1995; Ostrom et al. 1999; Schultz et al. 2007) in the decision-making process.

For instance, in the example of prioritizing areas for conservation in Mexico, the first step was to identify areas of interest, which may be based on a "pattern of biodiversity" selection. But to accept part of the pattern as a priority required to include all the primary interested parties, namely the major Federal government agencies, like the Protected Areas Commission (CONANP, the acronym in Spanish), the Forestry Commission (acronym in Spanish: CONAFOR), CONABIO (the biodiversity agency), the state governments and the major non-governmental organizations. All needed to agree on the conservation priorities (species, richness, species endemism, degree of conservation, wood coverage…). The existence of the large and comprehensive databases of CONABIO helped the conversation, but in the end, an agreement needed to be made about what mattered (policies), and this is an issue of values, not data (Callicott 2017). For CONAFOR having large surfaces of old forest, composed of commercially valuable timber, was more important than the number of species in those forests, or their endemicity. For CONABIO it was the reverse. Some of the global NGOs had their own priorities, sometimes established globally (Brooks et al. 2006). Agreeing about the priorities, and what methodology was to be used to create maps and targets, took many months of negotiations. When local stakeholders are included, negotiations become more complicated because there may be more objectives and systems of values (Folke et al. 2005; Berkes 2007). However, the local negotiations are the second and crucial step in defining a protected area. Conservation is basically an exercise in making the interests and objectives of multiple stakeholders compatible (Berkes 2007).

This requires an agreement with the local interested parties. These may be indigenous or traditional communities, ranchers, farmers, NGOs and maybe others. One excellent example is the Pinacate Desert Biosphere Reserve, in Northern Mexico (Castillo et al. 1994). This very large (~7,000 km^2) Biosphere Reserve was created in 1993 because of the great biological and geological importance of the area. In other words, because of a decision based on the "biodiversity pattern". However, to be created, negotiations took place, for a couple of years, and these included private owners of the land, representatives of "ejidatarios" (communal owners of the land), indigenous groups (the O'Odham nation is the traditional inhabitant of the region), and local and national conservation NGOs. All these interested parties had a saying in the document describing the Biosphere Reserve. Identifying the right participants may be a matter of simple political convenience or can be done using a formal methodology (Schultz et al. 2007), but the key point I want to make is that the problem is not just one of having "data." It is one of a variety of interested parties (multiple levels of decision making) agreeing on something.

In my view, the negotiation is mostly about what is valuable, how to determine it, and the actions to be taken to achieve such valuable aims, and less about factual matters. In other words, there is usually a degree of agreement about data. Having abundant and appropriate data is useful, even necessary, and if many of the participants were engaged in obtaining the data so much the better (Cash et al. 2003). However, I hypothesize that, often, there will be agreement about the "what is" (Berlin 1973), but the "what is to be done" requires negotiating points of view that may be even opposing.

Access to the information

Accepting that having the right kind of information enables better decision making, the fact is that information may exist and still remain unavailable, for a variety of reasons (Stephenson et al. 2017). Moreover, data may be simply lacking (Hortal et al. 2015; Troudet et al. 2017), or be of the wrong kind, or resolution.

As shown in table 1, the Internet has many databases of conservation importance. However, most of them require a degree of expertise to be not only accessed but also used. Moreover, for much of the world, these "global" databases are full of gaps (Peterson and Soberón 2018). The general pattern (Lira-Noriega and Soberón 2015) is that with the exception of a few developed countries, most of the world lacks data about not only the structure and functioning of the components of biodiversity, but even about its existence (Hortal et al. 2015). Finally, much conservation is local in nature. Having a ¼ of a degree presence-only database of species may be irrelevant to a community deciding whether to create a protected area, or not, in their land.

Discussion

We have now a historically unprecedented amount of accessible biodiversity data (Sousa-Baena et al. 2014). Much of this data can be used, and is used to obtain descriptions of the patterns of biodiversity, mostly at global extents and low spatial resolution (one degree pixels) (McAllister et al. 1986; Gaston 2000; Orme et al. 2006; Mora et al. 2011; Orr et al. 2021). There is no doubt that such descriptions can be useful for certain purposes, like designing "global" priorities (Mittermeier et al. 1998; Olson and Dinerstein 1998). Some have claimed that if we had enough data we do not need to think anymore (Kelling et al. 2009), with others strongly disagreeing (Pigliucci 2009). Predictability without understanding is not science.

