How puzzles are shaping our understanding of biodiversity

A call for more research into biodiversity representation in educational games

Games as a didactic tool (e.g., puzzles) are gaining recognition in environmental education to promote skill development, but also to develop a specific understanding of the natural world. However, a children's puzzle containing representations of nature may unwillingly lead to "misconceptions" of biodiversity themes and processes, and an over-simplification of the relationship between people and nature. To solve this problem, positive connotations of biodiversity may prompt a conceptual change to a more nuanced, multifaceted conception of biodiversity.

Maria Alejandra Parreño, Sara Petchey, Mollie Chapman, Florian Altermatt, Norman Backhaus, Anna Deplazes-Zemp, Katherine Horgan, Pascal A. Niklaus, Morana Mihaljević, Frank Pennekamp, Maria Joao Santos, Michael Schaepman, Bernhard Schmid, Vanessa Weber de Melo, Debra Zuppinger-Dingley, Owen L. Petchey

How puzzles are shaping our understanding of biodiversity. A call for more research into biodiversity representation in educational games | *GAIA* 31/3 (2022): 139–145 | **Keywords:** biodiversity, constructivism, educational games, education for sustainable development, environmental education

Environmental cognition is concerned with the way we learn about the environment, including how small children understand the environment that surrounds them (Palmer et al. 1996). Games as a didactic tool have been considered in numerous studies, usually with the approach of designing games specifically to promote skill development, but also to develop a certain understanding or encourage certain attitudes towards the environment (Madondo and Tsikira 2021, Garcia et al. 2022). Numerous everyday conceptions among children about different aspects of biology have been identified but little attention has been given in particular to the concept of biodiversity (Coley and Tanner 2012), especially in preschool.

In the absence of a conceptual change leading to understanding a scientifically correct concept, some everyday conceptions may result in detrimental decisions. Research on the effect of everyday biodiversity conceptions on decision making is lacking, but it is well known in other areas of knowledge and practice that misconceptions have an impact on the choices people make. The general aim of this article is to propose a framework on how biodiversity understanding could be shaped by everyday experiences, in particular by representations of biodiversity in puzzle games, to raise awareness of the current lack of research in this realm, and to present untested hypotheses that could promote dialogue and spark further research.

Maria Alejandra Parreño | University of Zurich | Department of Evolutionary Biology and Environmental Studies | Winterthurerstr. 190 | 8057 Zurich | Switzerland *and* University of Zurich | Department of Geography | Zurich | Switzerland *and* Technical University of Munich | Research Department of Life Science Systems | Munich | Germany | alejandra.parreno@tum.de

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Background: biodiversity conceptions

The conservation of biodiversity has become an urgent challenge for humanity, together with other challenges like tackling climate change, habitat loss and poverty (Watson et al. 2021). Aside from potential intrinsic value, biodiversity is of vital importance for ecosystem functioning and the regulation of the services ecosystems provide as well as adaptation to change (Duffy et al. 2017). Biodiversity provides long-term benefits for ecosystem services such as provisioning goods, cultural services and process regulation.

Tackling global biodiversity decline requires the involvement of people that are not biodiversity scientists in decision making, like the inhabitants of the spaces where biodiversity conservation programs are to be carried out (Michel and Backhaus 2019). The notions people have about biodiversity can affect their support of biodiversity management measures (Fischer and Young 2007, Hooykaas et al. 2020). Yet the abstractedness of the concept of biodiversity and the impossibility of directly perceiving many of its aspects by human senses represent a major problem to understanding, especially when personal concessions need to be made in order to set a common protection goal (Fischer and Young 2007). Therefore, it is relevant to ask: how do people develop a conception of biodiversity? >

From our perspective, there are two major venues where people learn about biodiversity: 1. what we learn from everyday experiences of biodiversity in informal environments, 2. what we learn from natural science education, usually in formal institutions, like schools. We focus on developing a framework and ideas related mainly to the first approach, which remains largely underexplored in the literature.

