

Chapter 13

From the Organizational Theory of Ecological Functions to a New Notion of Sustainability



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13.1 Introduction

In this chapter, we will address criticisms to the theory of ecological functions introduced by Nunes-Neto et al. (2014). In doing so, we intend to further develop the theory, as a possible basis for naturalizing the teleological and normative dimensions of ecological functions. We will also take the first steps in the construction of an integrated scientific and ethical approach to sustainability that is intended to avoid an anthropocentric perspective.

The problems of teleology and normativity are two classical problems related to the ascription of functions to biological items (Cooper et al., 2016). In a causal

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explanation, causes are presented in order to explain effects that are assumed to follow from them. Functional explanations are suspected to invert the temporal order of causes and effects. When one speaks of functions in biology, one often assumes that the explanation for the presence or existence of a given trait lies in its future utility. This is suggested, for instance, when one says that the function of sea turtles' paddle-shaped limbs is to increase swimming efficiency, which implicitly amounts to saying that they are born with such limbs for swimming efficiently in the future. This is the problem of *teleology*. After all, teleological explanations point to the fulfilment of a given goal. In a teleological explanation, it is claimed that an event takes place for a given purpose, i.e., that it occurs because it is the *kind of event that brings about that goal*. The fact that this is the necessary event for a given goal to be obtained in a certain state of affairs is regarded, in this mode of explanation, as a *sufficient condition* for the occurrence of the event (Taylor, 1964). Bearing in mind this temporal reversion problem, one of the philosophical challenges of ascribing functions to a trait or other biological item is to do so from a scientifically acceptable, naturalized perspective that implies a legitimate and admissible conception of causality from the standpoint of the natural sciences, not appealing to ontological conceptions inconsistent with scientific knowledge and practices (Mossio et al., 2009; Moreno & Mossio, 2015).

The second problem is that of *normativity*. When one ascribes a function to a trait, one refers not merely to what the trait does but to what it arguably *should do* (Cooper et al., 2016). Increasing swimming efficiency, for instance, is not simply something that the sea turtles' paddle-shaped limbs do but what they should do, as their function. That is, "attributing functions to traits implies a reference to some specific effect, which constitutes a criterion against which the activity of the trait can be normatively evaluated" (Mossio et al., 2009, p. 814). This normative evaluation, in turn, seems to depend on the teleological relationship expected to be fulfilled. If the expected specific effect does not take place, this entails *malfunctioning* (Davies, 2000; Cooper et al., 2016; Saborido et al., 2016), which is not an all-or-nothing feature but rather a matter of degree (Krohs, 2010, p. 342). A particular sea turtle limb, say, can be said to be malfunctioning (to some specific degree) when its activity fails in fulfilling the expected norms for efficient swimming. When one accounts for the normative dimension of functional ascriptions, it will be necessary, thus, to theoretically justify why a specific means-end relationship is the norm in that ascription. It is important to bear in mind, however, that it is not a moral sense of normativity that is at stake, but just an expectation about a given acceptable relationship of causality.

A scientifically compatible theory of functions that intends to preserve their teleology and normativity should do so in the context of a naturalized approach to purposefulness. This can be done, for instance, by appealing to the notion of "intrinsic purpose." This notion entails the idea that the organization of living beings is inherently teleological, i.e., that their own activity is, in a fundamental sense, first and foremost oriented toward an end, which is to determine and maintain themselves. The concept of self-determination connects biological organization to intrinsic teleology: biological organization determines itself in the sense that the effects of its activity contribute to establish and maintain its own conditions of existence (Moreno & Mossio, 2015; Mossio & Bich, 2017). This framework establishes a biologically

distinctive notion of purposiveness: teleology is intrinsic in the case of biological systems, while it is extrinsic in the case of artifacts (Jonas, 1966; Aristotle, 1984).¹

The question is how to build a theory of biological functions that can take in due account the intrinsic teleology of living systems and properly justify the teleological and normative dimensions of functional ascriptions and explanations. To address this question, we will begin by considering three approaches to function, namely, dispositional, etiological, and organizational theories, and how they deal with the teleology and normativity of functions. Then, we will introduce the organizational theory of ecological functions proposed by Nunes-Neto et al. (2014). We will then tackle the main criticisms raised against this theory, related to difficulties in individuating ecosystems such that they can be treated as organizationally closed, the importance of integrating evolutionary considerations into an organizational understanding of ecological functions in order to support the conceptual role of functional explanations in contemporary ecological research, and the ascription of functions to abiotic items. Finally, we will explore the implications of the organizational theory to environmental ethics, taking the first steps toward an integrated scientific and ethical approach to sustainability. This is intended to lead to a new notion of sustainability that offers an alternative to its common interpretation in anthropocentric and economically based terms.