This is well illustrated by a famous, and contradictory (Ayala 2009), pair of statements of Darwin: "I am turned into a kind of machine for grinding general laws out of large collections of facts." Darwin, in Barlow (1958). This would be the "machine learning" paradigm, whereby big data is grinded into patterns. However, the same Charles Darwin also stated: "How odd it is that anyone should not see that all observation must be for or against some view if it is to be of any service!" (Darwin, letter to H. Fawcett, 18 Sept 1861, in Darwin Correspondence Project, University of Cambridge https://www.darwinproject.ac.uk/). This second statement corresponds to the conventional scientific paradigm, of contrasting hypotheses and models against data, for the purpose of understanding (Pigliucci, 2009), as well as for the purpose of pattern discovering. Moreover, without "understanding" in some theoretical sense (that goes beyond the mere description of the patterns) there is no trust in prediction, another essential scientific objective.

The low resolution and economic bias of most public biodiversity databases (Peterson et al. 2015) also must be taken into consideration at the time of negotiating actions with local stakeholders. Most biodiversity conservation decisions are local in nature (Schultz et al. 2007) and require the sort of local data unavailable in global repositories. Traditional and indigenous data (Gadgil et al. 1993) may be of great help, despite not being covered by global databases. However, in the end, to agree on a "policy" (guidelines for actions to be taken) the different points of view of different participants need to be listened and incorporated. Based on my CONABIO experience, I suspect that this is more about values than data.

Acknowledgments

I would like to express my gratitude to my colleagues from CONABIO. During my time in that agency, I learned a lot from all of you. I would also need to declare that no competing interests exist for my authorship of this work.

Literature Cited

Agrawal, A. 1995. Dismantling the divide between indigenous and scientific knowledge. *Development and Change* 26:413-439.

Almond, R. E., M. Grooten, and T. Peterson. 2020. Living Planet Report 2020-Bending the curve of biodiversity loss. World Wildlife Fund.

Anderson, C. 2008. The end of theory: The data deluge makes the scientific method obsolete. *Wired* 16:16-07.

Ayala, F. J. 2009. Darwin and the Scientific Method. *Proceedings of the National Academy of Sciences, USA* 106:10033-10039.

Balmford, A., P. Crane, A. Dobson, R. Green, E., and G. Mace. 2005. The 2010 challenge: data availability, information needs and extraterrestrial insights. *Philosophical Transactions of the Royal Society B* 360:221-228.

Barlow, N., ed. 1958. The Autobiography of Charles Darwin 1809-1882. With the Original Omissions Restored. Collins, London.

Berkes, F. 2007. Community-based conservation in a globalized world. *Proceedings of the National Academy of Sciences USA* 104:15188-15193.

Berlin, B. 1973. Folk systematics in relation to biological classification and nomenclature. *Annual Review of Ecology and Systematics*:259-271.

Bevir, M. 2012. Governance: A very short introduction. OUP Oxford.

Bibby, C. J. e. a. 1992. Putting Biodiversity on the Map: Priority Areas for Global Conservation. International Council for Bird Preservation, Cambridge, UK.

Brooks, T. M., R. Mittermeier, G. da Fonseca, J. Gerlach, M. Hoffmann, J. Lamoreux, C. Mittermeier, J. D. Pilgrim, and A. S. Rodrigues. 2006. Global biodiversity conservation priorities. *Science* 313:58-61.