Everyday conceptions – the relevance of beliefs, views and opinions

Humans can perceive some aspects of biodiversity using all their sensory organs, for example aspects such as diversity of colors, shapes, sounds, and tastes. Other aspects, such as genetic diversity without clear phenotypic expression or more abstract concepts related to biodiversity and its role in the ecosystem, are impossible to perceive with the bare senses and can only be recorded indirectly with tools (Fischer and Young 2007). Furthermore, some people grow up immersed in knowledge about plant and animal species, whereas many others have limited access to this knowledge or to nature in general, and learn about biodiversity from secondary sources. These include books or visualizations, such as games, where biodiversity is represented often detached from intrinsic scientific knowledge about it and likely in the absence of targeted educational guidance.

For the purpose of this article we coined the term *everyday conceptions* to refer to the beliefs, views and opinions that may or may not be consistent with the science-based worldview claimed in underlying most national and international environmental policy documents. These everyday conceptions, similar to the ones referred to as *student conceptions* within educational literature, can be challenging to change if not identified during the educational process, but can also be beneficial, as a basis for the development of learning opportunities, when recognized and further challenged (Duit and Treagust 1998, Messig and Groß 2018). According to constructivist theories in education, children begin to build everyday conceptions based upon their everyday experiences, which can be inaccurate, incomplete or incorrect. They further develop those conceptions through formal schooling (Coley and Tanner 2012) though sometimes children hold misconceptions that require great effort to address, for example, the idea that correlation implies causation (correlation implies a relationship that may or may not be causal). Within natural sciences a typical misunderstanding is that humans evolved from great apes (instead, men and monkeys shared a common ancestor, which have then evolved to men and monkeys) (Groß et al. 2019).

A common everyday conception regarding biodiversity is, for example, to think that the human species and other species should not or cannot coexist in urban spaces – that each needs their pristine space to thrive (Soanes et al. 2019). This example could also be seen as a problem of individual species' livelihood rather than biodiversity, but for conservation programs in urban areas and for species like pollinators, "pests" and predators, it is a common issue that needs to be addressed with stakeholders prior to conservation program implementation or pursuing behavioral changes (Ostermann-Miyashita et al. 2021).

Constructivist learning: how we learn new concepts

As a framework for our study we explored the application of constructivist learning theory (Piaget 1953, Vosniadou 2007, Vygotsky 1978) to elucidate how the personal understanding of biodiversity is formed. In this perspective, new knowledge builds upon prior knowledge and is constructed through experiences and discoveries, according to a learner's developmental stage. Culture and language, among others, play an important role in how this process occurs and what its outcome can be, through limiting the type of experiences that the learners are exposed to and through the impressions that the tutors imprint on the learning process (e. g., values, beliefs).

