Where do “process-oriented” community ecologists go? In search of general laws that are just “good enough”

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Where do "process-oriented" community ecologists go? In search of general laws that are just "good enough"

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Abstract

Community ecologists often consider their research approaches as either process-oriented or pattern-oriented, which has frequently sparked controversy over the superiority or inferiority of each approach. Here, we argue the ambiguity in the distinction between pattern- and process-oriented approaches by reviewing previous studies. We then highlight three factors—interest, methods, and significance—that influence researchers' perceptions and evaluation of research approaches. This examination reveals the subjectivity inherent in classifying studies. Furthermore, we emphasize the complementary nature of pattern- and process-oriented perspectives in understanding ecological communities. We advocate a scientific culture that embraces diverse research approaches and acknowledges the various levels of generality required to address complex ecological issues. Ultimately, fostering an environment where ecologists with diverse approaches and perspectives collaborate constructively, rather than compete antagonistically, is essential for advancing community ecology.

KEYWORDS

cognition, generality, interests, methodology, scientific approaches

1 | INTRODUCTION

Approaches to community ecological research have been broadly classified into two categories: pattern-oriented and process-oriented. "Pattern" refers to spatiotemporal distributions of ecological variables in nature, such as abundance or species richness. "Process" refers to the interactions between ecological variables. Pattern-oriented approaches focus on identifying recurring patterns across systems, whereas process-oriented approaches aim to uncover the underlying mechanisms. This distinction aligns closely with the contrast between the "whole system" and "building blocks" perspectives (Schmitz, 2010), often representing different analytical scales—broad-scale patterns versus fine-scale processes—in exploring community dynamics. Process-oriented approaches have typically been paired with manipulative experiments, and

Mito Ikemoto and Yoko Wada contributed equally to this work.

pattern-oriented approaches with observational studies (see Section 3).

Importantly, neither approach is intrinsically superior to the other (Schmitz, 2010). Both approaches have undoubtedly contributed to community ecology by generating numerous important discoveries. In the example of intertidal rocky shore communities (Figure 1), Stephenson and Stephenson (1949) represent a pattern-oriented approach. From the experience of studying rocky coasts across various regions (Britain, North America, South Africa, the Indian Ocean, and Australia) for 30 years, they suggested that intertidal zonation is so widespread that it may be universal. Recognizing this widespread pattern enabled the comparisons of findings from different regions and the exploration of similar patterns in new areas, fostering the accumulation of data for broader ecological insights, such as the mechanisms responsible for such patterns. However, testing such hypotheses requires their application to specific biological systems. Process-oriented approaches using manipulative field experiments have contributed to uncovering mechanisms underlying observed patterns. The textbook cases of niche competition (Connell, 1961a, 1961b) and top-down control by keystone predators (Paine, 1966) are the least equivocal examples of this approach. Despite the obvious contributions of both approaches, their different objectives and methodologies have sometimes created tensions (Chapter 17 in Mittelbach & McGill, 2019a, 2019b), often leading to criticism and debate over their shortcomings. Process-oriented studies (i.e., studies employing process-oriented approaches) have been especially criticized for their context dependency. Some researchers argued that context dependency limits the general applicability of the conclusions (Lawton, 1999). We will return to this point in Section 4.

Vellend (2016) proposed a framework for community ecology inspired by population genetics, particularly the Hardy–Weinberg principle. Vellend's argument appears to offer a solution to the process-pattern dispute. In population genetics, evolution is driven by five processes: selection, drift, mutation, migration, and nonrandom mating. Vellend argued that community dynamics, analogous to changes in allele frequency, are driven by four of these processes (excluding nonrandom mating). For example, system-specific factors such as competition, predation, and other species interactions are categorized as "low-level processes." These low-level processes collectively contribute to the "high-level process" of selection, defined as deterministic differences in species' population growth. Vellend says, "*I think that a focus on low-level processes is entirely appropriate and indeed critically important when aiming to understand how particular systems work.... However, if the aim is conceptual synthesis or the development of general theory in community ecology, I think high-level processes may be the only place that either is possible*." This perspective supports process-oriented approaches because it argues that high-level processes offer general theories. However, this emphasis on high-level processes may inadvertently create the impression that low-level processes are merely system-specific cases with limited relevance to fundamental academic goals. Such a perspective can discourage community ecologists who are attracted by the intricate ways of life and strategies of individual organisms.

