DOI: 10.1017/psa.2025.10189
This is a manuscript accepted for publication in *Philosophy of Science*.
This version may be subject to change during the production process.

Interactive causes and causal selection

Robert Frühstückl

Abstract

This paper introduces a novel framework for causal selection based on an analysis of different ways in which causes interact. Some causal interactions function to enable the operation of a mechanism, while others modify the behavior or outcome of that mechanism, allowing fine-grained descriptions of causal relationships. Distinguishing between enabling and modifying makes it possible to separate distinct causal functions that are wrongly grouped into an undifferentiated category of background conditions. Drawing on case studies from ecology, the framework offers new insights into why some factors should be cited in explanations while others remain implicit, despite being causally indispensable.

1 Introduction

The problem of causal selection is about determining which among many contributing factors should be considered as *the* cause of an effect. The standard example is distinguishing the causal role of oxygen and the striking of a match for the outbreak of a fire (Waters 2007). I suspect that for many people, the intuitive answer would be that the striking of the match was the actual cause of the fire outbreak, whereas the presence of oxygen, albeit a background condition, was not. However, giving principled reasons for this intuition has proven to be surprisingly difficult.

For a long time, the standard view of causal selection has been that selecting causes as explanatory is essentially groundless and mainly driven by pragmatic and interest-relative considerations (Mill 1843; Lewis 1973). However, philosophical discussion has questioned this standard view from various perspectives. Recently, Ross (2018) has pushed this line of reasoning further by offering a more objective framework for causal selection. She analyzes how biologists identify multiple interacting causes within causal pathways. Focusing on examples like glycolysis (the gradual breakdown of monosaccharides in living organisms), Ross shows that after identifying factors that help explain the presence or absence of a target outcome, biological explanations often involve interacting causes, such as enzymes binding to specific substrates, which jointly exert causal control over the outcome of the process. These causal interactions are selected because their combined effect is necessary to produce specific results at biologically relevant time scales and with high specificity.

While her account is making much progress in pointing to the crucial role of causal interactions in multicausal systems, some features prevent it from being more widely applicable. The first is that the pathway concept is a pivotal component of her analysis. What allows for the identification of factors that exert causal control is the existence of a causal pathway, in the sense of a regular sequence of causal steps leading to a definite outcome (Ross 2018, 2021). However, many cases of multi-causality in the life sciences are not like that. Processes that determine the occurrence or non-occurrence of species in specific environments, for instance, are dependent on a multiplicity of causes and arguably involve interactions between distinct causal factors with varying degrees of causal control. However, it does not make sense to think of these processes in terms of causal pathways that lead from definite starting conditions to a definite outcome condition. Instead of a stable causal pathway, we are often confronted with a causal context that is much less stable and much messier. The second problem is that Ross does not distinguish between different forms of causal interaction. Causal factors in the pathway depend on each other to exert their characteristic causal control over the end product. However, as I will argue at length in the following, this dependency is just one way in which causal interactions manifest.

In this paper, I will present an account of causal selection that can address both these shortcomings. The framework I am suggesting is grounded in a novel analysis of the distinction between causes and conditions that differs from both necessity-sufficiency considerations (Mackie 1965) and counterfactual analyses (Broadbent 2008). Fundamental to this analysis is the claim that many approaches to distinguishing between causes and conditions have overlooked the significance of causal

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

interactions. In contrast, I argue that causal interactions are not only relevant to causal selection but also a functionally heterogeneous category. Some causal interactions function to enable the operation of a mechanism–establishing necessary but non-explanatorily salient conditions–while others modify the behavior or outcome of that mechanism, allowing fine-grained descriptions of causal relationships. Based on this, I differentiate between two fundamentally different types of interactive causes: *enabling* and *modifying* conditions.

A consequence of this distinction is that the standard way of framing the problem of selection as being about distinguishing *the* narrow foreground cause from the causal background is misleading because it tends to collapse distinct causal functions into a single undifferentiated category. This oversimplification hinders accurate analysis of multicausal systems, such as those commonly found in ecology and other fields marked by high complexity and context dependence, such as the social sciences and economics. The paper shows that causal analysis should instead be based on a three-part distinction between causes, causal context, and background conditions, grounded in the analysis of causal interactions that I am arguing for. In this way, it also becomes clear that context sensitivity of causes, rather than being a nuisance, can serve as a diagnostic tool for disentangling the structure of complex causal systems.

I will begin in Section 2 by explaining some background on causal interactions and their role for causal selection before introducing the distinction between enabling and modifying conditions in Section 3. Sections 4 and 5 apply this distinction to a case study from biological invasions. Section 6 considers potential objections against my account, whereas Section 7 discusses its consequences for related notions of causal analysis, like specificity and stability. Finally, Section 8 summarizes the most important points and gives an outlook on the relevance of my approach for other scientific fields.

2 Causal interactions and selecting causes

Causal interactions are relations where the causal effect of a factor X on another factor Y depends on the value of a third factor Z. As such, causal interactions were identified early in the philosophical literature on probabilistic causation as a

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

distinct and particularly challenging problem – alongside spurious associations – for characterizing causal relations in terms of probabilistic dependencies (Cartwright 1979; Eells 1986).

In statistical or causal models, interactions are typically treated by including an interaction term in the equation, e.g., $Y = X + Z + XZ$ (Duncan and Kefford 2021; Spake et al. 2023). While the interaction term (XZ) looks the same in both modeling approaches, conceptually, they encapsulate different understandings of the relationship between the individual factors X and Z. In statistical models, interactions are generally symmetric as they do not allow for any claim as to whether X depends on Z or the other way around. In the causal interpretation, however, interactions are not necessarily symmetric (despite their mathematical form) (Keele and Stevenson 2021). Consider the following example, where the effect of a drug (D) on recovery depends on the presence of a specific genetic variant (G). In patients who carry the variant, D is effective for recovery; However, in people who lack G, it is not. In this case, the interaction is asymmetrical because the impact of the drug is contingent on the genetic variant but not vice versa. The presence of the genetic variant affects how the drug works, but the drug does not affect the genetic variant itself.[1]

Arguments of this kind have led Cartwright (1989) to argue that interactions have to be interpreted in terms of causal capacities:

> One does not just say the acid and the base interact because they behave differently together from the way they behave separately; rather, we understand already a good deal about how the separate capacities work and why they should interfere with each other in just the way they do (165).

I agree with Cartwright on this point. Causal interactions reflect distinct functional relationships among causal factors in a system, and as such, they are, in principle, open to empirical investigation and explanation. Of course, this does not mean that we must always have an explanation for a causal interaction to use statistical or causal models to account for it.

1. An example for such a case would be Mega et al. (2009)

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

However, while the language of capacities or causal powers captures the idea that causes can be interactive, it offers limited resources for distinguishing the specific and varying roles such causal factors play within a system. For this reason, I adopt a mechanistic interpretation of causal interactions in this paper. A mechanistic approach, following the minimal conception of Glennan (2017) and Glennan, Illari, and Weber (2022), focuses on the organization and interactions of components within complex causal systems, providing a more fruitful framework for understanding the diverse roles that causal factors play in producing complex phenomena. According to this understanding, causal interactions, as they manifest in probability distributions, are the result of underlying mechanisms that generate them. For example, in the case of the genetic variant just discussed, the gene variant G might code for a protein, be it a receptor or enzyme, that is necessary for the drug D to exert its effect. The drug happens to bind to or interact with that protein, which triggers a cascade of biochemical events leading eventually to recovery. A central claim of this paper is that causal interactions, understood in this sense, are crucial to the problem of causal selection.