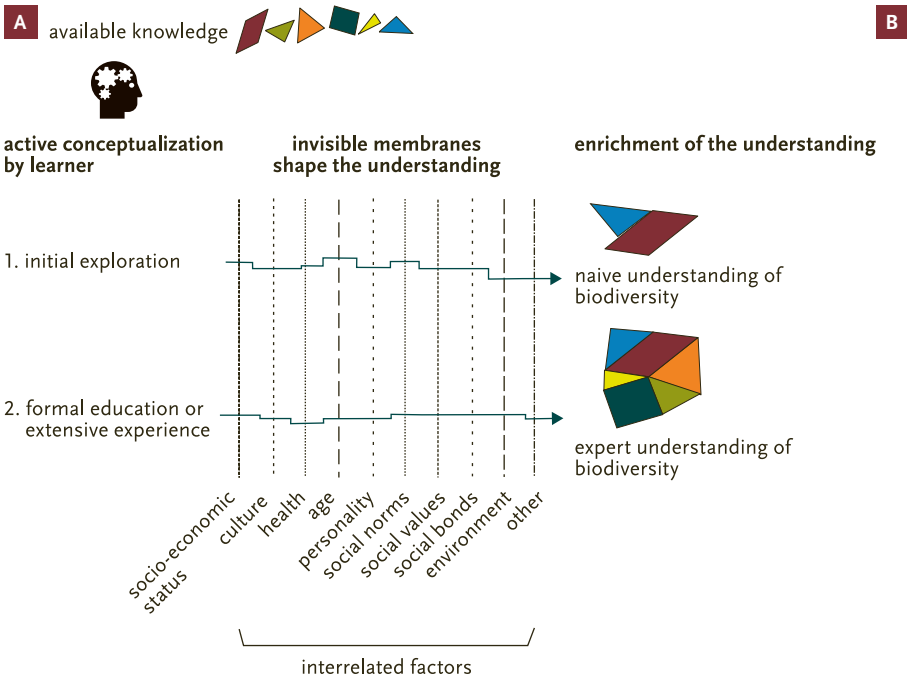
We develop a conceptual model of biodiversity understanding, drawing on the idea of "invisible membranes" and naïve understandings (Roopnarine and Johnson 2015, Pope and Gilbert 1983) (figure 1). Knowledge is constructed actively by the learner putting together available pieces of information that are filtered through "invisible membranes", for example, cultural background, social norms, that shape that construction. These factors are interrelated, for example, culture is strongly shaped by values, which also relate to social norms and personality. During the exploration phase, a naïve understanding of a topic is forged. If contested, further education and experience allow the learner to correct inaccurate conceptions that may have developed during the exploration phase and to dive deeper into a topic and develop an expert understanding.

We propose that this framework is useful for describing how biodiversity understandings are built, and for looking at how naïve understandings are formed and what factors may influence these. A large body of research by cognitive psychologists and developmental researchers demonstrates that children develop many concepts from their experience of nature (Busch et al. 2018). However, a large proportion of people have only limited access to experiences of nature (Kowarik 2018) and learn about it through secondary sources (books, games, TV shows, or oral information).

We use this forum to spark the discussion and lay the foundations of what conceptual change may mean in biodiversity understanding, and so we leave the door open for richer interpretations of conceptual change to be built upon our framework.

Experiencing biodiversity through puzzles

Games and puzzles are one of the first ways in which many children are introduced to concepts in life (Brown and Freeman 2001). Through playing and exploring, children instinctively build naïve



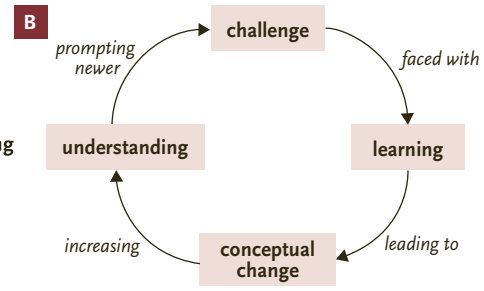


FIGURE 1: A conceptual model of construction of the personal understanding of biodiversity. ***Panel A:*** the learners get their first notions on a topic (e. g., biodiversity) through exploration of nature and everyday life, shaped by internal and external factors, such as culture. This naïve understanding is later contested and expanded through experience and formal education. ***Panel B:*** the learning process continues during the learner's life, only if challenges faced through exploration and learning lead to conceptual changes and expanded understanding.

understandings, based on experience, even without input from formal education. Games, puzzles, books and other media are informal sources of information that encourage interpretations about the biological world, consistent with the beliefs of the mainstream culture (Geerdts et al. 2016, Crowley et al. 2021). The gamification of education and science is the process of transmitting educational and scientific concepts through games, mostly in order to increase motivation and engagement of students (Kalogiannakis et al. 2021).

Most literature on educational games and their effects focus on technological and software games (sometimes named serious games) rather than traditional or generic ones, and disproportionally on university levels rather than initial, primary- and secondary-school levels (Kalogiannakis et al. 2021). Education games that have been tested at the kindergarten level for their effect in everyday knowledge and behavioral change (e. g., health and grooming) and understanding of physics through targeted serious games show a high level of engagement and enhanced scientific thinking, dependent on verbal communication and attention capacity of the different children (Van der Graaf et al. 2016, Riska et al. 2021).