13.2 Philosophical Theories of Function and Their Approach to Teleology and Normativity

Two philosophical approaches have been typically used for understanding functional explanation in biology (Cooper et al., 2016). On the one hand, dispositional theories explain functions in terms of the contribution(s) or causal role(s) of a system's part to an emergent capacity at the level of the whole (e.g., Cummins, 1975; Adams, 1979; Bigelow & Pargetter, 1987; Craver, 2001). To use a classical example, from this perspective, the function of the human heart is to pump blood because pumping blood is what the heart does that contributes to a specific human systemic capacity, namely, the circulation of gases and nutrients. This is an approach that relies on current means-ends relationships to conceive of functional explanation, intending to ground normativity without appealing to teleology – an approach that has been argued to be able to support only an epistemic normativity, dependent on the researchers' choices about which systems and which systemic capacities to

¹Babcock and McShea (2021) argue that this distinction between externalist and internalist teleological explanations, which comes back to Aristotle's *Physics*, has been a misstep in the debates on teleology. They argue, in contrast, for a single type of legitimate teleological explanation, an artifact model of teleology in which goal-directed entities are guided by a nested series of upper-level fields (McShea, 2012, 2016). In this chapter, we will keep reference to the usual distinction between intrinsic and extrinsic teleology, leaving Babcock and McShea's proposal to be discussed elsewhere.

study (see below). It intends to dissolve the problem of the teleology of functions by reducing them to any causal contribution to a higher-level capacity that a trait/part may give, such that the normative dimension of functions is reduced to the claim that the causal effect must contribute to a higher-level capacity, with no reference to a “benefit” for the system. For those committed to this approach, teleological reasoning is merely an element of a superseded worldview, which should have no application in the way modern science explains natural phenomena. However, a common criticism of this way of understanding biological functions follows from the fact that it does not include a teleological element, namely, that it underdetermines the normative dimension of functional ascriptions, being unable to distinguish proper functions from accidental effects and to account for malfunctionality, because in the end functional ascription depends on the observer’s choice of the phenomenon to be accounted for in functional terms (Millikan, 1989; Kitcher, 1993; Mitchell, 1993; Godfrey-Smith, 1994; Mossio et al., 2009). Novel versions of the dispositional theories of function have been proposed in order to include additional requirements in an effort to avoid the drawbacks pointed out by critics (e.g., Weber, 2005).

On the other hand, etiological theories seek to naturalistically ground both the teleological and normative dimensions of functions by appealing to an evolutionary perspective, i.e., turning to the selective causal history (or etiology) of organisms’ traits/parts (Wright, 1973, 1976; Millikan, 1984, 1989; Neander, 1991; Godfrey-Smith, 1994). From this perspective, organisms have functional traits because those traits have increased the fitness of past organisms in their respective lineages. Accordingly, function is not a mere effect of a trait but a selected effect that explains its current presence or prevalence. From this perspective, the function of the human heart is to pump blood because pumping blood is the selected effect that explains the current presence of hearts in humans. A causal loop between the functional effect of a given trait and its persistence through time grounds the teleology and normativity of functions: Fitness-enhancing effects of past tokens explain the presence of the contemporary trait type and provide a normative standard for evaluating present tokens. This approach has been criticized, however, for being too narrow to accommodate all functional talk in biology, particularly because it makes the current contribution of a trait irrelevant to determine its function and, thus, does not account for functional ascriptions that are often made in several areas of biology in relation to current rather than past effects. This is at odds, in short, with the fact that functional attributions to biological items do seem to bear some relation to what they currently do that increases an organism’s survival and reproduction chances, and not only to what explains their current existence. It is in the sense that it has been argued that etiological theories seem to offer a problematically epiphenomenal account (Christensen & Bickhard, 2002). Another criticism concerns the fact that this sort of explanation appeals only to natural selection, while this is neither the single evolutionary process important to explain how organisms came to be how they are nor the single explanation for the presence of all traits to which we ascribe functions (Cooper et al., 2016). These criticisms have been discussed and addressed by

advocates of the etiological theories, which have developed them in different versions in an attempt to overcome the pinpointed problems (see, *e.g.*, Garson, 2015, 2016).