Despite the historical controversy, the distinction between the two approaches is often ambiguous or arbitrary, as many studies encompass elements of both approaches (Figure 1). For example, Menge et al. (2002) examined the effects of physical factors (e.g., ocean currents) on rocky shore communities through observations and experiments at multiple sites on a global scale. Although their study aimed to examine processes, they also compared patterns across these sites. Ashton et al. (2022) explored the relationship between latitude and species interaction strength, which we, as the present authors, classify as pattern-oriented, although they also sought to uncover underlying mechanisms through manipulation experiments traditionally associated with process-oriented studies. The ambiguous boundary between process- and pattern-oriented approaches questions the validity of the process-pattern controversy. Rather than pursuing a strict definition of "pattern-oriented" and "process-oriented" approaches in community ecology, we ask what shapes individual researchers' perceptions of studies as process- or pattern-oriented, and of the superiority of the two approaches. When deciding on a research direction, individual researchers typically develop their interest in a topic and select an appropriate and feasible methodology, keeping in mind the significance of the topic. We argue that the first two factors, personal and subjective interest, and the methodology employed, play a critical role in shaping perceptions of the two approaches, while scientific significance is more directly related to the evaluation of approaches. Because individual researchers collectively shape the academic atmosphere, these factors ultimately influence how studies (or publications) are evaluated and which approaches gain popularity within an ecological society.

In the following three sections, we discuss each of the three factors one by one. Ecologists often select research themes based on personal subjective interests. The interest influences which species to study, how many species to study, which questions to ask, etc. Various methods are available, and the same or similar questions can be asked in many different ways. The choice of methods

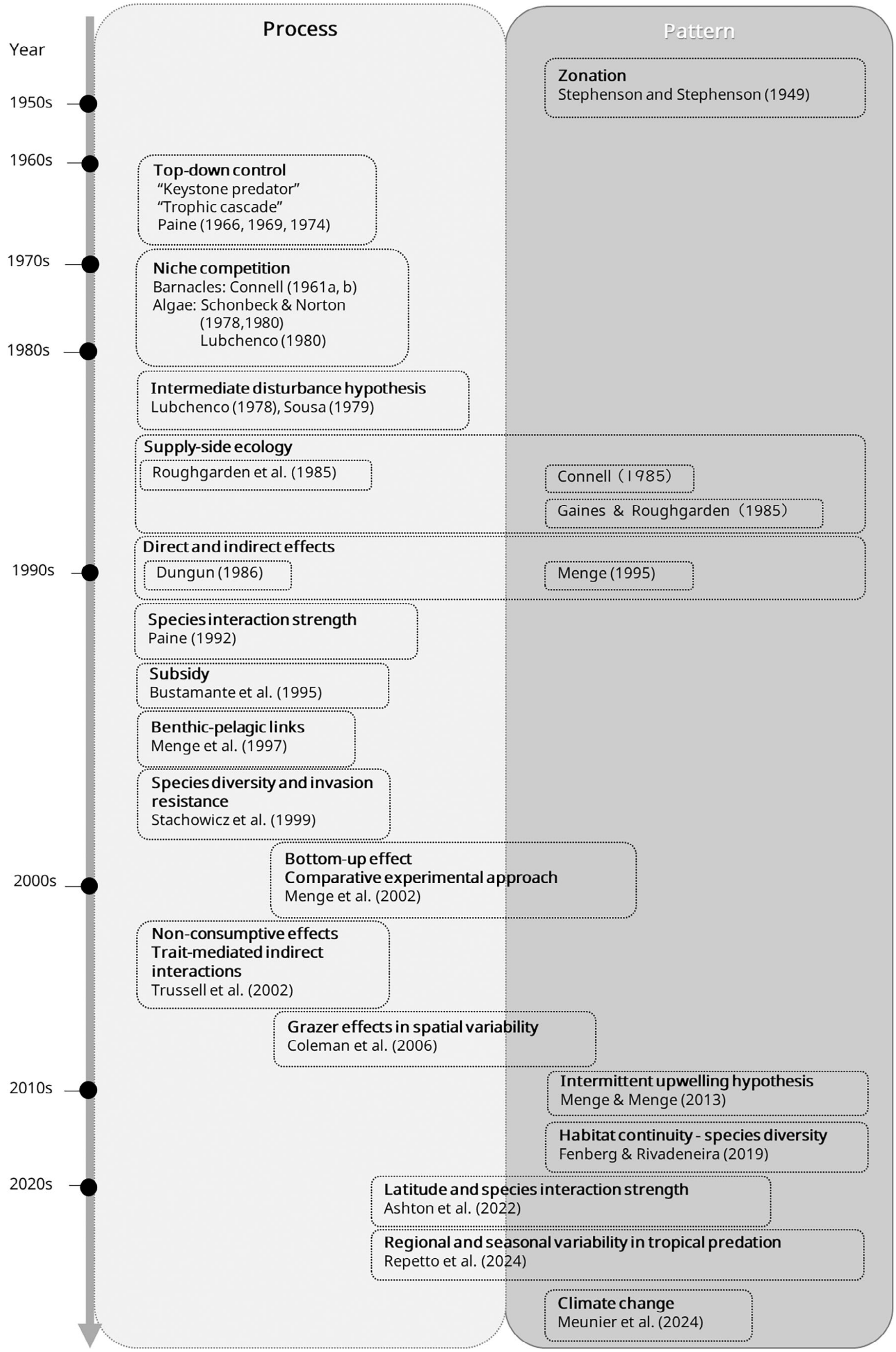

FIGURE 1 Legend on next page.