Early education shapes the way students later learn and some of these early formed conceptions remain despite formal education and are highly resistant to change (Duit and Treagust 2003). For example, misunderstandings about natural selection, caused by over-simplification and interpretation of evolution are widespread in initial education and hard to overcome even after lengthy higher education activities (Emmons et al. 2018). Naïve understandings and conceptual changes (Duit and Treagust 2003) in sciences have been explored thoroughly for concepts in mathematics, physics, and general biology (e. g., the concept of evolution) – but not yet for biodiversity (Thompson 2006). We wonder whether early experiences might have large and long-lasting effects on children's understandings of biodiversity and its effects on the functioning of ecosystems and the natural world at large. Children's picture books have been found to influence how children understand the world around them, particularly regarding animals and plants (Kelemen et al. 2014). Some books include a puzzle often played by children is known as "Which one does not belong?" or "Which is the odd one out?" It encourages sorting of objects based on differences among them (figure 2, p. 142).

This puzzle is usually played in its most basic form by young children in kindergarten, often under six years old. Puzzles in which geometric shapes and colors have to be grouped and matched are used as an effective tool for developing of fine-motor, linguistic and mathematical skills in kindergarten and primary school (Fonstad 2016, Mahmud and Samad 2020). These puzzles do not describe themselves as relating to biodiversity and were not designed with developing its understanding. However, when including representations of organisms, we are able to identify how certain aspects of the concept of biodiversity could transpire from these puzzles: a group of organisms that display some pattern of variation/difference in their properties, where the player is required to identify a particular element of that diversity and do something with that pattern of variation (i. e., match, separate, relate).

We looked into three aspects of this puzzle that may be problematic for the building of conceptions of biodiversity, and we provide possible ideas on how these aspects may be better approached by tutors to use them as a basis for conceptual change: 1. language, 2. grouping of elements as "correct", 3. tendency to homogenize.

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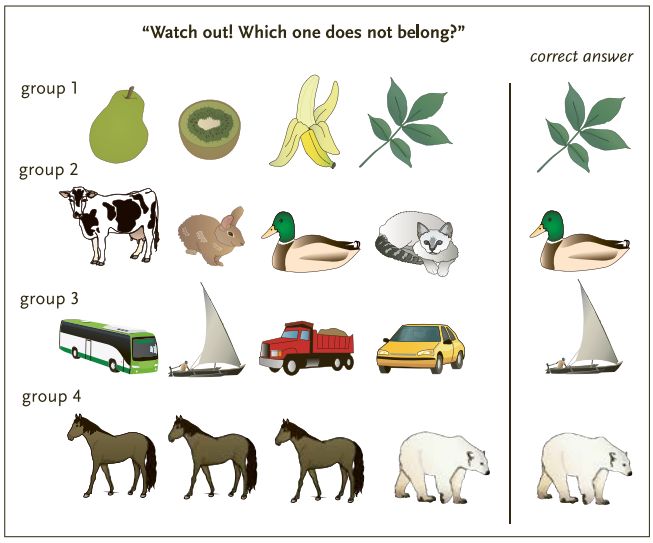

FIGURE 2: A typical preschool sorting puzzle, with the title "Watch out! Which one does not belong?" representing common descriptions of what such puzzles exclude. This image has been based particularly on a game found in a public library for children in Germany, but is similar to many others found online on educational websites.

Language

These puzzles commonly use language that implies difference as an undesirable property of an object, such as "Watch out! Which one does not belong?", "Cross out the picture that does not go with the rest", "Select the one that does not fit". The criteria of the classification required are not written; hence they are left for self-determination or for decision of an adult tutor. We hypothesize that this use of language could lead to a conceptual understanding that one object being different from others is a negative attribute, and therefore that diversity in a group of objects is undesirable. Hence, from the earliest age, the language of these puzzles could encourage an understanding that being different is a negative attribute, and that objects that are different from the majority should be excluded from a group when in the minority. This could be a misconception in general, and certainly is so relative to understandings of the functional importance of biodiversity in which both rare and distinct members of a community promote its functioning and stability.