To illustrate, consider the following well-known toy example: the occurrence of a spark and the role of oxygen in causing a fire outbreak. Traditional views on causal selection, such as those by Mill (1843) and Lewis (1973), would have you believe that there is no objective ground on which to distinguish between cause and background condition in such cases. The spark is just as much a cause of the fire as the presence of oxygen. Several philosophers have challenged this assessment.

For example, building on famous arguments by Hart and Honoré (1985), Peter Menzies (2004, 2009) argues that a distinction between causes and background conditions can be drawn contextually based on a distinction between default and deviant values of certain variables. On this line of reasoning, the actual cause of an effect is the causal factor that deviates in some way from the "normal" course of events, regardless of whether this normality is defined on the basis of statistical averages or ethical and legal standards.[2] Whereas in statistically normal circumstances, the occurrence of a spark would be identified as the reason for the house burning down, in a context where the burnt-down building was a laboratory

2. Hitchcock and Knobe (2009) distinguish three senses of normativity that are relevant to selection: Statistical, moral, and norms of proper function.

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

where meticulous precautions were taken to ensure the absence of oxygen, the fire would probably be attributed to the unusual presence of oxygen as the primary cause. According to such views, selection is based on the contrast class, which in turn depends on the context of the situation (Reiss 2015, Ch. 6).

There are other objections to the view that causal selection is groundless that are not motivated by considerations of normativity but by ontological distinctions between causes. Kenneth Waters (2007), for instance, argues against causal parity based on distinguishing "actual" from "potential difference makers" and identifying the former in an actual population. If we slightly modify our toy example and treat the action of striking a match as a cause, the individual matches in a matchbox would be an actual population, and the difference between those matches that get struck and those that do not would be an actual difference in Waters' sense. In contrast, oxygen would be present for all matches and is, therefore, not an actual difference maker. As Waters emphasizes, this is an argument based on ontological distinctions among causes. Causes *are* actual or potential difference makers. He claims: "My point is that once the effect is fully specified as an actual difference in a real population, the issue of which causes are the actual difference makers is an ontological one" (570).

Although I agree with both Waters' and Menzies' conclusions, I do not agree with how they arrived at them. The contrastive account by Menzies gives us an adequate picture of how causal selection can be approached in everyday contexts or in cases that afford a clear normative or statistical notion of normality. However, the problem with this approach is that it does not work very well in those scientific contexts, where a distinction between default and deviant values of variables or a normative concept of function cannot be presupposed. This is especially the case for ecology, where it is often difficult to determine what a "normal" functioning ecosystem is or what the baseline condition for normal functioning should be (Odenbaugh 2019; Lean 2021; Morrow 2023).

Likewise, Water's distinction between actual and potential difference makers is undoubtedly an important step towards investigating the ontological nature of the causes that are involved in producing an effect. However, there is still more to be said about the ontological nature of individual causes beyond the distinction between potential and actual difference-making, specifically when multiple causes

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

of an effect are interactive. Specifically when multiple causes of an effect are interactive.

Even relatively simple cases, such as the fire outbreak, involve causal interactions between relevant causal factors. Woodward's (2003) discussion of combustion makes it clear that oxygen (O) and the spark (S) do not just linearly contribute to the fire (F). One without the other is not sufficient to produce the effect at all (Fig. 1). As he puts it, "there is an 'interaction' between S and O with respect to F. When oxygen is present, changing the value of S from 0 to 1 will lead to the occurrence of a fire, but when oxygen is absent, a similar change in S will lead to no change in F" (Woodward 2003, 44). Oxygen interacts with the spark, implying that it alters the causal effect of the spark on the occurrence of a fire.

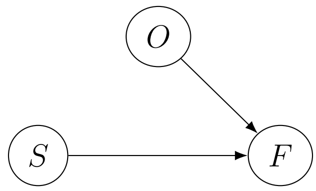

Figure 1: Interaction of oxygen (O) and the occurrence of a spark (S) as causal factors for the outbreak of a fire (F) (Woodward 2003, 45)

Many approaches to the causal selection problem implicitly assume that causes operate in a linearly additive manner. This framing casts the problem as one of distinguishing a narrow foreground cause from a relatively homogeneous background (Franklin-Hall 2015). However, such a division oversimplifies the causal landscape. When causes interact, they introduce complex forms of context dependence – interactions that can fundamentally alter the presence but also the sign and magnitude of causal relationships. These differences are obscured when all non-selected factors are lumped together under the vague label of "background conditions." In particular, the following section argues that two functional forms of causal interactions need to be distinguished. The first is enabling- while the second is modifying conditions. I will discuss both of them in turn and then show how they can be used in analyses of causal selection.

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

3 Unpacking causal interactions

3.1 Enabling conditions

Let us return to our toy example. On closer inspection, there is an asymmetry between the causal role of oxygen and the occurrence of the spark that is not obvious by looking at the causal structure (Fig. 1) alone. We have already established that oxygen must be present for the spark to have a causal role in producing a fire. Without oxygen, the fire will not start, regardless of any other factors. By contrast, once oxygen is present, the fire does not require a spark to be ignited; it can, in principle, also start when sufficient heat is present, allowing for autoignition to occur.

Consequently, although oxygen and the spark will both be treated as the same type of variable in a causal model, they play very different roles in the natural systems that these models represent. This asymmetry suggests that while the occurrence of a spark is a cause of the fire, the presence of oxygen is a mere *enabling condition*.

Distinguishing between causes and enabling conditions is common in causal analysis. According to Thomson's (2003) definition, a factor x is enabling if it is "physically necessary" for y without it having to be the case that x caused y. In particular, Thomson argues that we should resist the inference from "x was physically necessary for y" to "x caused y" (Thomson 2003, 96–97). This reveals a deeper problem with difference-making accounts of causation. As Thomson puts it:

> It has often been said that an event x caused an event y if the occurrence of x 'made a difference' to whether y would occur. If that were right, then any event x whose occurrence was necessary for the occurrence of y caused y. But it is patently not right: an event x caused an event y only if x made y occur (97).

Difference-making, whether considered a distinct causal concept (Godfrey-Smith 2009) or merely as a type of evidence for a causal relation (Russo and Williamson 2007), does not allow for drawing fine-grained distinctions between the different roles that causal factors can play. In the combustion example, we can readily see

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

that on the level of difference-making alone, there is symmetry between the causal factors. For some value of S, intervening to change the value of O will change F, and for some value of O, intervening to change the value of S will change F (Woodward 2003, 44). Nevertheless, the occurrence of a spark and the presence of oxygen are not symmetric because they are ontologically distinct causal factors that play different roles in the mechanism that leads to the outbreak of a fire.

However, I disagree with Thomson that this difference is best thought of in terms of x being a necessary condition for y. Instead, I want to pursue a different line of reasoning, inspired by Aronson (1971), which holds that an enabling condition is one that "enables the cause to act" (425). In this understanding, enabling is a relationship between different causes of an effect rather than a relationship between a single cause and the effect. An enabling factor enables a causal factor to contribute to an effect. This does not imply that the enabling factor is also a direct cause of the effect (although it can be) nor that it is a necessary condition for the effect.