(including but not limited to feasibility) is contingent upon several factors: personal skills, budget constraints, equipment availability, and technical advances. Undoubtedly, different methods may be better suited to different research objectives, but this does not preclude the arbitrariness of method choices. Significance here refers to its contribution to the development of science, but not to individual researchers' satisfaction (i.e., interest). Note that we refer to significance that is perceived and assumed by individual researchers, rather than immortal "real" scientific significance (if it exists). Scientific significance matters at various stages of research, including grant proposals, conference presentations, and manuscript drafting. Therefore, the significance of a study is subject to the judgments of evaluators, such as funding bodies, academic communities, and peer reviewers. If there are situations where certain approaches are regarded as more valued, individual researchers are more likely to select the superior one. Through such effects on our choice of research themes, significance impacts the prevalence of pattern-oriented versus process-oriented studies in the research communities (i.e., academic landscape). Our discussion of the three factors highlights the futility of the controversy between proponents of the two apparently different approaches. We argue that embracing diverse approaches strengthens community ecology research by encouraging individual researchers' original thinking, without being overly swayed by trends. We hope this paper encourages constructive communication among diverse researchers.

2 | INTERESTS

In this section, we first point out that personal interests influence the perceived distinction between process- and pattern-oriented studies. We also point out that subjective interests are important drivers of individual ecologists. We then discuss how subjective interests drive the science of ecology as a whole. The roles of personal and subjective interests in advancing ecology are seldom discussed formally. This is understandable because personal and subjective interests do not appear consistent with the objectivity of science. Yet, we claim that personal and subjective interests are not negligible drivers of community ecology.

Motivated by several factors, including personal interests, ecologists choose study questions, which set the stage for an ecological phenomenon of interest to be interpreted either as a process or a pattern. Let us consider interspecific competition as an example. Experimental manipulation of conspecific and heterospecific densities is a classical approach to studying interspecific competition (Connell, 1983; Schoener, 1983). One may think that interspecific competition quantified in this way is a process that generates patterns such as distributions and demographic dynamics. However, this approach is agnostic about the behavioral mechanisms of the competitive interaction. The presence of heterospecifics can reduce the performance of a population (e.g., population growth) through various mechanisms: for example, consumption of shared resources (Levins, 1968; MacArthur & Levins, 1967; Tilman, 1982), nonrandom spatial distribution (Kuno, 1988; Pimm & Rosenzweig, 1981; Shorrocks et al., 1984), or interspecific mating interactions (Kyogoku, 2015). For researchers interested in behavioral mechanisms of competitive interactions, individual-level interactions are processes, and the impact of heterospecifics on performance is the resultant pattern (and individual-level interactions are patterns for those who are interested in trait expression). Whether a particular ecological phenomenon is a process or pattern is thus not an inherent characteristic of the phenomenon, but it is context-dependent.

One may wonder if personal and subjective interests are important determining factors of research questions. When conducting empirical studies, researchers typically focus on a small number of taxa in a particular ecosystem. The choice of which taxa to study is largely arbitrary. While ecologists may shift the taxa they study over their careers, the shifts between ecosystems (e.g., from terrestrial to marine) are less frequent, and the choice of ecosystems is also arbitrary. We ecologists know from experience that sometimes study taxa or methods are chosen for reasons that are obviously personal. Some people work on, say, charismatic taxa at least in part because of their love of them, though many journals require implications beyond a specific taxon.

We do not mean that the love of organisms is the only driver for community ecologists. Some taxa are more suitable for certain experimental manipulations than others, and some taxa are commercially more important than

FIGURE 1 Transition between pattern- and process-oriented approaches in studies conducted at intertidal rocky shores. The intertidal rocky shore is one of the communities where especially extensive research has been performed. The historical overview illustrates how the study of community ecology has been conducted using either process- or pattern-oriented approaches and how these approaches have developed. For simplicity, here we classified studies into process- and pattern-oriented. However, as we discuss in the main text, the distinction between the two is not always clear, and we admit that some people may disagree with this classification.

others (e.g., crops and their pests), influencing researchers' decisions. However, even in such cases, the underlying reason for conducting particular experiments or being concerned about agricultural production often stems from personal interests. Personal interest is thus a broad concept, encompassing how individual ecologists weigh factors like the love of an organism, academic curiosity, social responsibility, publication impact, vocational ambition, etc. Ultimately, why someone becomes an ecologist, rather than a physicist or lawyer, is (at least partly) a problem of personal interest. Thus, even choices with seemingly logical reasons are influenced by personal interests.