We hypothesize that simple changes in titles, questions and descriptions of these games could fundamentally change players' views of diversity and biodiversity. Moreover, when children are guided by a tutor, being aware of this misconception as a possible unintended consequence of the game could help them tailor their guidance to promote dialogue and clarify whether this is the learner's impression or not.

Grouping of elements as "correct"

There are several forms of this puzzle that differ in the number of answers allowed as "correct", but often there is only one correct answer allowed. The use of categories to classify objects is one of the educational purposes of these puzzles. We hypothesize that using categories related to more meaningful interactions between the objects in different contexts rather than to their basic shape or color would serve to achieve a higher understanding of the system, in particular for organisms (such as plants and animals, figure 3). In contrast, we risk a limited learning when little interaction between elements is being established, and in the absence of a tutor that invites the child to rethink groups based on different classification schemes.

Busch et al. (2018) tested children's reasoning when classifying organisms and showed that children of young ages naturally favored ecological reasoning, for example, grouping organisms based on their ecological functions (e. g., plant/pollinator relations) over classification based on taxonomical groups and similarities (Busch et al. 2018, Kattmann 2001). Encouraging classifications that are not based on observable ecological relations between organisms could potentially be a source of misconceptions through the educational process, such as placing all plants as land organisms, or other oversimplifications.

We propose that a change to use interactions between elements is needed, as these are the fundamental aspects of complementarity, facilitation and division of labor, tailored to the cognitive level of the learners (Kattmann 2001). Tasks could be re-framed to present diversity as a positive or neutral characteristic of the group or to align with ecological reasoning, without this re-framing becoming detrimental to the original aims of the puzzle (developing mathematical, attention, linguistic and fine motor skills).

Tendency to homogenize

The last aspect of the puzzles we look at is the limited variability among objects of the same type; for which the most extreme case would be when the same object is repeated several times with no differences between that object. However, this is in stark contrast to the environment around us and in particular the natural world, where variability among elements, even similar ones, is a most general feature. We hypothesize that this oversimplification of organismic diversity could be partially responsible for limited appreciation of biodiversity, due to internal idealizations that homogeneity is normal and perhaps is desirable because there is one "perfect" specimen. However, a more diverse genetic background may have positive effects for overall survival of species, for example in genetic drift or bottleneck events (Van Dyke 2008). The implications of such idealizations without proper intervention from a tutor could be misunderstandings of the concept of biodiversity or the non-recognition of varieties and plants and animals. In general, the tendency to homogenize can have negative consequences such as being unwillingly classified by others, slowing progress or limiting our creativity (Bowker and Leigh Star 1999).