Organizational theories offer a third way for building an understanding of functional ascriptions and explanations (*e.g.*, Schlosser, 1998; Bickhard, 2000, 2004; Collier, 2000; McLaughlin, 2001; Christensen & Bickhard, 2002; Delancey, 2006; Edin, 2008). In particular, we rely here on the theory developed by Mossio et al. (2009), which aims at explaining at the same time the persistence of a trait through time and its current contribution to the maintenance of a system.

As formulated by Saborido et al. (2011), a trait T has a function if, and only if, it exerts a constraint subject to closure in an organization O of a system S , which entails the fulfilment of three conditions:

- C_1 : T exerts a constraint that contributes to the maintenance of the organization O .
- C_2 : T is maintained under some constraints of O .
- C_3 : O realizes closure.

These conditions naturalize teleology as they state how the system realizes a circular causal regime that can be grasped through the concept of “closure” (Varela, 1979; Moreno & Mossio, 2015).² If the heart pumping blood makes it possible that the organization of a living system and, consequently, the heart itself be maintained, then that activity of the heart is a cause of its very existence and can be identified as its function. Normativity is also naturalized by these conditions, since the expected behavior of an organism’s trait is related to the production of the specific effect that contributes to the systemic organization in which the trait is included and that is responsible for its very maintenance. The specificity of this effect allows for a distinction between function and nonfunctions, as well as between proper and accidental functions.

The causal loop involved in the intrinsic teleology of living systems shows the distinctive property of being a closure of constraints, rather than merely a closure of processes, as we observe in a number of physicochemical systems showing mutual dependence of entities and processes. Constraints are local and contingent causes that reduce the degrees of freedom of the dynamics on which they act (Pattee, 1972) but remain conserved at the time scale relevant to describe their causal action with respect to those dynamics (Mossio & Bich, 2017). Thus, the kind of closure expressed in conditions C_1 and C_2 is a closure of constraints, *i.e.*, an organization in which each constraint is involved in at least two different dependence relationships, playing the role of enabling and dependent constraint, respectively (Moreno & Mossio, 2015). Therefore, as developed in detail by Mossio and Bich (2017), it is not any form of causal circularity that will show intrinsic teleology. Rather, it should be a circular causal regime of constraints that are collectively able to self-determine

²In very general terms, by “closure” one means a feature of systems by virtue of which their constitutive components and operations depend on each other for their production and maintenance and, also, collectively contribute to determining the conditions under which the system itself can exist (Mossio, 2013).

(or, more specifically, self-maintain) through self-constraint. Or, to put it differently, circularity is a necessary but not sufficient condition for intrinsic teleology, and biological organization shows this distinctive property because it realizes self-constraint. In these terms, the idea of biological function does not rely only on teleological and normative dimensions but also on the idea of organization. Or, to put it differently, the idea of organization as closure necessarily includes teleological and normative dimensions.

13.3 The Organizational Theory of Ecological Functions

Functional language is ubiquitous in ecology. Ecologists commonly talk about the function of a given tree species in a forest, or the function of decomposers in relation to soil properties, or the functional role of organisms' traits in a given ecological process, among many other possible examples (for detailed analyses of the uses of function by ecologists, see Jax, 2005; Nunes-Neto et al., 2016a). However, in spite of this extensive reliance on functional language in both descriptions and explanations in ecological research, it is not clear yet how to properly justify the use of functional language in ecology in scientifically compatible terms. However, several steps have been taken in this direction in a number of recent works (e.g., Jax, 2005; Nunes-Neto et al., 2014; Dussault & Bouchard, 2017; Odenbaugh, 2019; Millstein, 2020; Lean, 2021).

We have proposed a theoretical perspective to justify functional ascriptions and explanations in ecology from an organizational point of view (Nunes-Neto et al., 2014; El-Hani & Nunes-Neto, 2020). In order to explain it, let us begin by considering the ways in which the concept of function is used in ecology (see Jax, 2005; Cooper et al., 2016). Jax, for instance, differentiates between four different and complementary ways this concept is employed by ecologists: (1) as a purely descriptive meaning that refers to some change of state or to what happens in the relationship between biotic or abiotic objects; (2) to refer to the functioning of a whole ecosystem; (3) to refer to the role functions of biotic and abiotic components of an ecosystem in relation to its functioning as a whole; and (4) to refer to ecosystem services to some human need or purpose. Here we are specifically interested in use (3), related to the role functions of ecosystems' parts in relation to ecosystem processes (e.g., the role of plants as primary producers within an ecosystem).³ These