The arbitrariness of choice is especially relevant in ecology. Ecology (and evolutionary biology) is a science that deals with diversity. There are millions of species on Earth, and it is not practical for individual ecologists to study all of them. Furthermore, species is just one of the taxonomic scales. Populations can be different from each other, and the patterns and processes related to between-population differences (or similarities) are worth investigating (e.g., in butterflies and moths, populations at higher latitudes use larger numbers of host plant species; Lancaster, 2020). Taxonomic scales above species can also exhibit patterns and processes. A subfamily of butterflies, Pierinae, including the cabbage white, can detoxify glucosinolates produced by Brassicales, which is predominantly used as their larval diet (Wheat et al., 2007). Which taxa of which taxonomic scale a researcher is to study is inevitably arbitrary, as explained above. The hierarchy of biological organization (i.e., individuals, species, community, etc.) thus adds another dimension to the arbitrariness of the choice of study questions. Other components of choice include, though not exhaustive, theory (e.g., coexistence theory, metapopulation theory, etc.), hypotheses, methodology, and paradigms (Pickett et al., 2007).

The diversity of personal interests is an important driver not only for individual scientists but also for the entire field of ecology. Because ecology is the science of diversity, studies on various taxa, scales of the biological hierarchy, etc., are necessary (i.e., the diversity of studies). The diversity of personal interests guarantees the diversity of studies. Personal interests may sound too subjective for the discussion in science. However, science advances through "transformative interrogation" by a diverse community of scientists (Longino, 1990). Thus, though personal interests per se are subjective, they collectively underlie the objectivity of science (Pickett et al., 2007). Interestingly, subjective interest can be a double-edged sword for the progress of community ecology. The same data can appear to represent a process or pattern when seen through the lens of personal interests, potentially causing process-pattern confrontation. Alternatively, one may be tempted to put supremacy blindly into their approach over others. Diversity of interests is not negligible for individual scientists or the community ecology as a whole.

3 | METHODS

Whether a study is perceived as pattern- or process-oriented appears to partly depend on which methods those studies use. In this section, we describe how methods influence the distinction between pattern-oriented and process-oriented studies. We also discuss the roles methodological developments play in research advances in community ecology. By doing so, we point out how recent advances in methodology may bridge so-called process- and pattern-oriented approaches. Community ecologists use two types of methodologies—observational and manipulative. Observational studies observe natural communities, often consisting of many species, thereby describing the "spatial and temporal patterns" of species diversity and functioning. Manipulative studies conduct manipulative experiments on a subset community, typically consisting of a few species, to test "causal processes" between ecological variables. Note that theoretical approaches have also played an important role in community ecology, which are fundamentally grounded in both observational and manipulative studies. In this paper, however, we focus on empirical approaches rather than theoretical ones.

Observations and manipulations have their advantages and disadvantages, which may have caused controversies in the relationships between ecologists applying process- and pattern-oriented approaches. A notable example is a notorious debate on the importance of interspecific competition (reviewed by Connell, 1983; Denno et al., 1995; Kaplan & Denno, 2007; Schoener, 1983). In this debate, segregated spatial distribution between species based on purely observational studies was once thought of as the signal of interspecific competition (Diamond, 1973; MacArthur, 1958; Schoener, 1974). However, this naïve view was strongly criticized (Connell, 1980, 1983; Schoener, 1983), as segregated distribution does not necessarily result from interspecific competition (Connell, 1980), nor does the lack of spatial segregation mean no competition (Denno et al., 1995; Lawton & Strong, 1981). This dispute left the impression that purely observational studies cannot prove "causal processes" between species. Shortly after the critiques, ecologists turned to focus on manipulative experiments, successfully revealing the presence or absence of interspecific competition between many pairs of species (reviewed by Connell, 1983; Denno et al., 1995; Kaplan & Denno, 2007; Schoener, 1983). Then, however, such studies were criticized as insufficient to conclude that competition structures ecological communities. This is because a biological community contains not only the two interacting species but also a diverse assemblage of species surrounding them and because complex interactions among multispecies cause an emergent property of ecological communities, which modifies the consequences of competition for community structure (Billick & Case, 1994; Mayfield & Stouffer, 2017; Ohgushi, 2005; Sugihara et al., 2012; Yodzis, 1988).

Distinguishing observational and manipulative studies helps describe the nature of data (e.g., Mittelbach & McGill, 2019a, 2019b; Vellend, 2016). Although many ecologists tend to associate observations with pattern-oriented studies and manipulations with process-oriented studies, this distinction primarily concerns methodology and the nature of the resulting data, not the types of questions asked or approaches (i.e., process versus pattern). We argue that these implicit associations between methods and approaches have at least partly contributed to the conflict between pattern- and process-oriented studies. The methods chosen for a study do not automatically determine the specific questions or goals pursued. Therefore, the method-approach association should not be accepted uncritically. The wide and implicit linkage between the approaches and methods may stem from the practical difficulties of conducting manipulative studies involving many species. If processes in multi-species systems could be inferred without manipulation, such methods could help bridge the gap between pattern- and process-oriented studies.