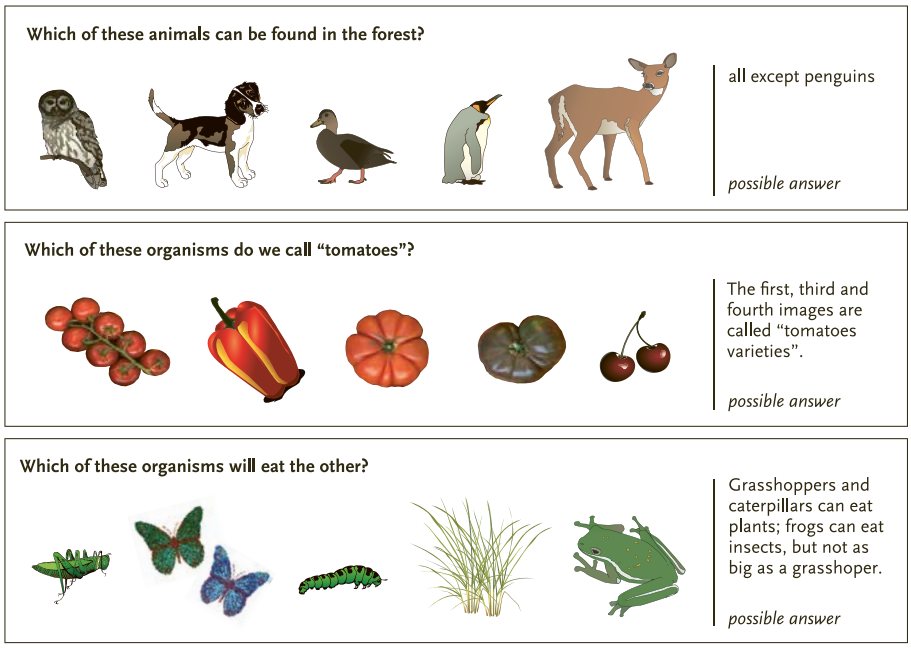

FIGURE 3: Goal-oriented alternative puzzles in which diversity is acknowledged and can be perceived as positive or neutral attribute of a system.

Conclusions

How people develop understandings of biodiversity outside formal science education should be a key issue for transdisciplinary research, given the pressing need for biodiversity conservation. Here we have presented some ideas open to debate on how a game could shape personal understandings of biodiversity and we have provided numerous hypotheses that could be tested. Other children's games where there is a representation of nature and species would also be of interest to study in a similar method, for example memory games. Furthermore, other topics relevant to conservation such as climate change, pollution and land use could also be taken into consideration in our educational framework and its representation in educational media further explored.

We call for fostering collaboration among different disciplines in game design, namely biologists, game designers, psychologists, educators. Interdisciplinary teams can test the outcome of the impact that the games have on understanding, for example, through interventions, experiments or surveys. Without transdisciplinary collaboration such games may have unintended and potentially undesirable effects on how children understand biodiversity, and indeed diversity at large. It is worth further exploring the effects of these games played in different settings have on biodiversity understandings. For example, re-playing the games in an environmental science education setting may prompt a conceptual change from oversimplistic representations to a more nuanced, multifaceted conception of biodiversity (figure 3). Naturally, not all aspects of biodiversity can be represented through puzzles or perhaps games in general.

There are clearly objections to our perspective as we are limited to our own experiences. It would be interesting to have an inter-cultural discussion about which other forms of biodiversity representations could be influencing the understanding of biodiversity.

Moreover, we have not developed further the role and definition of each of the "invisible membranes" and how they are affecting biodiversity understanding from a socio-psychological perspective as this exceeds the scope of the present paper – clarifications in this direction would be beneficial. In particular, research could elaborate what might constitute such invisible membranes in the context of biodiversity understandings. This could be achieved with a collaboration consortium to test different aspects of this hypothesis, to provide much needed data to answer key questions in environmental education and conservation biology. For example: to what extent effect kindergarten and primary school traditional games with nature representations the understanding of biodiversity? Which aspects of biodiversity can be represented (and misrepresented without proper guidance) in children's games? And to what extent are naïve understandings of biodiversity significantly influenced by everyday activities?

We expect that exploring these questions would lead to practical implications for conservation: increased knowledge on how people's understanding of nature "evolves", ideas to enhance everyday activities for children towards a more inclusive conception of biodiversity, inclusion in transdisciplinary research of stakeholders from different cultural and social groups outside western, industrialized, rich and democratic countries (Henrich et al. 2010), and enhanced understanding of biodiversity conceptions of people.

Finally, we acknowledge that in contexts other than scientific ones (e.g., religious rituals and spiritual connections) different notions of biodiversity are relevant – and often the different notions are connected (Frascaroli 2016). Secondly, it is important to note that we do not think that all experiences of biodiversity should be orchestrated to create only positive attitudes towards it. But we think that alignment of people's understandings with well-evidenced and broadly accepted scientific conclusions could lead to an increase in the quality of connections between people and nature, by addressing hidden misconceptions.

