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No need for niches in new ecology

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ABSTRACT

The concept of 'niche' has been extensively used to explain ecological patterns. However, the concept has been defined differently and is continuously under discussion. Does the concept truly help ecology become the predictive science we urgently need to stop the decline of biodiversity? To find an answer to this question, we discuss recent developments in ecological thinking based on agency, information, and complexity.

The ecological agent, usually referred to as an organism, continuously and autonomously decides how to act based on processing information that it collects from within—its experience and current state—and from its environment. The collective decisions of all organisms in a community together result in ecological patterns. These patterns may not always align with the patterns that humans perceive in the environment. This new approach to ecology implies a non-deterministic view of ecosystems, which are constantly changing at all levels of scale.

Community ecology would become an explanatory science if it could predict ecological patterns based on the information available to organisms and how these decide to act based on that information.

We argue that the concept of the niche is tied to traditional thinking rooted in a deterministic worldview about static ecosystems, which includes a fixed distribution of organisms in space and time. In the new ecological approach, the niche is no longer useful for accurate predictions of ecological patterns. However, we believe that new developments in machine learning – AI - may be helpful, given the vast amount of information involved in these predictions.

1. Introduction

Everywhere in nature, we observe patterns, and this is also true for ecological communities. Following Grimm and Railsback (2005), we define an ecological pattern as a display of order within communities, including the regular distribution of organisms in space and time, regular structures of interactions, and the ordered changes within them. Examples include zonation (Rowan and Knowlton, 1995; Cai and Reavie, 2018), stratification (Basham et al., 2023), succession (Prach and Walker, 2011; Chang and Turner, 2018), food pyramids (Barbier and Loreau, 2018), and body plans (Niklas, 2000; He and Deem, 2010). Not only can we observe these patterns everywhere on Earth today, but we find them also in the fossil record (e.g., Erwin et al., 1997).

The concept of the 'niche' has long been used to explain ecological patterns. The great 19th-century naturalists, such as Humboldt, Linnaeus, Wallace, and Darwin, discovered modern taxonomy and observed that each new species they encountered had its own living range, where it thrived because it was so well-adapted to that environment. This view coincided with the emerging idea of organisms as machines, which contributed to a deterministic view of nature (Ball, 2023).

The notion that every plant and animal species has a specific role to play in the divine plan of the world's creator is very old and likely common across human civilizations. For example, think of Noah, who was instructed to bring a male and female of every animal onto his ark to restore nature after the great flood (Genesis 7:18–22). However, the term 'niche' itself was not used until the early 20th century. It was first introduced in 1910 by Johnson in relation to ladybirds, but became a significant ecological concept after Grinnell used it in 1917 to describe the place a species occupies within its environment (Chase and Leibold, 2003). Since then, new interpretations have been proposed and thoroughly discussed. Niche theory played an important role in community ecology for many years, especially in connection with the idea of competition (Pocheville, 2015). However, ecologists have not reached a consensus on the meaning and use of the term 'niche' (Pocheville, 2015; Sales et al., 2021). It has been used in fundamentally different ways, and there is disagreement even over whether the niche is a property of the

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environment, the species, or the individual (Sales et al., 2021). It is not surprising that some authors have considered abandoning the term from scientific ecological publications (e.g., Hurlbert, 1981). This raises the obvious question: What is the role of the concept in future ecology? More specifically, can the concept help ecology become the predictive science we urgently need to stop the decline of biodiversity?

2. New community ecology

2.1. The need for predictive power in ecology

Natural ecosystems across the biosphere are increasingly being damaged or destroyed, leading to significant declines in biodiversity. Since the international Convention on Biological Diversity (CBD) in Rio de Janeiro in 1992, countries have been striving to halt this decline. However, these efforts have not been very successful to date (GBO 5, 2020; WWF, 2024). While we believe that the success of nature conservation policy depends largely on socio-economic and political processes, we also believe that we urgently need an ecology that can assist conservation policy with accurate predictions. This would help conservation policymakers understand the consequences of alternative management options in scenarios considered realistic, while also providing trustworthy explanations for laypeople regarding the management decisions made.

Traditionally, a key attribute of explanatory science is its ability to make accurate predictions (Peters, 1991). Accurate predictions are possible through sound theoretical derivations, precise statistical analyses of high-quality empirical datasets, or a combination of these (Han et al., 2023). Such predictions are urgently needed to inform the right measures - what to do, where, and when - to stop the decline of biodiversity (Musters et al., 2023).

To explore the role of the niche concept in predicting ecological patterns, we will first outline what we consider to be the essential characteristics of modern theoretical ecology, based on agency, information, and complexity theory (Mitchell, 2009; Kaufmann, 2019; Ball, 2023; Mitchell, 2023; Adami, 2024). Second, we will discuss what is necessary to increase the predictive power of this new approach to ecology. Finally, we will assess whether the concept of the niche still deserves a place in ecological thinking.