Some techniques are promising for the inference of processes in multi-species systems: species distribution modeling (SDM) that is based on the spatial or temporal pattern of observational data (Austin, 2002) and non-linear time series analysis (especially, empirical dynamic modeling (EDM), Chang et al., 2017). A common characteristic of both approaches is that they use pattern data from observations (SDM: spatial patterns, EDM: temporal patterns) to infer ecological processes such as biotic interactions. SDM has originally been used to correlate the occurrence or abundance of a species with abiotic environments, but there have been several attempts to correlate species occurrence/abundance with biotic interactions by using SDM (Evans et al., 2016). Among these, joint species distribution models (JSDMs, Pollock et al., 2014), which extract the signal of biotic interactions represented by the residuals of co-occurrence models, are becoming increasingly popular. On the other hand, EDM is the method that extracts the underlying processes from time series data, under the assumption that the focal system is governed by deterministic processes. Specifically, EDM can (1) detect causality between species (i.e., demographic level interspecific interactions) (Sugihara et al., 2012) and (2) quantify the sign and strength of interaction effects between species (Deyle et al., 2016; Suzuki et al., 2017). As such, EDM can reconstruct species-interaction networks, that is, processes, from purely observational, time series data of community dynamics (Hashimoto et al., 2024; Ushio et al., 2018). Of course, the interpretation of JSDM and EDM depends on a number of assumptions. For JSDM, assumptions include no missing important abiotic variables, independence between environment and biotic interactions, and the direction of interactions assumed a priori (Blanchet et al., 2020). The assumptions of EDM include deterministic processes, stationarity, and nonlinearity (Clark & Luis, 2020; Munch et al., 2020; Ye et al., 2015). Thus, careful diagnostics are needed to conclude that spatial and temporal pattern data reflect biotic interactions.

An important advantage of the SDM and EDM is that they can infer community processes (biotic interactions) from observational data. This expands the feasibility of process-oriented community ecology toward complex, multispecies systems. We illustrate this in Figure 2. The conventional studies form a diagonal line (i.e., pattern-

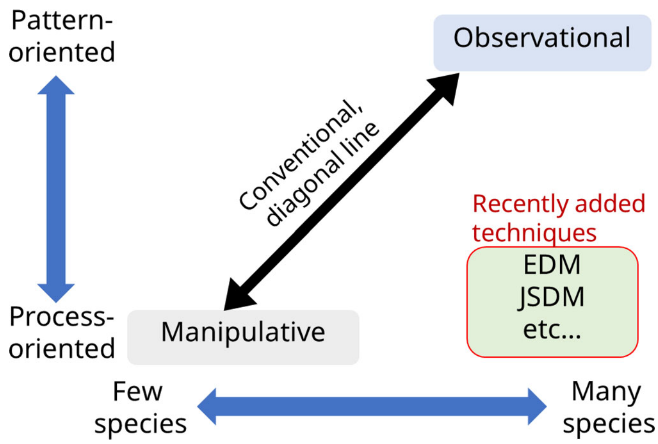

FIGURE 2 Expansion of the choices of what we can do in community ecology. There are two axes for categorizing studies in community ecology: one is a pattern- or process-oriented contrast, and the other is the number of species in the subject community. For the majority of conventional studies, process-oriented studies have been restricted to manipulating a few species because manipulating many species is often infeasible. Therefore, until recently, ecologists have had no choice but to apply manipulative methods to perform process-oriented studies. Recently, however, newly developed techniques such as joint species distribution modeling (JSDM) and empirical dynamic modeling (EDM) can infer ecological processes such as biotic interactions by analyzing observational data from systems containing a large number of species, deviation from the conventional diagonal line (i.e., pattern-oriented studies with many species and process-oriented ones with many species).

oriented studies with many species and process-oriented studies with few species), but new techniques such as JSDM and EDM may enable process-oriented studies with many species, deviating from the conventional diagonal. This expansion of the possibilities within the realm of "methods" may loosen the boundary between pattern-oriented and process-oriented studies.

4 | SIGNIFICANCE

In this section, we discuss the relationship between scientific significance and the perception of pattern- and process-oriented studies. The significance perceived by individual researchers has affected the direction of ecological research historically, being influenced by various factors. We emphasize that the evaluation of scientific significance is not necessarily objective or absolute.

The scientific significance of a study never determines whether the study is pattern-oriented or process-oriented. In contrast, whether the study is process- or pattern-oriented may influence the evaluation of significance. One of the cliches in criticizing pattern-oriented study is "This study only shows a pattern." This implies that causal relationships are important to receive a positive evaluation. Criticism of process-oriented studies may go like "this study only reports a specific case," or "the effect size is small." These imply that generality is also important. That is, pattern-oriented studies are often considered more generalizable than process-oriented ones due to their broader descriptive coverage across systems or contexts. On the other hand, process-oriented studies are considered more effective at identifying causal relationships than pattern-oriented ones.