Butchart, S. H. M., M. Walpole, B. Collen, A. van Strien, J. P. W. Scharlemann, R. E. A. Almond, J. E. M. Baillie, B. Bomhard, C. Brown, J. Bruno, K. E. Carpenter, G. M. Carr, J. Chanson, A. M. Chenery, J. Csirke, N. C. Davidson, F. Dentener, M. Foster, A. Galli, J. N. Galloway, P. Genovesi, R. D. Gregory, M. Hockings, V. Kapos, J.-F. Lamarque, F. Leverington, J. Loh, M. A. McGeoch, L. McRae, A. Minasyan, M. H. Morcillo, T. E. E. Oldfield, D. Pauly, S. Quader, C. Revenga, J. R. Sauer, B. Skolnik, D. Spear, D. Stanwell-Smith, S. N. Stuart, A. Symes, M. Tierney, T. D. Tyrrell, J.-C. Vié, and R. Watson. 2010. Global Biodiversity: Indicators of Recent Declines. *Science* 328:1164-1168.

Callicott, J. B. 2017. Hume's is/ought dichotomy and the relation of ecology to Leopold's land ethic. *The Ethics of the Environment*:121-132.

Cash, D. W., W. C. Clark, F. Alcock, N. M. Dickson, N. Eckley, D. H. Guston, J. Jager, and R. B. Mitchell. 2003. Science and technology for sustainable development special feature: knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences USA* 100:8086-8091.

Castillo, C., P. Turk-Boyer, R. Venegas, F. Paz-Moreno, E. Villalpando, F. Valentine, L. Varela, J. Garcia, I. Rojas-Caldelas, T. Gaona, L. Enas, F. Corral-Chavira, and I. Granillo. 1994. Programa de Manejo de la Reserva de la Biosfera "El Pinacate Gran Desierto de Altar," Sonora, Mexico *in* S. d. A. N. P. d. E. d. Sonora, ed. Gobierno del Estado de Sonora, Hermosillo, Sonora.

De Regt, H. W., S. Leonelli, and K. Eigner. 2009. Scientific understanding: Philosophical perspectives. University of Pittsburgh Pre.

Edwards, J. L., M. Lane, and E. Nielsen. 2002. Interoperability of biodiversity databases: biodiversity information on every desktop. *Science* 289 2312.

Ehrlich, P. 1995. The scale of the human enterprise and biodiversity loss. Pp. 233 *in* J. H. Lawton, and R. M. May, eds. Extinction Rates. Oxford University Press, Oxford.

Farley, S. S., A. Dawson, S. J. Goring, and J. W. Williams. 2018. Situating ecology as a big-data science: Current advances, challenges, and solutions. *BioScience* 68:563-576.

Farrell, M. J., L. Brierley, A. Willoughby, A. Yates, and N. Mideo. 2022. Past and future uses of text mining in ecology and evolution. *Proceedings of the Royal Society B* 289:20212721.

Folke, C., T. Hahn, P. Olsson, and J. Norberg. 2005. Adaptive governance of social-ecological systems. *Annual Review of Environmental Resources* 30:441-473.

Franklin, J. 2009. Mapping Species Distributions: Spatial Inference and Prediction. Cambridge University Press, Cambridge.

Gadgil, M., F. Berkes, and C. Folke. 1993. Indigenous knowledge for biodiversity conservation. *Ambio* 22:151-156.

Gaston, J. K. 2000. Global patterns in biodiversity. *Nature* 405:220-227.

Gilpin, L. H., D. Bau, B. Z. Yuan, A. Bajwa, M. Specter, and L. Kagal. 2018. Explaining explanations: An overview of interpretability of machine learning. Pp. 80-89. 2018 IEEE 5th International Conference on data science and advanced analytics (DSAA). IEEE.

Griesmaier, F.-P. and J. Lockwood. 2022. This is Philosophy of Science. Wiley-Blackwell.

Guisan, A., W. Thuiller, and N. E. Zimmermann. 2017. Habitat suitability and distribution models: with applications in R. Cambridge University Press.

Haddaway, N. R. and H. R. Bayliss. 2015. Shades of grey: two forms of grey literature important for reviews in conservation. *Biological Conservation* 191:827-829.

Hempel, C. G. and P. Oppenheim. 1948. Studies in the Logic of Explanation. *Philosophy of science* 15:135-175.

Hortal, J., F. de Bello, J. A. F. Diniz-Filho, T. M. Lewinsohn, J. M. Lobo, and R. J. Ladle. 2015. Seven shortfalls that beset large-scale knowledge of biodiversity. *Annual Review of Ecology, Evolution, and Systematics* 46:523-549.