Based on these considerations, I suggest the following definition of an enabling factor:

> **Enab:** Let X, Y, and Z be (many-valued or binary) variables. Assume that X is a direct cause of Y, while Z can but does not have to be a direct cause of Y and that X and Z are interacting. If X is a positive causal factor for Y only for some values ϑ_i of Z, but is no causal factor for Y for values ϑ_j of Z, where $i \neq j$, then Z is an enabling factor for the $X-Y$-relationship, or short an *enabler*. The interaction between X and Z is then an *enabling interaction*.

Several aspects of this definition require further elaboration. First, I follow Woodward (2003) in describing causal relationships as relations between values of variables rather than as a relation between events. In this view, variables represent the properties of entities, and the central claim of **Enab** is accordingly that entities with different properties give rise to factors with different causal roles.

Second, for Z to be an enabling factor, Z does not need to be a direct cause of Y as well. In the combustion case, it just happens to be the case that both factors are direct causes, but this is not a precondition for an enabling relation. To see

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

that, consider the example where the effect of a drug on recovery is dependent on the presence of a genetic variant from section 2 again. In people with the genetic variant, the drug works; in people without it, it does not. In this case, taking the drug is a direct cause of recovery. However, this effect is enabled by the genetic variant, which is an interactive cause in this system without being a direct cause of recovery itself.

Third, the important point about **Enab** is that X changes its status as a causal factor for Y depending on the value that Z takes. This can be most easily seen in the case where X, Y, and Z are interpreted as binary variables. However, neither of the variables has to be binary for an enabling condition, although the difference is merely nominal. If an enabling factor is many-valued, it will likely be enabling for some subset of its range but disabling for the complement of its range. In other words, there will be a threshold level, which, in effect, boils down to the same thing as being binary. However, we will later in this paper encounter cases where the difference between binary and many-valued variables matters more deeply. Before that, however, I want to define a second category of interactive factors that markedly differs from the effect of enabling factors.

3.2 Modifying conditions

Consider the following case. Let us assume that the effect of a fertilizer on plant growth is dependent on soil pH. If the soil is slightly acidic, the fertilizer has a significant effect on plant growth. However, when the soil is either strongly acidic or strongly alkaline, fertilizer is not merely ineffective; it actually becomes harmful to the plant, say by creating chemical imbalances or affecting soil microbes[3]. In this case, soil pH cannot reasonably be interpreted as an enabling factor. Depending on the pH, fertilizer does not merely become ineffective for plant growth (as an enabling factor would); it becomes detrimental. This suggests that soil pH plays a more nuanced causal role. Rather than merely enabling the relationship, it modifies its form, allowing for a more fine-grained characterization of the causal relationship.

Modifying factors allow us to make statements about how a causal relationship

3. An example for such a case would be Xia et al. (2024)

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

develops under changing conditions, which are defined by the values of a modifying factor. Modifying a causal relationship by changing the magnitude or even the sign of the effect is thus very different from turning a relationship entirely on or off.

We can thus define modifiers as follows:

> **Modif:** Let X and Y be (binary or many-valued variables), and Z be a many-valued variable. Assume that X is a direct cause of Y, while Z can but does not have to be a direct cause of Y, and that X and Z are interacting. If (i) X is a positive/negative causal factor for Y for some values ϑ_i of Z but is a negative/positive causal factor for Y for values ϑ_j of Z where $i \neq j$; or (ii) X is a small/large causal factor for Y for some values ϑ_i of Z, but is a large/small causal factor for Y for values ϑ_j of Z where $i \neq j$, then Z is a modifying factor for the $X - Y$-relationship, or short a *modifier*. The interaction between X and Z is then a *modifying interaction*.

The distinction between enabling and modifying factors may appear subtle. However, they can be clearly distinguished by considering their respective contrast classes. In terms of probability distributions of variables, the effect of an enabling factor is:

$$P(Y|X,Z) > P(Y) \text{ and } P(Y|X,\neg Z) = P(Y) \tag{1}$$

In contrast, the effect of a modifying factor is:

$$P(Y|X,Z) > P(Y) \text{ and } P(Y|X,\neg Z) < P(Y) \tag{2}$$

If the modifying factor is a binary variable, the conditions refer to the presence or absence of the factor. However, if it is many-valued, the modifying factor defines a gradient along which the phenomenon may manifest differently, but where the causal relation persists.

In terms of mechanistic approaches to causal interactions, the distinction lies between factors that enable the operation of a mechanism and factors that determine the outcome of the mechanism. The absence of enabling factors implies that the mechanism cannot operate at all. In contrast, the absence of a modifier implies that the mechanism may still operate but produces a different manifestation of the phenomenon.

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

How does this bear on causal selection? The answer is that it does so by showing that background conditions do not form a homogeneous category but require a more fine-grained analysis of interacting causal factors to differentiate between indispensable but explanatorily non-salient factors and modifying factors that help explain how a phenomenon is produced. In the next section, I will discuss this using an example from invasion biology.

4 The causes of invasion success

Invasive species are a growing concern for both biologists and policymakers due to their often severe ecological impact and the substantial economic costs they can entail (Simberloff 2005; Elliott-Graves 2016; Turbelin et al. 2023). The problem of causal selection in ecological invasions arises because multiple factors contribute to invasion success (i.e., the establishment of a self-sustaining population in a novel range); yet, ecologists want to be able to identify which cause or causes are most relevant for explaining invasions.

The following example focuses specifically on the invasion of giant bamboo (*Phyllostachys bambusoides*) in Japan.[4] Originally native to China, bamboo was deliberately introduced to Japan for various reasons. While posing no particular threat when managed, abandoned bamboo forests become a problem because "bamboo plants extend their rhizomes laterally, driving bamboo forest expansion into adjacent secondary forests" (Spake et al. 2021, 1994). This spread can not only have various detrimental effects on native biodiversity (Suzaki and Nakatsubo 2001) but also likely continue northwards under even moderate climate change scenarios (Takano et al. 2017). When attempting to identify the reasons for the transition from establishment to spread stage in the invasion pathway of *P. bambusoides*, a complex causal structure emerges. According to Spake et al. (2021), several types of causal factors are involved. These are (i) factors rooted in the physiology of *P. bambusoides*, (ii) interspecific interaction[5] of bamboo with native

4. I have discussed this case from a different perspective in a forthcoming publication (Frühstückl 2025), where I use it as an example for a conceptual analysis of ecological context and its relevance for transferability and extrapolation. Here, I refer to the same case to support my argument concerning causal selection.

5. It should be pointed out that the term "interaction" in the context of species interactions is

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

tree species, and (iii) various climatic and other environmental factors. Let us begin with the interspecific interactions.

In theory, interspecific interactions between invasive giant bamboo and native tree species can be either positive, negative, or neutral. If bamboo and native species compete for resources, and bamboo consistently gets out-competed, the effect would be negative. On the other hand (ignoring the possibility of neutral interactions for the moment), native tree species could also have mutualistic or facilitative effects on bamboo. That is, the native tree species could provide essential resources to bamboo or alter the environment in such a way that it facilitates bamboo occupancy. Needless to say, in this case, the interspecific interaction would be a positive contributing factor to bamboo occupancy.