"Generality" appears to be an especially important criterion for evaluating the scientific significance of a study. In fact, approximately 40% of the top ecology journals demand that submissions are relevant for other species, ecosystems, biomes, or time periods (Spake et al., 2022). Historically, the pessimism that most ecological studies are not significant enough has not been rare, because there are too many specificities and contingencies. For example, Rosenzweig (1991), published in June 1991, highlighted this sentiment, stating, "*Yet some ecologists have formed a party of gloom, dwelling on our false starts and despairing that ecology will never achieve general principles*." In September of the same year, Lawton referred to a criticism from a physicist, suggesting that ecologists never actually appear to solve crucial problems (Lawton, 1991). Such views may be partly derived from critics of the robustness of biological laws from philosophers of science (e.g., Beatty, 1995). However, recent pessimistic views on generality in ecology, especially in process-oriented approaches, would be largely influenced by Lawton's famous opinion paper, "*Are There General Laws in Ecology?*" (Lawton, 1999). This paper sparked a heated debate about the significance of ecology as a science, and about the presence of general laws in ecology (Berryman, 2003; Colyvan & Ginzburg, 2003; Murray, 2000; O'Hara, 2005; Simberloff, 2004; Turchin, 2002). Today, most textbooks on community ecology cite Lawton's paper (Leibold & Chase, 2017; Mittelbach & Mcgill, 2019a, 2019b; Vellend, 2016).

Lawton (1999) argued that community ecology is "*the worst of all worlds*" because ecological processes that structure local communities are too complicated and contingent, and thus cannot bring laws that work in every system, like those of physics. In contrast, he suggested macroecology, which focuses on ecological phenomena at a broad scale and today is regarded as a part of community ecology, is superior because it can discover "*general patterns*" without being bothered by trivial events at the local scale (Lawton, 1999). However, Lawton (1999) also clearly stated that these discovered patterns in macroecology are not general laws, as he considered laws to be a kind of principle that creates patterns we observe. As a result, the tone that emphasizes the superiority of macroecology gradually stalls in the paper, and Lawton just concludes that contingencies in macroscales are manageable compared to intermediate scales (i.e., scales of traditional community ecology), even if it is not a panacea to find universal laws.

The shortcomings of Lawton's claims have been pointed out in many subsequent papers. Firstly, the argument stemmed from a biased understanding of scientific laws; although his argument is based on the robustness of the laws in physics, situational dependence exists in physical laws as well, and, in the first place, a causal understanding of laws is not essential in science (Colyvan & Ginzburg, 2003; Pickett et al., 2007). Additionally, the assertion that predictability is a requirement for general laws is challenged from a different perspective on the purpose of science, which regards science as the process of linking concepts and phenomena to foster understanding by causal explanation, generalization, and testing (Pickett et al., 2007). Furthermore, there are arguments that the presence or absence of a universal law is irrelevant to the significance of science (O'Hara, 2005; Simberloff, 2004), as it is sufficient for individual events and theories to function cumulatively rather than having a single unified law. These cast doubt on the supremacy of physics within science, and most reached a reasonable conclusion that ecology, including community ecology, is sufficiently significant as a science.

Given the many counterarguments to Lawton, it seems difficult to agree on the assertion that pattern-oriented

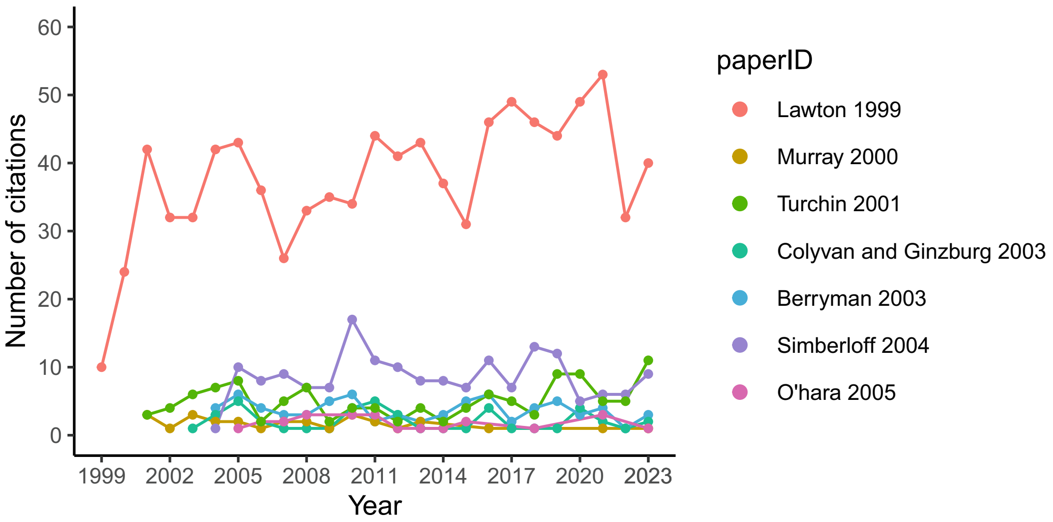

FIGURE 3 The temporal changes in the number of citations of Lawton, 1999 and the representative articles against this paper from 1999 to 2023. Citation numbers are based on the analytical results of the "final publication year" in Web of Science.