³When we refer to ecological role functions, this is not in opposition to thinking on individuals or groups/types from an organizational perspective. Rather, as we make explicit in the organizational account, functions are specific roles ascribed to items of biodiversity or abiotic items (under the influence of the biotic community) that constrain the thermodynamic flows in an ecological system. These parts are identified through decomposition/localization analyses (Bechtel & Richardson, 2010), but these are not arbitrary, or under the mere discretion of the researcher, since they should be guided by hypotheses or models on the contributions of the components to the norms of the ecological system's behavior, i.e., to the maintenance of its conditions of existence. Therefore, the components fulfil the causal roles defined in a given decomposition/localization model or hypothesis when they do what they are supposed to do in relation to those norms.

role functions are connected, in turn, with the use of functional reasoning to classify organisms or species according to their effects on ecosystem processes, as we see in the common reference to functional traits and functional groups in ecological research (see, e.g., Hooper et al., 2005; Petchey & Gaston, 2006).

Based on the organizational theory of functions developed by Mossio, Saborido, Moreno, and colleagues, we have defined an ecological function as “a precise (differentiated) effect of a given constraining action on the flow of matter and energy (process) performed by a given item of biodiversity, in an ecosystem closure of constraints” (Nunes-Neto et al., 2014, p. 131). At the same time, assuming this definition as a starting point for an organizational theory of ecological systems under construction, we have recently proposed to broaden the range of organizational functional items in the ecological domain in order to include abiotic items, if one shows how they can play the role of constraints (El-Hani & Nunes-Neto, 2020).⁴ In other words, an adequate set of functional items should include not only items of biodiversity (i.e., organisms, populations, functional groups, guilds, etc.) but be more encompassing, including abiotic items. Looking at individual organisms helps making this clear: a honey bee nest is an abiotic, non-biological structure (in the sense that it is not made of living cells) but at the same time is clearly functional (or at least it is typically assumed to be so by biologists). The same seems to be true of ecological systems: abiotic parts of ecosystems (for instance, fire) may play relevant functions in the whole system of which they are parts. The key point when ascribing functions to abiotic items in either organismic or ecological systems is to show how they can act as constraints internal to the organization of the systems, involved in the maintenance of their conditions of existence.

To consider an example of how the organizational approach works, let us look at an ecological system from the point of view of its main activities, decomposing it in three functional groups: producers, consumers, and decomposers. Consider, also, an abiotic factor that producers subject to their closure, namely, carbon dioxide. The functional groups form a hierarchical organization comprising two levels (i.e., a hierarchy of control, *cf.* Ahl & Allen, 1996): the level of the functional items – in this case composed by items of biodiversity – which act as constraints, and the level of the material, thermodynamic flow of carbon atoms, which is the constrained process. Considering the functional items, the producers of organic matter (plants) constrain, through photosynthesis, the flow of carbon atoms, reducing its degrees of freedom, which is something that can be clearly noticed in the building of complex biomolecules from carbon atoms as basic ingredients. The flow of carbon atoms

⁴The individuation of abiotic items, as components of ecological systems, poses in itself important challenges. Here we will not focus on these challenges, which will be faced, in fact, by any theory that intends to ascribe functions to abiotic items, such as Dussault and Bouchard’s (2017) persistence enhancing propensity (PEP) or Odenbaugh’s (2019) systemic capacity accounts. Rather, our main concern in the present work is the individuation of ecological systems. In passing, we can remark, however, that the fact that abiotic items can only be ascribed role functions according to the organizational theory if they act as constraints in relation to the organization and conditions of existence of ecological systems means that we may be able to individuate at least their role as constraints, even if it may be difficult to individuate them as entities.

becomes more determinate, more harnessed, as these atoms, initially contained in atmospheric carbon dioxide molecules, become part of plant biomass. Parts of plant biomass (leaves, fruits, sprouts, etc.) are eaten by consumers (herbivorous animals), which realize a second channeling of the flow of carbon atoms, when these atoms in the plant biomolecules, after digestion and absorption of nutrients, become part of their bodies. And the same is true of a whole network of consumers. In turn, when the consumers and producers die, the animal carcasses and plant leaves, fruits, twigs, and roots become part of the organic matter that is further processed by decomposers, which transform it into available nutrients for plants, thus closing the cycle by reducing once again the degrees of freedom of the flow of carbon atoms. Moreover, due to respiration, along the whole chain of processes, carbon dioxide molecules are sent back to the atmosphere, from where they can be cycled back to the system through photosynthesis (Fig. 13.1).