Climatic and other environmental factors also have a causal influence on bamboo occupancy. To put it simply, depending on its physiological properties and requirements, *P. bambusoides* presumably has (i) an optimum of environmental conditions (temperature, precipitation, soil properties, etc.) under which it flourishes the most, (ii) extreme conditions that it cannot tolerate (at least not for an extended period of time) and (iii) a mediate zone of conditions that are not optimal but that it can tolerate (also for more extended periods of time).

In the case at hand, Spake et al. reasoned that competition between giant bamboo and native tree species is a causal factor in bamboo occupancy because the shade cast by native tree cover reduces the amount of light available for photosynthesis in the understory vegetation. In this sense, interspecific interaction would be a negative causal factor for bamboo occupancy. On the other hand, due to its unique physiological makeup, organisms of *P. bambusoides* exhibit light sensitivity, indicating that there is an upper limit to the light intensity they can utilize for photosynthesis. Because of this, environments with relatively high light intensity that would otherwise be unsuitable for giant bamboo can be made tolerable by the shade that is cast by native tree species. In this case, the interspecific interaction would be a facilitative factor.

Therefore, while solar radiation influences bamboo occupancy, its effect is me-

not to be confused with statistical or causal interactions. Interspecific interactions are encounters of at least two organisms of different species in the environment that can have different effects on the organism.

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

diated by the shading provided by native tree species. However, this is not the only special feature of the causal structure in this case. In addition to the mediation of the effect of solar radiation, the photoinhibition of *P. bambusoides* also turns out to be strongly temperature-dependent. As Spake et al. explain, "physiological studies of multiple *Phyllostachys* species under controlled settings have demonstrated that photoinhibition (light-induced decline of photosynthesis) occurs under moderate light intensities at low temperatures but can be ameliorated at warmer temperatures or under shade" (Spake et al. 2021, 1994). For this reason, they conclude that there is a three-way interaction between solar radiation, temperature, and interspecific interaction with native tree species that is an essential part of the causal structure that determines bamboo occupancy:

> At relatively low levels of solar radiation, canopy cover had little effect on the thermal niche of bamboo in secondary forests, shown by the similarity of bamboo probability distributions with different levels of canopy cover [...]. In regions with high light intensity, however, canopy cover became an important facilitator of bamboo occupancy, with bamboo more able to establish in secondary forests at lower temperatures under dense canopies, than in forests with more open canopies [...]. However, at higher temperatures, dense canopies become more limiting than open canopies, with bamboo occupancy tending towards being more likely in open (60% cover) than closed (100%) canopies beyond 15°C [...]. (1998)

This is an example, then, where multiple causal factors influence the variable of interest, but they do so not linearly but interactively. How do we approach this from the perspective of causal selection?

5 Selecting causes and contexts

The traditional approach to considering this case is to treat temperature and solar radiation as background conditions for the causal effect of interspecific interaction on bamboo occupancy. In this approach, interspecific interactions are the primary or ecologically interesting cause. In contrast, solar radiation and temperature are

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

backgrounded as conditions or context, describing environmental factors that also influence the relationship of interest but are not treated as explanatorily salient.

This line of reasoning also aligns with the traditional view of the environment concept, which was particularly prevalent in the latter half of the 20th century, as an external backdrop to the biological processes of primary interest (Baedke and Buklijas 2023). From an ecological perspective, the focus is on how interactions between different species influence bamboo occupancy, while environmental conditions represent a broad range of background factors that are essential but external and, therefore, not the primary topic.

This is the strategy that presumably also underlies reports of the *context dependence* of interspecific interactions in this and similar cases. Context dependence is a common term used in the ecological literature to describe how relationships vary with causally interactive factors that are unevenly distributed (present in one context but absent in another) or have different effects depending on their specific values in different contexts (Catford et al. 2022; Rodgers et al. 2022). Context dependence is not uncommon in ecology, where it is typically encountered through observing or experimentally ascertaining a particular relationship and then finding that it varies somewhat unexpectedly when observed under different environmental conditions (Chamberlain, Bronstein, and Rudgers 2014). Indeed, explaining "how environmental context determines the nature of biotic interactions" (Spake et al. 2021, 1993) was one of the main objectives of the study I have just discussed. This framing of the research question could be taken to suggest that interspecific interaction is the selected narrow cause, and environmental factors are relegated to the background.

However, this is not what Spake et al. described. What they are claiming is not that the outcome of interspecific interaction depends on background conditions but instead that the environmental context influences it. It is an unspoken presupposition of much of the literature on causal selection that this is the same thing. Following the traditional view would lead to equating the context dependence of interspecific interaction with its dependence on background conditions because the traditional view tends to treat *background conditions* as a lumping category in which everything that is not the narrow cause itself is supposed to fall. However, analyzing the causal structure of the giant bamboo invasion by using the

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

distinction between enabling and modifying factors reveals that there are apparent ontological differences between how the different factors operate.

In the giant bamboo invasion, we saw that temperature and solar radiation had an effect on bamboo occupancy by influencing the effect of interspecific interaction with native tree species (see Fig. 2). *Prima facie*, this seems to suggest, in analogy

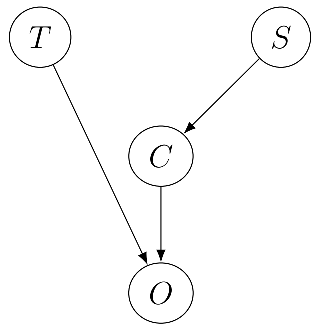

Figure 2: Author's own reconstruction of the causal structure of bamboo invasion building on Spake et al. (2021). Temperature (T), interspecific competition (C), and solar radiation (S) are causal factors for bamboo occupancy (O).

with the combustion case, that temperature and solar radiation are background causes for the effect of interspecific interaction for bamboo occupancy just as the presence of oxygen is for the spark's effect on combustion.

However, in the bamboo example, temperature does not act as an enabling factor in the sense in which I have defined the term. First of all, temperature is a factor that cannot, strictly speaking, be absent since it is a property describing the kinetic energy among particles in a system. In contrast, oxygen is a substance that can be absent from a system. Temperature can decrease to absolute zero, but it is questionable whether this would be accurately described as the absence of temperature. However, even if that were the case, that is not the main point. Temperature could still be an enabling factor in the sense that it must assume specific values for the effect to occur at all. While this is true, and I will return to that in a moment, this is not what is happening in the causal processes determining bamboo invasion in Japan's secondary forests. What we have seen is that temperature *influences* the effect of interspecific interaction on bamboo occupancy without, however, enabling it. Changing temperature values will affect how inter-

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

specific interactions either support or inhibit bamboo occupancy, but they are not a precondition for interspecific interactions to have a causal effect at all.