studies are more "significant" than process-oriented ones. Recent studies also urge us to consider what generality is deeply (Spake et al., 2022; Travassos-Britto et al., 2021) and what causes contingency (Catford et al., 2022). Nevertheless, even now, Lawton (1999) is much more cited than the subsequent counterargument papers (Figure 3), and process-based approaches tend to be criticized as messy. The reason for this may be because the questions raised by Lawton (1999) are crucial. However, it may very well be that extreme statements leave long-lasting impressions. As Arnqvist (2013) notes, the works that discuss their findings in a balanced manner, referring to many related studies, can be underestimated in terms of novelty. In addition to this, the person who makes these statements should have a strong influence on the evaluation. There is growing awareness of how psychological bias influences our research evaluation, even in ecology; for example, opinion articles and special features on this theme were published in *Nature Ecology and Evolution* (Baum & Martin, 2018) and *The American Naturalist* (Kamath et al., 2022). In addition, uncontrollable trends also influence our research evaluation. A culturomics analysis over 80 years in ecology and conservation biology showed the boom-and-bust of many research themes (Anderson et al., 2021). Such changes in research trends can occur rapidly, even within 10 years. We analyzed the words included in the abstracts of the annual meeting of the Ecological Society of Japan for 11 years (Figure 4). It shows that the words utilized changed rapidly along PC1. For example, "predation," "food," and "structure" became less popular, while "grasslands," "evolution," and "diversity" became more popular. Interestingly, the PC2 score of the 59th meeting (2012) is an outlier, suggesting that the Great East Japan Earthquake in 2011 strongly influenced research themes. It is important to recognize that our evaluation of scientific significance can be influenced not only by truly universal values but also by fluctuating and unpredictable social needs and atmosphere.

5 | DISCUSSION

We have discussed how interests, methods, and significance influence the perception and evaluation of research approaches and consequently the development of (community) ecology. These factors are not mutually exclusive but rather interdependent. Our exploration has illuminated how interests and methods influence what is considered a process or a pattern, revealing the inherent ambiguity of the distinction. Ultimately, process- and pattern-oriented approaches examine the same systems from different perspectives, complementing each other. The perception of research approach seems to be a factor that sparked discussion on the scientific significance of research. It is easy to criticize individual studies —the lack of generality in process-oriented studies and the lack of causal relationships in pattern-oriented studies— but those criticisms seem to be based on a biased understanding of scientific significance. Furthermore, the significance of research themes is not static but fluctuates over time. Some areas gain prominence due to urgent social needs (e.g., COVID-19 or climate change), while others may be influenced by psychological biases or other less rational factors. Faced with the arbitrary nature of the dichotomous classification of pattern- and