Johnson, J. T., R. Howitt, G. Cajete, F. Berkes, R. P. Louis, and A. Kliskey. 2016. Weaving Indigenous and sustainability sciences to diversify our methods. *Sustainability Science* 11:1-11.

Kelling, S., W. M. Hochachka, D. Fink, M. Riedewald, R. Caruana, G. Ballard, and G. Hooker. 2009. Data-intensive science: a new paradigm for biodiversity studies. *BioScience* 59:613-620.

Kress, W. J., w.R.Heyer, P.Acevedo, J.Coddington, D.Cole, T.L.Erwin, B.J.Meggers, M.Pogue, R.W.Thorington, R.P. Vary, M. J. Weitzman, and H.Weiztman. 1998. Amazonian biodiversity: assessing conservation priorities with taxonomic data. *Biodiversity and Conservation* 7 1577.

Kwok, R. 2019. AI empowers conservation biology. *Nature* 567:133-135.

Liebhold, A. M. and P. C. Tobin. 2008. Population ecology of insect invasions and their management. *Annual Review of Entomology. 53: 387-408.* 53.

Lira-Noriega, A. and J. Soberón. 2015. The relationship among biodiversity, governance, wealth, and scientific capacity at a country level: disaggregation and prioritization. *Ambio* 44:391-400.

McAllister, D. E., S.P.Platania, F.W.Schueler, M.E.Baldwin, D.S.Lee, C. H. Hoccut, and E.O.Wiley. 1986. Ichthyofaunal patterns on a geographic grid. Pp. 17. The Zoogeography of North American. John Wiley and Sons.

McCain, K. 2015. Explanation and the nature of scientific knowledge. *Science & Education* 24:827-854.

McNeely, J., K. R. Miller, W. V. Reid, R. Mittermeier, and T. Werner. 1990. Conserving the World's Biological Diversity. The World Bank, Washington, D. C.

Mittermeier, R. A., N. Myers, J. B. Thomsen, G. da Fonseca, and S. Olivieri. 1998. Biodiversity hotspots and major tropical wilderness areas: Approaches to setting conservation priorities. *Conservation Biology* 12 516-520.

Mora, C., D. P. Tittensor, S. Adl, A. G. B. Simpson, and B. Worm. 2011. How Many Species Are There on Earth and in the Ocean? *PLoS Biol* 9:e1001127.

Noss, R. F. 1990. Indicators for monitoring biodiversity: A hierarchical approach. *Conservation Biology* 4 355-364.

Olson, D. and E. Dinerstein. 1998. The global 200: a representation approach to conserving the earths most biologically valuable ecoregions. *Conservation Biology* 12:502-515.

Orme, D. L., R. Davies, V. A. Olson, G. H. Thomas, T.-T. Ding, P. C. Rasmussen, R. S. Ridgeley, A. Stattersfield, P. M. Bennett, I. P. F. Owens, T. M. Blackburn, and J. K. Gaston. 2006. Global patterns of geographic range size. *PLoS Biology* 4:1276-1283.

Orr, M. C., A. C. Hughes, D. Chesters, J. Pickering, C.-D. Zhu, and J. S. Ascher. 2021. Global patterns and drivers of bee distribution. *Current Biology* 31:451-458. e454.

Ostrom, E., J. Burger, C. B. Field, R. B. Norgaard, and D. Policansky. 1999. Revisiting the commons: local lessons, global challenges. *Science* 284:278-282.

Pawar, S., M. S. Koo, C. Kelley, M. F. Ahmed, S. Chaudhuri, and S. Sarkar. 2007. Conservation assessment and prioritization of areas in Northeast India: Priorities for amphibians and reptiles. *Biological Conservation* 136:346-361.

Pereira, H. M., S. Ferrier, M. Walters, G. N. Geller, R. Jongman, R. J. Scholes, M. W. Bruford, N. Brummitt, S. Butchart, and A. Cardoso. 2013. Essential biodiversity variables. *Science* 339:277-278.