This is different for solar radiation, which we can reasonably treat as an enabling condition in this system. This is because the mechanism that is affected by the modification through temperature is the photosynthesis occurring in individual *P. bambusoides* organisms. Solar radiation, in itself, is an enabling condition for photosynthesis. However, even if it would have a modifying effect on *P. bambusoides* in principle, in this system, its effect is mediated by the interspecific interaction with native tree species. For this reason, the difference in the intensity of solar radiation can be accounted for in terms of the canopy cover, and we can treat the solar radiation itself as an enabling condition in this system. In fact, in their paper, Spake et al. (2021) speculate on the potential of management strategies that work through thinning forest canopy to increase light intensity for understory vegetation. Based on the causal interaction with temperature, they conclude that cutting forest canopy may be an effective strategy to hinder bamboo occupancy under low-temperature conditions but that it would have the opposite effect under high-temperature conditions (1995).

The distinction between enabling and modifying interactions allows us to differentiate between explanatorily salient context dependence and causally necessary but explanatorily non-salient dependence on background conditions for a phenomenon (ϕ) that matches and systematizes the different causal contributions in this system. Summarizing these considerations, we can formulate two selection principles:

1. If a causal factor C acts as a *modifier* in the system, it needs to be cited as (part of) the cause of ϕ.
2. If a causal factor C acts as an enabler in the system, it does not need to be cited as a cause of ϕ but is appropriately treated as a background condition.

It follows that emphasizing interspecific interaction as biologically and explanatorily salient, while relegating temperature and solar radiation to the background, as the traditional view would do, does not do justice to the causal complexity of the system. Not only is there an explanatorily relevant difference in how the causal

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

factors operate to produce the phenomenon, but missing the modifying effect of temperature would also lead to ineffective interventions because reducing canopy cover can have positive as well as negative effects in this system.

While causal selection is often presented as a pragmatic or interest-relative choice, these principles suggest that selection can be grounded in objective features of causal interactions, specifically in the roles of factors as enablers or modifiers. This should not be taken to imply that causal selection is purely objective, however. Causal selection is inherently tied to explanation, and to the extent that criteria for adequate explanations also depend on our epistemic needs and interests, there will always be a pragmatic dimension involved in causal selection. When explaining biological invasions, for instance, there is a distinction between describing how a non-native species was transported to a novel range and explaining why it became invasive *after* arriving in that range. Explaining the invasion event in one of these ways will always be relative to our interests. Are we seeking ways to limit the transport of non-native species? Or are we interested in understanding the reasons for the spread of non-natives after they established a self-sustaining population? Depending on the answers to these questions, entirely different causal factors will be relevant in the explanation. However, that does not mean that after making these decisions about what is important to us, there is no more room for causal analysis. Once our explanatory interests have been determined, there are objective features of the causal relationships upon which selection can be based, and these are expressed in the principles stated above.

Before I discuss the broader consequences of this account of causal selection, I want to address potential objections that question whether the distinction between enabling and modifying conditions that I have presented is sound.

6 Is the distinction sound?

One might object that the distinction between enabling and modifying conditions is problematic, since, strictly speaking, there are probably not many causes that are purely enabling conditions as such, if there are any at all. My definition of the term in Section 3 was motivated by the observation that oxygen needs to be present for the fire to occur, whereas the spark does not, since there are many different ways

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

of supplying the activation energy needed to initiate the process of combustion. However, so the objection goes, doesn't the same apply to the presence of oxygen, given that there are other oxidants, such as chlorine or nitric acids? For instance, hydrogen can burn in chlorine without the presence of oxygen. But if there is more than one oxidant, just as there is more than one way of supplying the activation energy for initiating combustion, what is the difference here?

This objection also applies to the case of invasive giant bamboo. I have claimed in section 5 that solar radiation can be treated as an enabling condition since its presence is a precondition for the photosynthetic activity of *P. bambusoides*. However, it is possible to provide plants with light energy from artificial sources, provided it meets certain conditions regarding its wavelength, intensity, and duration. If this is possible, it is hard to see why we should treat solar radiation as an enabling condition in this case at all, rather than as an explanatorily salient causal factor on a par with other factors that contribute to bamboo occupancy.

I believe that this objection rests on a mistaken interpretation of the term "enabling". Although I have taken care to define the notion of an enabling factor without using any modal notions, the very concept of enabling seems to have counterfactual import by itself. That a condition is enabling for some phenomenon seems to imply that were the condition not satisfied, the phenomenon would not be observed. In this sense, enabling conditions would just be necessary conditions for a phenomenon, and evaluating the specific function of causal factors thus would involve considering different possible worlds in which the phenomenon occurs. Quite obviously, as we have seen, there are possible worlds, not that different from ours in terms of the standard laws of nature, in which combustion occurs without the presence of oxygen, such that the latter cannot be an enabling condition.

However, the misunderstanding is that an enabling condition is not a necessary condition for a phenomenon directly. It is an enabling condition for a different causal factor to contribute to the production of a phenomenon. That a factor X makes a positive contribution to the phenomenon ϕ only when Z is present is compatible with the fact that ϕ can also occur when Z and X are absent. Generally, a phenomenon may be produced by different mechanisms. However, that does not mean that within any specific mechanism, there are no objective differences in the causal roles that different factors play in producing the phenomenon. In the com-

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

bustion example, we have been concerned with the causal role of a spark resulting from striking a match for the occurrence of a fire. For this factor to be a cause of the phenomenon, the presence of atmospheric oxygen is an enabling condition. In contrast, the spark could have also been supplied by a lightning strike, instead of the matches or the fire could have been started without a spark at all by using a magnifying glass to focus sunlight. For all of these causes, however, atmospheric oxygen is an enabling condition for the phenomenon but not the other way around. Likewise, in the case of invasive giant bamboo, the claim is not that solar radiation from the sun is a metaphysically necessary condition of photosynthesis. Instead, the claim is that in secondary forest ecosystems, solar radiation is an enabling condition for the causal factors of interspecific interactions and temperature to contribute in their specific ways to bamboo occupancy.

A different way of disputing the robustness of the distinction between enabling and modifying conditions is that these are vague concepts, and their difference, thus, at best, a matter of degree. This would imply that, even if there were clear-cut cases at the endpoints of a continuum, there would be considerable overlap in many cases such that the distinction cannot be used as a basis for causal selection.

Support for this objection comes from the fact that even clear cases of enabling, such as the presence of oxygen for combustion, allow for degrees and thus seem to be modifying as well. Under standard conditions, the atmosphere contains around 20% oxygen. This is sufficient for combustion to occur. However, adding oxygen to the fire, as any seasoned barbecue chef will tell you, considerably enhances both temperature and speed of the combustion process. Since this is nothing else than changing the magnitude of the causal effect, and my definition of modifying factors takes into account changes in magnitude as well, it follows that the presence of oxygen is not merely enabling but also modifying at the same time.