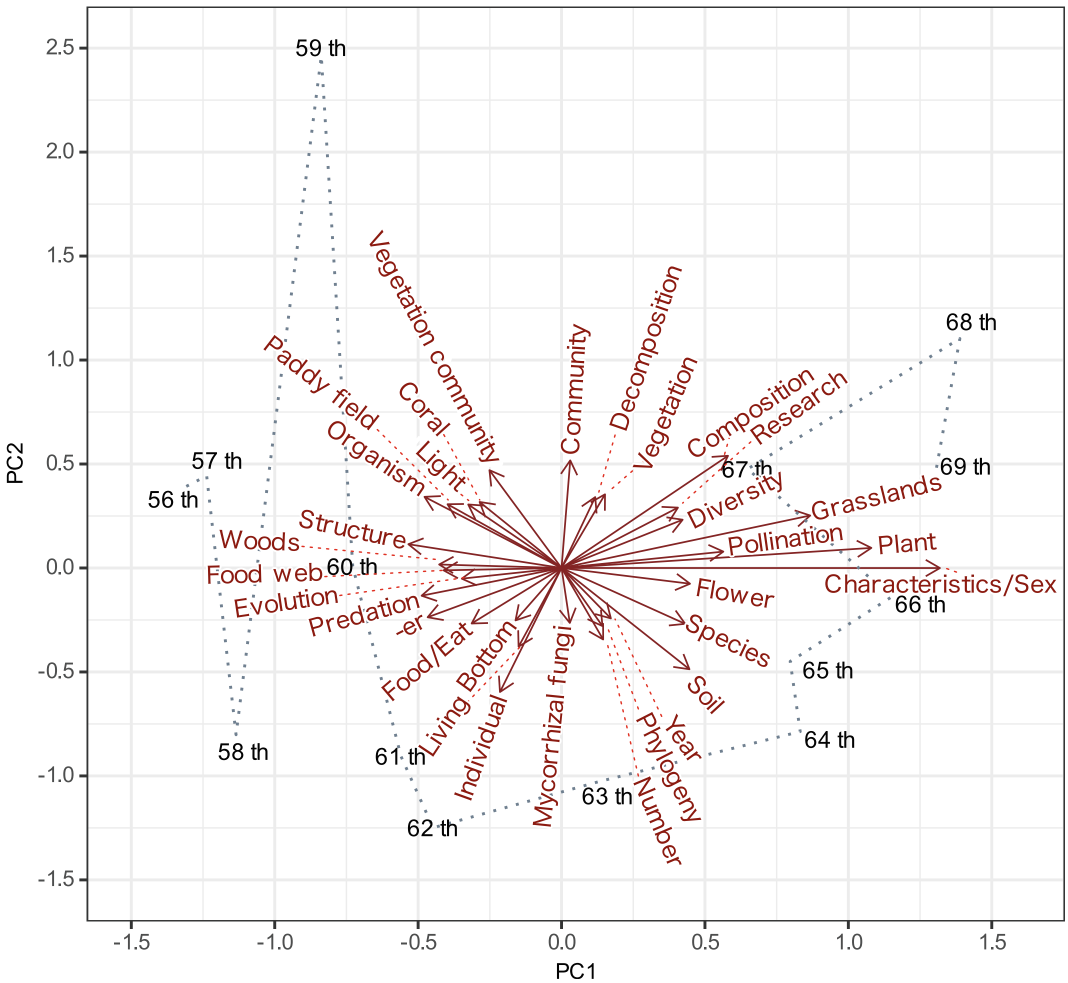

FIGURE 4 Trajectory of research trends in the annual meeting of the Ecological Society of Japan. The words were extracted from Japanese abstracts of symposia, organized sessions, and workshops from the 56th (2009) to the 68th (2021) annual meeting of the Ecological Society of Japan. Only noun morphemes were used for principal component analysis (PCA) after morphological analysis in RMeCab (e.g., prepositions, prefixes, or suffixes were excluded). The gray dotted lines connect the position of the abstracts of each annual meeting on the PCA plot. The arrows represent factor loadings. Their directions indicate the contributions of variables to the principal components (PCs), while their lengths reflect the magnitude of the variables' contributions to the explained variance of the PCs. The top 10 words contributing to PC1 and PC2, shown in this figure, were translated into English manually (see Supporting Information Text SI and Table S1). Note that there is no one-to-one correspondence between English and Japanese (e.g., a single Japanese word can mean sex or characteristics). See Supporting Information for the PCA in Japanese (Figure S1) and the translation dictionary (Table S1).

process-oriented studies and the instability of research significance, one might wonder how to choose research topics effectively. Here, we propose two important sights in this regard.

First, it is futile to argue that one approach is superior to the other. The ambiguity in the process-pattern distinction means such debates are not productive. In Section 4, we emphasized that generality, often viewed as an indicator of research significance, is more nuanced than it appears, through the historical discussion about general laws. We consider that generality exists on a spectrum: at one extreme, broadly applicable theories (e.g., Modern Coexistence Theory) are highly abstract and empirically little falsifiable; On the other end, highly specific studies (e.g., conservation studies of particular taxa) address narrow, context-dependent issues. Most ecological work falls somewhere between these extremes. Such studies are tests of general theories in specific contexts, or they deepen the understanding of specific taxa (hence implications in more and less general contexts). These intermediate studies, while not universally applicable, provide valuable insights. Thus, rather than seeking universal generality, it is crucial to determine the appropriate level of generality for each study and appreciate the "just good enough" general laws (i.e., intermediate abstractness).

Second, we advocate a scientific culture that embraces diverse approaches. As discussed in Section 2, ecology inherently deals with diversity. Given the growing need for research that integrates big data to address global environmental challenges, we recognize the importance of such large-scale studies. Fortunately, the technical development of methods enables the analysis of massive data, with the possibility to infer causal processes without manipulative experiments (see Section 3). However, there is a caveat, too; focusing solely on broad goals might discourage researchers from working on specific taxa or systems. Fostering diverse research interests, approaches, and ecological questions is essential (Enquist et al., 2024) for deepening our understanding of ecological communities.

While criticism is indeed a necessary evil to drive the development of science, critics of a different research approach without appropriate rationales often hamper progress (Pickett et al., 2007). By embracing diversity in research topics and avoiding overemphasis on trends of apparent "significance," we can ensure the improved robustness and advancement of community ecology.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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