Peterson, A. T. and J. Soberón. 2018. Essential biodiversity variables are not global. *Biodiversity and Conservation* 27:1277-1288.

Peterson, A. T., J. Soberón, and L. Krishtalka. 2015. A global perspective on decadal challenges and priorities in biodiversity informatics. *BMC ecology* 15:15.

Pigliucci, M. 2009. The end of theory in science? *EMBO Reports* 10:534-534.

Pressey, R. L., C. J. Humphries, C. R. Margules, R. I. Vane-Wright, and P. H. Williams. 1993. Beyond opportunism: key principles for systematic reserve selection. *Trends in ecology & evolution* 8 124-128.

Reid, W. V. 1998. Biodiversity Hotspots. *Trends in ecology & evolution* 13:275-280.

Sarukhán, J. and R. Jiménez. 2016. Generating intelligence for decision making and sustainable use of natural capital in Mexico. *Current Opinion in Environmental Sustainability* 19:153-159.

Sarukhán, J., T. Urquiza-Haas, P. Koleff, J. Carabias, R. Dirzo, E. Ezcurra, S. Cerdeira-Estrada, and S. Jorge. 2014. Strategic actions to value, conserve, and restore the natural capital of megadiversity countries: the case of Mexico. *BioScience* 65:164-173.

Schultz, L., C. Folke, and P. Olsson. 2007. Enhancing ecosytem management through social-ecological inventories: lessons from Kristianstads Vattenrike, Sweden. *Environmental Conservation* 34:140-152.

Scott, J. M. 1993. Gap analysis: a geographic approach to protection of biological diversity. *Wildlife Monographs* 123:1-41.

Simberloff, D. 1988. The contribution of population and community biology to conservation science. *Annual Review of Ecology and Systematics* 19:473-511.

Soberón, J. and P. Koleff. 2000. The national biodiversity information system of Mexico. Pp. 625 *in* P. Raven, ed. Nature and Human Society: Proceedings of the 1997 Forum on Biodiversity. National Academies Press, Washington, D. C.

Soulé, M. E. 1985. What is conservation biology? *BioScience* 35:727-734.

Sousa-Baena, M. S., R. García, L. Couto, and A. T. Peterson. 2014. Completeness of digital accessible knowledge of the plants of Brazil and priorities for survey and inventory. *Diversity and Distributions* 20:369-381.

Steffen, W. W. B., L. Deutsch, O. Gaffney, C. Ludwig. 2015. The trajectory of the Anthropocene: The Great Acceleration. *The Anthropocene Review* 2:81-98.

Stephenson, P., N. Bowles-Newark, E. Regan, D. Stanwell-Smith, M. Diagana, R. Höft, H. Abarchi, T. Abrahamse, C. Akello, and H. Allison. 2017. Unblocking the flow of biodiversity data for decision-making in Africa. *Biological Conservation* 213:335-340.

Stockwell, D. R., J. H. Beach, A. Stewart, G. Vorontsov, D. Vieglais, and R. S. Pereira. 2006. The use of the GARP genetic algorithm and Internet grid computing in the Lifemapper world atlas of species biodiversity. *Ecological Modelling* 195:139-145.

Sutherland, W. J., A. S. Pullin, P. M. Dolman, and T. M. Knight. 2004. The need for evidence-based conservation. *Trends in ecology & evolution* 19:305-308.

Troudet, J., P. Grandcolas, A. Blin, R. Vignes-Lebbe, and F. Legendre. 2017. Taxonomic bias in biodiversity data and societal preferences. *Scientific reports* 7:1-14.

Turner, N. 2014. Ancient pathways, ancestral knowledge: ethnobotany and ecological wisdom of indigenous peoples of northwestern North America. McGill-Queen's Press-MQUP.

Turner, N. J., M. B. Ignace, and R. Ignace. 2000. Traditional ecological knowledge and wisdom of aboriginal peoples in British Columbia. *Ecological Applications* 10:1275-1287.

Von Der Porten, S. 2012. Canadian indigenous governance literature: A review. *AlterNative: An International Journal of Indigenous Peoples* 8:1-14.