I am willing to bite the bullet on this one. However, I do not think that this is a decisive objection against the soundness of the distinction. Below a certain threshold of oxygen saturation, combustion will not occur. Above this threshold, combustion does occur, but its magnitude is also dependent on the amount of oxygen that is present. This is compatible with my definition of enabling and modifying factors. Enabling and modifying are not properties of the factors themselves; they are functional roles that factors can play in specific mechanisms. Further-

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

more, they are defined in terms of the values different causal factors can take. Accordingly, it is possible that the same factor can be both enabling and modifying as long as there is no complete overlap between the enabling and modifying ranges. In the case of invasive bamboo, temperature is an enabling factor within a specific range of values, as it demarcates the conditions that *P. bambusoides* can physiologically tolerate. In this sense, environmental factors that are enabling are similar to those dimensions covered by Hutchinson's concept of the fundamental niche (Hutchinson 1957). The fundamental niche encompasses the environmental factors required for a species' survival, as well as the specific ranges of these factors within which the species can persist indefinitely. However, in the case of giant bamboo, within that interval, there is a sub-interval of values where temperature can also be a modifying factor because, as we have seen, it causally interacts with other factors to change how interspecific competition affects bamboo occupancy. Temperature, taken as a factor *simpliciter*, can thus have different causal roles depending on the specific range of values it takes. However, there are good reasons not to include the enabling range of the temperature values as a causal factor explaining bamboo occupancy, since this range, i.e., the temperature conditions that *Phyllostachis* species can physiologically tolerate at all, are mere enabling conditions for other causal factors to come into play, such as the interspecific interaction with native tree species, light intensity, and the modifying range of temperature.

Distinguishing the enabling and modifying roles in these cases is further justified because, in both examples, we have a more detailed mechanistic understanding of what explains the causal interaction observed at the level of measurable properties. We have a fairly comprehensive and detailed mechanistic understanding of the combustion process, the function of an oxidant in this process, and how oxygen, in particular, can fulfill this function. Similarly, controlled studies have shown that the photosynthetic apparatus, particularly Photosystem II (PSII), of *Phyllostachis* species becomes overexcited under high-light and low-temperature conditions because the absorbed light energy cannot be efficiently utilized in photochemistry or dissipated as heat (Van Goethem et al. 2015). Contrary to the raised objections, then, the distinction between enabling and modifying factors is sound, and it is, in principle, open to mechanistic explanation in concrete cases.

In the following section, I will outline some implications of distinguishing be-

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

tween enabling and modifying factors in relation to our understanding of background conditions and related causal concepts, such as specificity and stability.

7 Consequences for Causal Analysis

Recent discussions in the philosophy of causation have converged on the claim that causal complexity does not preclude causal analysis (Ferreira Ruiz 2021). A seminal paper in this respect is Woodward (2010), which introduces the concepts of stability, proportionality, and specificity as important dimensions of causal analysis, complementing the traditional focus on the conditions under which causal inference is warranted at all.

In section 5, I have argued that modifying conditions should generally be cited as (part of) the cause of a phenomenon, whereas enabling conditions are properly relegated to the background. A similar argument is made by Woodward (2010) based on the notion of causal specificity. Woodward is concerned with arguments put forth, among others, by Waters (2007) regarding the specificity of the causal role of particular nucleotide sequences of DNA for transcribing RNA molecules in contrast to the unspecific role of RNA polymerase in this process. According to his analysis, the role of DNA is more causally specific in the sense that it allows for more "fine-grained and *specific* control over which RNA molecules or proteins are synthesized", whereas the role of "RNA polymerase in RNA and protein synthesis instead seems more *switch-like*" (Woodward 2010, 306).

The standard example to illustrate how two kinds of causes that differ in specificity combine to produce their effect has become known in the literature as Woodward's radio (Calcott 2017; Ferreira Ruiz and Umerez 2021). Woodward's radio features an on/off switch and a dial that enables tuning to various radio stations. By comparing the respective contributions of these two "causes", we notice that one allows for more fine-grained causal control over what is heard (by tuning to many different stations), whereas the other is less specific in that it allows only for the selection between two states (whether anything is heard at all or not). Woodward (2010) argues that this distinction in causal specificity is what underlies the classification of some causes as enabling conditions (in the sense of Thomson (2003)). If X is a cause of Y but it is an unspecific cause, we are, according to

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

Woodward, "more likely to regard X as a mere enabling (or background) condition for Y" (Woodward 2010, 317).

One might think that the differential function of enabling and modifying interactions in the *P. bambusoides* case is analogous to Woodward's radio in that the effect of temperature has a very fine-grained influence on bamboo occupancy, whereas the effect of solar radiation is rather unspecific (because mediated by the interspecific interaction) in comparison. The selection rules (1) and (2) that I proposed in section 5 thus seem to follow Woodward's analysis in the principle that the more specific causes should be cited in causal selection. However, this is not very accurate. The distinction between enabling, modifying, and other causal factors is not necessarily based on comparing their relative degrees of causal specificity but instead on the types of interaction among these different causal factors. What makes the switch an enabling condition in the radio is not the fact that it is less specific than the dial in terms of the number of states of the effect variable that can be mapped onto it, but the fact that the switch interacts with the dial in such a way that it is a condition for the dial to have a causal effect at all.

This point has also been argued by Calcott (2017). He contrasts Woodward's "competitive approach" to analyzing causal interactions with an alternative "hierarchical" approach (488). According to his proposal, "we assume a *background cause* (the switch) controls the causal relationship between a *foreground cause* (the dial) and an *effect* (what we hear)" (ibid.). The distinction between foreground and background causes, in turn, is made in terms of asymmetries in manipulability and temporal stability, specifically in biological and developmental pathways. Based on these considerations, Calcott proposes an understanding of the distinction between instructive and permissive causes in developmental pathways, where permissive causes enable conditions under which an instructive cause operates. The distinction between enabling and modifying conditions that I have introduced follows Calcott (2017) in that it also assumes a hierarchical approach to analyses of causal interactions. However, it moves beyond his proposal in pointing out that the category of background cause is itself heterogeneous in that not all "background causes" have to be enabling. The distinction between enabling and modifying is thus more flexible, as it allows for the analysis of causal complexity that involves more than two factors, and it provides a rationale for distinguishing

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

between background conditions and explanatorily salient context dependence.

This last point can be generalized. In section 5, I have argued that a nondiscriminatory concept of *background conditions* likely hides essential causal complexity from our view and bases causal selection on false premises. There is relevant causal context, the importance of which differs from the role of background conditions. Failing to differentiate between the role of background conditions and causal context dependence has had detrimental consequences for causal analysis, as it is based on the unspoken premise that stability is the core feature of causal relationships. Dependence on causal context is often viewed as an epistemic obstacle to the discovery of general and invariant causal relationships, as it appears to limit the conditions under which a relationship can be considered stable. However, rather than treating context dependence as a nuisance in this way, I suggest it can also serve as a diagnostic tool for disentangling aspects of the underlying structure of complex causal systems. If the effect of the variable X on the variable Y is moderated by a third variable, Z, then the relationship between the factors represented by X and Y changes with the variation of Z so that it has a particular shape in terms of magnitude and sign. This means that the relationship between X and Y unfolds along a gradient defined by Z. Therefore, instead of focusing on stability in the sense of invariance between X and Y, causal analysis can also proceed by examining gradients of causal influence between the factors of interest.

In the case of invasive bamboo, we have already established a relationship between forest tree canopy cover and bamboo occupancy. There are then two types of questions that we can raise concerning this relationship: (i) What are the general conditions for it to take place at all? (ii) How does this functional relationship develop, given certain environmental contextual factors? Invariance or stability is not the best guide to answering questions of the second kind. However, such variation along gradients would be significant to ecologists because it allows them to analyze not only whether a relationship exists but also what it looks like in relation to certain other factors. The distinction between enabling and modifying factors allows us to do just that, as it encourages a reinterpretation of context dependence by separating it from considerations of stability and invariance of causal relationships, and makes it possible to describe causal relationships along specific gradients of interest. The advantages of this change of perspective, then,

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

would not only be limited to ecology but would be significant for the study of all kinds of systems in which multiple causes interact.