2.2. New theoretical ecology

In modern ecology, the agent is central (Ball, 2023). Typically, the organism is regarded as the ecological agent (Kauffman, 2019; Ball, 2023), but other entities could theoretically also be considered ecological agents. For example, most multicellular organisms harbor microbiomes living in their organs or on their bodies, and these microbiomes should be regarded as part of the agent because they may influence the behavior and survival of the organism (Ezenwa et al., 2012; Worsley et al., 2021). In this sense, agents may be viewed as sets of communities. Recently, we proposed calling this new community ecology, based on agents, 'Organism-based Ecology' (Musters et al., 2023). For clarity, we will continue to use the term 'organism' when referring to the ecological agent.

An organism constantly and autonomously decides what actions to take for survival and reproduction (DeAngelis and Diaz, 2019; Ball, 2023; Mitchell, 2023; Sayin et al., 2025). To do so, it predicts its options using information from itself and its surroundings. It processes information stored in its genes, its current metabolic state, past experiences, and environmental data. In terms of environmental information, the organism can be said to be attempting to predict ecological patterns. Due to the complexity of the information network involved, the organism's predictions are highly uncertain, as is the likelihood that the resulting decision will lead to the highest probability of successful survival and reproduction. However, organisms with the best predictive abilities are more likely to thrive and are therefore the fittest. This holds true for all types of organisms, whether animals, plants, fungi, or microbes.

An organism lives in an environment that is constantly changing over time and space, both predictably (e.g., daily and seasonal changes, gradients) and unpredictably (e.g., weather, disasters, spatial discontinuities). It also exists within a community, a network of organisms that occur together in space and time. Therefore, it interacts with other organisms and may expect to encounter them in the future. Its responses to these organisms depend on its internal state: it may be attracted to some (e.g., partners, prey, shelter) or try to avoid others (e.g., competitors, predators, diseases). Some organisms might even migrate. Consequently, other organisms will respond to the presence and actions of the focal organism. These interactions lead to positive and negative feedbacks, altering the ecosystem locally and regionally, sometimes unpredictably, both in the short and long term. Well-known examples include how the 'landscape of fear' (i.e., perceived spatial variation in risks) affects the distribution of organisms non-linearly (Gaynor et al., 2019), and the emergence of various spatial patterns in some vegetation that evade tipping points (Rietkerk et al., 2021).

Described this way, communities and ecosystems appear deeply nondeterministic (Kauffman, 2019; Ball, 2023; Mitchell, 2023). Yet, as mentioned earlier, natural systems exhibit clearly recognizable patterns that give the impression of order and resilience. This is reassuring: the autonomic reactions of organisms to their local environment may give rise to predictable patterns within the systems they inhabit. Modern community ecology can thus be seen as an effort to understand these emerging community patterns from the autonomic actions of individual organisms.

However, caution is warranted. New theoretical ecology suggests that the ecological patterns we, humans, observe are based on the processing of information stored in *our* genes and memories, as well as information collected through *our* sensory organs. These patterns are tailored to human decision-making, which means that the patterns we perceive may, first, not be the only or most important patterns present in communities, and second, they may not even be what we think they are, or they may not be patterns at all. Information processing can easily go awry because it is adapted to historical ecosystems that may no longer exist. This may be true for all organisms.

2.3. Predictions in new ecology

Ecology is rich in theoretical hypotheses about the mechanisms that cause the patterns we observe in communities (Gaston and Blackburn, 1999; Vellend, 2016). These mechanisms typically describe the relationship between species traits, certain abiotic or biotic variables, and the spatial or temporal distribution of species or the structures of species networks, under given environmental conditions. A wealth of empirical knowledge is available on these mechanisms, including the parameters that mathematically describe the relationships (see Chase and Leibold, 2003, for examples of niche theory). In fact, textbooks on ecology can be regarded as extensive catalogues of such mechanisms (e.g., Begon et al., 2005). However, in order to describe these relationships mathematically, they are necessarily simplified, which leads to parameters that depend on local and temporal conditions. As a consequence, ecologists often find both support and rejection for specific parameters in empirical datasets. Therefore, especially community ecology has been said to suffer from contingency (Lawton, 1999).

As mentioned earlier, in new ecology, the ecological agent is the fundamental entity whose autonomic decisions cause ecological phenomena. A useful way to study the relationship between the actions of different agents and the emerging patterns of the systems they inhabit is by simulating the workings of the proposed mechanisms using Agent-based Models (ABMs, also called Individual-based Models [IBMs]; Grimm and Railsback, 2005; DeAngelis and Diaz, 2019; Musters et al., 2023). This approach does not simplify the system but seeks to understand its complexity (Grimm and Railsback, 2005) and builds on the extensive empirical knowledge of ecology. The patterns these models generate need to be thoroughly studied due to the complexity involved and should be compared with patterns in empirical datasets (Grimm and Railsback, 2005).