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Author contribution: All authors participated in the creation of this paper. Additionally, *Maria Alejandra Parreño* performed the general literature search, drafted figures and coordinated co-authors contributions. *Sara Petchey* performed literature search regarding education and performed substantial editions to the manuscript. *Mollie Chapman* made substantial contributions to the figure development and conclusions. *Owen L. Petchey* developed the original idea and first draft of the manuscript and supervised contributions.
Disclaimer: The educational concept behind this puzzle is to provoke discussion of variety in students' answers specifically related to math. In none of the examples using animals or plants is there an intention to discuss biological concepts or an awareness on how this phrasing might be useful in math but potentially harmful in terms of biodiversity understanding. The puzzle in figure 2 is based on an existing puzzle offered commercially for children, but due to copyright issues we are not allowed to include the brand or exact picture of it.

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Maria Alejandra Parreño
Studies in genetics, ecology and conservation in Argentina, the United States and Switzerland. Postdoctoral researcher at Technical University of Munich, Germany. Research interests: interdisciplinary research in global change sciences, particularly land use impacts on human wellbeing and biodiversity conservation.

Sara Petchey
Studies biology and education in the United States and in the United Kingdom. PhD student on the utility of school pedagogical techniques and training for higher education, University of Zurich, Switzerland. Research interests: teaching science and math and training science teachers around the world.

Mollie Chapman
Studies in conservation and social sciences. Postdoctoral researcher, University of Zurich, Switzerland. Research interests: relational values, market-based conservation, food systems, sustainability transformations, biodiversity and ecosystem services.

Owen L. Petchey
Studies in biology and biodiversity sciences in the United Kingdom and in the United States. Professor of ecology and Vice Dean, Faculty of Science, University of Zurich, Switzerland. Research interests: understanding and advancing the predictability of ecological patterns and processes, using methods including experimental ecology, theoretical modelling, and analyses of observational data.

AUTHORS

Maria Alejandra Parreño
University of Zurich, Department of Evolutionary Biology and Environmental Studies, *and* Department of Geography, Zurich, Switzerland, *and* Technical University of Munich, Research Department of Life Science Systems, Munich, Germany

Sara Petchey
University of Zurich, Institute of Education, Zurich, Switzerland

Mollie Chapman
University of Zurich, Department of Geography, Zurich, Switzerland

Florian Altermatt
University of Zurich, Department of Evolutionary Biology and Environmental Studies, Zurich, Switzerland, *and* EAWAG (Swiss Federal Institute of Aquatic Science and Technology), Department of Aquatic Ecology, Dübendorf, Switzerland

Norman Backhaus
University of Zurich, Department of Geography, Zurich, Switzerland

Anna Deplazes-Zemp
University of Zurich, Ethics Research Institute, Zurich, Switzerland

Katherine Horgan
University of Zurich, Department of Evolutionary Biology and Environmental Studies, Zurich, Switzerland, *and* The Berkshire, Buckinghamshire *and* Oxfordshire Wildlife Trust, Oxford, *and* Lindengate Mental Health Charity, Wendover, United Kingdom

Pascal A. Niklaus
University of Zurich, Department of Evolutionary Biology and Environmental Studies, Zurich, Switzerland

Morana Mihaljević
University of Zurich, Department of Geography, Switzerland, *and* University of Zurich, Science Lab, Zurich, Switzerland

Frank Pennekamp
University of Zurich, Department of Evolutionary Biology and Environmental Studies, Zurich, Switzerland

Maria Joao Santos
University of Zurich, Department of Geography, Zurich, Switzerland

Michael Schaepman
University of Zurich, Department of Geography, Zurich, Switzerland

Bernhard Schmid
University of Zurich, Department of Geography, Zurich, Switzerland

Vanessa Weber de Melo
University of Zurich, Department of Evolutionary Biology and Environmental Studies, Zurich, Switzerland, *and* EAWAG (Swiss Federal Institute of Aquatic Science and Technology), Department of Aquatic Ecology, Dübendorf, Switzerland

Debra Zuppinger-Dingley
University of Zurich, Department of Evolutionary Biology and Environmental Studies, Zurich, Switzerland

Owen L. Petchey
University of Zurich, Department of Evolutionary Biology and Environmental Studies, Zurich, Switzerland, *and* EAWAG (Swiss Federal Institute of Aquatic Science and Technology), Department of Aquatic Ecology, Dübendorf, Switzerland