8 Conclusion

The framework presented in this paper offers a novel approach to distinguish between background conditions and proper causes in scientific practice, and to differentiate which factors should be explicitly cited in explanations and which should remain implicit, despite being causally indispensable. Applying the distinction between enabling and modifying conditions to the ecological case study of *Phyllostachys bambusoides* invasion dynamics shows that background conditions are not a homogeneous category. Some causal factors, though indispensable for the phenomenon, are not explanatory, while others fundamentally alter the causal dynamics and, therefore, should be included in explanations. Recognizing this heterogeneity enables scientists and philosophers to move beyond oversimplified accounts of context dependence and gain a deeper understanding of the causal structure of complex systems.

While I have emphasized throughout that causal interactions play a pivotal role in resting causal selection on more objective grounds, I have also provided important caveats to the claim that selection is entirely objective. Not only do subjective interests determine which phenomena warrant scientific investigation and explanation, but mechanistic explanations can also be given at different scales or levels of abstraction. By understanding enabling and modifying factors in terms of their specific roles in mechanisms, the account presented seeks to strike a balance between purely pragmatic or interest-driven and purely ontological accounts. Once explanatory interests, including scales of observation and levels of abstraction, have been determined, causal analysis can still rest on objective distinctions between different causal functions, however.

Furthermore, the distinction I propose is not tied to the ecological case study presented here but is applicable to all causal systems characterized by multicausality and context sensitivity of causal relationships, where a clear concept of normal function cannot be presupposed. For instance, analyses of the suitability of policy-interventions across different political and socio-cultural contexts might benefit

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

from more clearly distinguishing enabling conditions from potential modifiers of the intervention in at least two ways: First, by allowing us to distinguish the factors that need to be present or removed from those that need to be adjusted for the policy to be successful; Second, by helping to identify suitable target factors to achieve desired effects across different systems. However, I must reserve a more detailed discussion of the role of enabling and modifying factors in the analysis of mechanisms in the social sciences for a future paper.

Acknowledgments

I would like to express my gratitude to Alkistis Elliott-Graves, Uljana Feest, Phyllis Illari, Marie Kaiser, Anton Killin, and Katie Morrow for their helpful comments on earlier drafts of this paper. I am also grateful to the members of Bielefeld University's *Philosophy of Life Sciences* group and the *Philosophy of Science* reading club at Johannes Kepler University Linz for their valuable feedback and discussion. Finally, I thank the two anonymous reviewers for their insightful comments, suggestions, and questions.

Funding information

Research for this paper was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Project 254954344/GRK2073.

Declarations

None to declare.

References

Aronson, Jerrold L. 1971. "On the Grammar of 'Cause'." *Synthese* 22 (3/4): 414–430. https://www.jstor.org/stable/20114765.

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

Baedke, Jan, and Tatjana Buklijas. 2023. "Where Organisms Meet the Environment: Introduction to the Special Issue 'What Counts as Environment in Biology and Medicine: Historical, Philosophical and Sociological Perspectives'." *Studies in History and Philosophy of Science* 99:A4–A9. https://doi.org/10.1016/j.shpsa.2022.09.008.

Broadbent, Alex. 2008. "The Difference Between Cause and Condition." *Proceedings of the Aristotelian Society* 108 (1/3): 355–364. https://doi.org/10.1111/j.1467-9264.2008.00250.x.

Calcott, Brett. 2017. "Causal Specificity and the Instructive–Permissive Distinction." *Biology & Philosophy* 32 (4): 481–505. https://doi.org/10.1007/s10539-017-9568-0.

Cartwright, Nancy. 1979. "Causal Laws and Effective Strategies." *Noûs* 13 (4): 419–437. https://doi.org/10.2307/2215337.

———. 1989. *Nature's Capacities and Their Measurement.* Oxford: Oxford University Press. https://doi.org/10.1093/0198235070.001.0001.

Catford, Jane A., John R. U. Wilson, Petr Pyšek, Philip E. Hulme, and Richard P. Duncan. 2022. "Addressing Context Dependence in Ecology." *Trends in ecology & evolution* 37 (2): 158–170. https://doi.org/10.1016/j.tree.2021.09.007.

Chamberlain, Scott A., Judith L. Bronstein, and Jennifer A. Rudgers. 2014. "How Context Dependent Are Species Interactions?" *Ecology Letters* 17:881–890. https://doi.org/10.1111/ele.12279.

Duncan, Richard P., and Ben J. Kefford. 2021. "Interactions in Statistical Models: Three Things to Know." *Methods in Ecology and Evolution* 12 (12): 2287–2297. https://doi.org/10.1111/2041-210X.13714.

Eells, Ellery. 1986. "Probabilistic Causal Interaction." *Philosophy of Science* 53 (1): 52–64. https://doi.org/10.1086/289291.

Elliott-Graves, Alkistis. 2016. "The Problem of Prediction in Invasion Biology." *Biology & Philosophy* 31 (3): 373–393. https://doi.org/10.1007/s10539-015-9504-0.

Ferreira Ruiz, María. 2021. "What Is Causal Specificity About, and What Is It Good for in Philosophy of Biology?" *Acta Biotheoretica* 69 (4): 821–839. https://doi.org/10.1007/s10441-021-09419-x.

Ferreira Ruiz, María, and Jon Umerez. 2021. "Interactionism, Post-interactionism, and Causal Complexity: Lessons From the Philosophy of Causation." *Frontiers in Psychology* 12. https://doi.org/10.3389/fpsyg.2021.590533.

Franklin-Hall, Laura R. 2015. "Explaining Causal Selection with Explanatory Causal Economy: Biology and Beyond." In *Explanation in Biology: An Enquiry into the Diversity of Explanatory Patterns in the Life Sciences,* edited by Pierre-Alain Braillard and Christophe Malaterre, 11:413–438. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-017-9822-8.

Frühstückl, Robert. 2025. "Ecology in Context. A Conceptual Model for Analyzing the Significance of Context in Ecological Research." *Philosophy, Theory, and Practice in Biology* 17 (3): 11.

Glennan, Stuart. 2017. *The New Mechanical Philosophy.* Oxford: Oxford University Press.

Glennan, Stuart, Phyllis Illari, and Erik Weber. 2022. "Six Theses on Mechanisms and Mechanistic Science." *Journal for General Philosophy of Science* 53 (2): 143–161. https://doi.org/10.1007/s10838-021-09587-x.

Godfrey-Smith, Peter. 2009. "Causal Pluralism." In *The Oxford Handbook of Causation,* edited by Helen Beebee, Christopher Hitchcock, and Peter Charles Menzies, 326–337. Oxford Handbooks in Philosophy. Oxford: Oxford University Press.

Hart, Herbert Lionel Adolphus, and Tony Honoré. 1985. *Causation in the Law.* 2nd ed. Oxford: Clarendon press.

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

Hitchcock, Christopher, and Joshua Knobe. 2009. "Cause and Norm." *The Journal of Philosophy* 106 (11): 587–612. https://www.jstor.org/stable/20620209.