A well-known challenge with this approach is that different mechanisms may lead to the same pattern. The most important alternative explanation, which must always be tested, is that the pattern is not an ecological phenomenon at all but merely the result of stochastic and physical processes. In that case, maximum entropy in the spatial and temporal distribution of organisms can be expected. For this reason, null models based on the maximum entropy of the unexplained variance are recommended (Harte, 2011; Musters et al., 2023; Gerkema et al., 2025).

Although not widely used, ABMs have been applied in community ecology for some time now (Grimm and Railsback, 2005). However, *a posteriori* testing of their results using independent empirical datasets is rare, mainly because comprehensive and community-wide datasets of organisms, their actions, and their environment are scarce (Musters et al., 2023). Only after extensive testing can ABMs be relied upon to make reliable predictions of patterns (Grimm and Railsback, 2005).

Recent developments in machine learning and Artificial Intelligence (AI) offer new opportunities to increase the predictive power of ecology (Reynolds et al., 2025). However, current applications also suffer from a lack of suitable datasets for training AI programs (Desjardins-Proulx et al., 2019; Wilson, 2024). According to new ecology, such datasets should not only include standard information on the traits and locations of organisms, but also contain data on the information organisms use to make decisions, and the actions the organism take after decision making. This includes not only the past and present state of the environment—such as the presence of other organisms, land use, climate, and disturbances—but also information that organisms might perceive without humans being aware of it, such as sounds, smells, electromagnetic fields, and other yet-to-be-discovered cues (Sagar et al., 2024; Frazier and Song, 2025). Such data may soon be collected automatically at large scales (Besson et al., 2022; Van Cleemput et al., 2025). Once AI programs are trained with this extensive data, they can be asked to predict future changes in a community under certain climate or management scenarios (Ullah et al., 2024; LTER-LIFE, 2025).

Of course, AI applications come with risks that need to be properly addressed (Reynolds et al., 2025). Moreover, predictions made by AI programs, however accurate, will be purely statistical and not based on an understanding of the processes within communities. As with ABM applications, thorough *a posteriori* analyses of the predictions are needed. Attribute Importance Analysis (AIA) can be used for this purpose (Musters and Van Bodegom, 2018). These analyses might reveal new mechanisms and patterns that need to be tested against null models, as described earlier.

3. The niche in new ecology

In the description of predicting based on new ecology above, niches no longer seem to play a significant role. Both the state of organisms and ecosystems are so dynamic at all spatial and temporal scales that the concept of fixed niches becomes unnecessary. Additionally, competition is no longer seen as the central issue. Symbiotic cooperation between microorganisms, fungi, plants, and animals appears to be pervasive, even within our own bodies. Therefore, the exchange of information between organisms, which they can use to inform their decisions, seems far more important.

Although the first ABMs were designed well before Hubbell's *The Unified Neutral Theory of Biodiversity and Biogeography* (2001) was published, it was this work that significantly impacted the debate on the necessity of assuming niches in modern community ecology. The 'neutrality' of the theory lies in the assumption that all organisms have equal fitness. In new ecology, neutrality would suggest that all organisms are equally effective predictors. This assumption is reasonable when designing a null model to study the effects of dispersal on species distributions and relative abundance.

The challenge in new ecology, however, is to account for differences between organisms, not only in their physical traits but also in their ability to process information. To find general relationships between the numerous variables that capture these differences, it is necessary to group organisms according to predicting variables, i.e., classifying them into 'Operational Ecological Units' (Musters et al., 2023). For this task, AI can be particularly useful (Sanchez-Martinez et al., 2024). It's crucial to recognize, however, that the groups of organisms discovered through this approach are a result of empirical data analysis, not predetermined. This makes them fundamentally different from 'Operational Taxonomic Units', usually species, which are associated with fixed niches.

4. Conclusions

As we indicated in the Introduction, the idea of each species having its own role in communities is very old. However, we believe it is not the role of ecologists to attempt to change the use of the word 'niche' in the stories we tell about nature, even though we now know that it only provides us with an illusion of understanding. Furthermore, the term has expanded beyond ecological contexts, such as in the concept of 'niche' markets in economics.

Nonetheless, when communicating the findings of modern ecology, we should avoid using the term 'niche.' If it is used at all, it should be made clear that it is a relic of a deterministic worldview, a metaphor for the idea that organisms act in certain fixed ways in specific situations. Living nature, as we now understand it, is neither deterministic nor static.

What we certainly should avoid is attempting to create a formal, comprehensive definition of 'niche' that suggests it is a scientifically sound concept. Niches cannot be relied upon for predicting ecological patterns. Meanwhile, such predictions are urgently needed to halt the decline of biodiversity. Machine learning – AI - might offer a solution, but it is too early to confirm its effectiveness.

CRediT authorship contribution statement

C.J.M. Musters: Writing – review & editing, Writing – original draft, Conceptualization. **Geert R. de Snoo:** Writing – review & editing, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to check the grammar. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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