Hutchinson, George E. 1957. "Concluding Remarks." *Population Studies: Animal Ecology and Demography. Cold Spring Harbor Symposia on Quantitative Biology* 22:415–427.

Keele, Luke, and Randolph T. Stevenson. 2021. "Causal Interaction and Effect Modification: Same Model, Different Concepts." *Political Science Research and Methods* 9 (3): 641–649. https://doi.org/10.1017/psrm.2020.12.

Lean, Christopher Hunter. 2021. "Invasive Species and Natural Function in Ecology." *Synthese* 198 (10): 9315–9333. https://doi.org/10.1007/s11229-020-02635-x.

Lewis, David. 1973. "Causation." *The Journal of Philosophy* 70 (17): 556–567. https://doi.org/10.2307/2025310.

Mackie, J. L. 1965. "Causes and Conditions." *American Philosophical Quarterly* 2 (4): 245–264. https://www.jstor.org/stable/20009173.

Mega, Jessica L., Sandra L. Close, Stephen D. Wiviott, Lei Shen, Richard D. Hockett, John T. Brandt, Joseph R. Walker, et al. 2009. "Cytochrome P-450 Polymorphisms and Response to Clopidogrel." *New England Journal of Medicine* 360 (4): 354–362. https://doi.org/10.1056/NEJMoa0809171.

Menzies, Peter. 2004. "Difference-Making in Context." In *Causation and Counterfactuals,* edited by John David Collins, Edward J. Hall, and L. A. Paul, 139–180. Representation and Mind. Cambridge, Mass: MIT Press.

———. 2009. "Platitudes and Counterexamples." In *The Oxford Handbook of Causation,* edited by Helen Beebee, Christopher Hitchcock, and Peter Charles Menzies, 341–367. Oxford Handbooks in Philosophy. Oxford: Oxford University Press.

Mill, John Stuart. 1843. *A System of Logic, Ratiocinative and Inductive: Being a Connected View of the Principles of Evidence, and the Methods of Scientific Investigation.* London: John W. Parker.

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

Morrow, Katie H. 2023. "A Causal-Role Account of Ecological Role Functions." *Philosophy of Science* 90 (2): 433–453. https://doi.org/10.1017/psa.2022.95.

Odenbaugh, Jay. 2019. "Functions in Ecosystem Ecology: A Defense of the Systemic Capacity Account." *Philosophical Topics* 47 (1): 167–180.

Reiss, Julian. 2015. *Causation, Evidence, and Inference.* London: Routledge.

Rodgers, Vikki L, Sara E Scanga, Mary Beth Kolozsvary, Danielle E Garneau, Jason S Kilgore, Laurel J Anderson, Kristine N Hopfensperger, Anna G Aguilera, Rebecca A Urban, and Kevyn J Juneau. 2022. "Where Is Garlic Mustard? Understanding the Ecological Context for Invasions of *Alliaria Petiolata*." *BioScience* 72 (6): 521–537. https://doi.org/10.1093/biosci/biac012.

Ross, Lauren N. 2018. "Causal Selection and the Pathway Concept." *Philosophy of Science* 85 (4): 551–572. https://doi.org/10.1086/699022.

———. 2021. "Causal Concepts in Biology: How Pathways Differ from Mechanisms and Why It Matters." *The British Journal for the Philosophy of Science* 72 (1): 131–158. https://doi.org/10.1093/bjps/axy078.

Russo, Federica, and Jon Williamson. 2007. "Interpreting Causality in the Health Sciences." *International Studies in the Philosophy of Science* 21 (2): 157–170. https://doi.org/10.1080/02698590701498084.

Simberloff, Daniel S. 2005. "Non-Native Species DO Threaten the Natural Environment!" *Journal of Agricultural and Environmental Ethics* 18 (6): 595–607. https://doi.org/10.1007/s10806-005-2851-0.

Spake, Rebecca, Diana E. Bowler, Corey T. Callaghan, Shane A. Blowes, C. Patrick Doncaster, Laura H. Antão, Shinichi Nakagawa, Richard McElreath, and Jonathan M. Chase. 2023. "Understanding 'It Depends' in Ecology: A Guide to Hypothesising, Visualising and Interpreting Statistical Interactions." *Biological Reviews* 98 (4): 983–1002. https://doi.org/10.1111/brv.12939.

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

Spake, Rebecca, Masashi Soga, Jane A. Catford, and Felix Eigenbrod. 2021. "Applying the Stress-Gradient Hypothesis to Curb the Spread of Invasive Bamboo." *Journal of Applied Ecology* 58 (9): 1993–2003. https://doi.org/10.1111/1365-2664.13945.

Suzaki, Toko, and Takayuki Nakatsubo. 2001. "Impact of the bambooPhyllostachys Bambusoides on the Light Environment and Plant Communities on Riverbanks." *Journal of Forest Research* 6 (2): 81–86. https://doi.org/10.1007/BF02762492.

Takano, Kohei Takenaka, Kenshi Hibino, Ayaka Numata, Michio Oguro, Masahiro Aiba, Hideo Shiogama, Izuru Takayabu, and Tohru Nakashizuka. 2017. "Detecting Latitudinal and Altitudinal Expansion of Invasive Bamboo Phyllostachys Edulis and Phyllostachys Bambusoides (Poaceae) in Japan to Project Potential Habitats under 1.5°C–4.0°C Global Warming." *Ecology and Evolution* 7 (23): 9848–9859. https://doi.org/10.1002/ece3.3471.

Thomson, Judith Jarvis. 2003. "Causation: Omissions." *Philosophy and Phenomenological Research* 66 (1): 81–103. https://www.jstor.org/stable/20140515.

Turbelin, Anna J., Ross N. Cuthbert, Franz Essl, Phillip J. Haubrock, Anthony Ricciardi, and Franck Courchamp. 2023. "Biological Invasions Are as Costly as Natural Hazards." *Perspectives in Ecology and Conservation* 21 (2): 143–150. https://doi.org/10.1016/j.pecon.2023.03.002.

Van Goethem, D, A Van Elst, S De Smedt, R Valcke, G Potters, and R Samson. 2015. "The Effect of Light Intensity and Temperature on the Chlorophyll Fluorescence of Phyllostachys Aureosulcata Bamboo Plants under Controlled Growth Chamber Conditions." *Bamboo Science & Culture* 28:10–22.

Waters, C. Kenneth. 2007. "Causes That Make a Difference." *The Journal of Philosophy* 104 (11): 551–579. https://www.jstor.org/stable/20620058.

Woodward, James. 2003. *Making Things Happen: A Theory of Causal Explanation.* Oxford, New York: Oxford University Press.

https://doi.org/10.1017/psa.2025.10189 Published online by Cambridge University Press

Woodward, James. 2010. "Causation in Biology: Stability, Specificity, and the Choice of Levels of Explanation." *Biology & Philosophy* 25 (3): 287–318. https://doi.org/10.1007/s10539-010-9200-z.

Xia, Yun, Junna Feng, Hongbo Zhang, Deyu Xiong, Lingdong Kong, Robert Seviour, and Yunhong Kong. 2024. "Effects of Soil pH on the Growth, Soil Nutrient Composition, and Rhizosphere Microbiome of Ageratina Adenophora." *PeerJ* 12:e17231. https://doi.org/10.7717/peerj.17231.