There is a clear mutual dependence between these constraints. By constraining the flow of matter (carbon atoms), the consumers, for example, create conditions of possibility (or enabling conditions) to the existence of the decomposers and, in this manner, exert an effect on the ecological system as a whole. And while, on the one

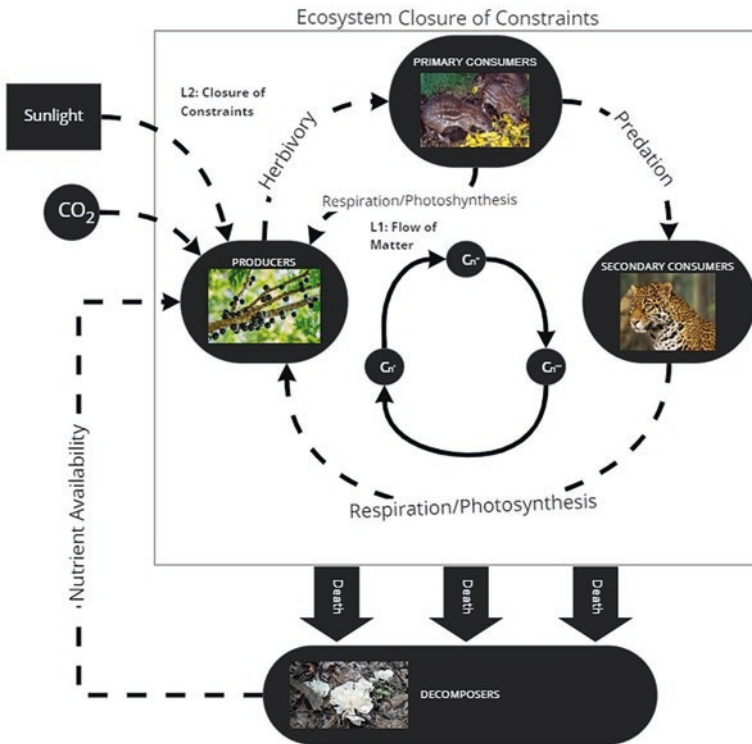


Fig. 13.1 Organizational functions in an ecosystem closure of constraints – a schematic view. (Figure elaborated by Felipe Rebelo Gomes de Lima)

hand, the consumers are enabling conditions to the existence of decomposers, they depend, on the other hand, on the producers from which they derive the matter and energy needed for their self-maintenance. Therefore, we can say that they are dependent on both the producers of organic matter and the very decomposers that mobilize nutrients to the producers. In sum, producers, consumers, and decomposers – as functional items – exert specific constraining actions that amount to the role functions they play within the ecological system of which they are parts, contributing to the self-maintenance of its organization.

13.4 Organizational Functions and the Individuation of Ecological Systems

Ecosystem individuation raises questions for the organizational theory of ecological functions (Cooper et al., 2016). As functions are ascribed in this theory to constraints subject to closure, it is a requisite to functional ascription to establish where the ecosystem closure of constraints lies. In more detail, the problem consists in that, as ecological systems interpenetrate one another at their fringes, this fuzziness of physical boundaries typically also entails a fuzziness of functional relationships, making it harder to decide which constraints are part of one or another ecosystem (or, perhaps, both) and, thus, which functions are to be ascribed to them as subject to the closure of the distinct systems. In short, to ascribe functions to ecosystem components and, accordingly, to naturalistically justify the teleology and normativity of ecosystem functions depend on the ecosystem closure of constraints and mutual dependences between items of biodiversity and abiotic items.

This does not seem to be a particular problem challenging the application of the organizational theory to ecological cases. As Bich (2019) argues, to account for limit cases in which functional closure cannot be realized from within is a more general challenge faced by this theoretical framework. This follows in fact from the thermodynamic openness of living systems and, thus, goes all the way back to Piaget's (1967) crucial conception of the complementarity in such systems between organizational closure and thermodynamic openness. In order to self-maintain themselves, biological systems often need to recruit external constraints or expand their network of control interactions to include previously external constraints, which belong to other systems, subjecting them to their own organizational closure. As we will elaborate below, the control of flammability by fire-adapted plant species in ecosystems is an example of how a boundary condition⁵ external to the

⁵Boundary conditions are typically conceived as conditions defined externally to a system that contribute to determine its behavior and dynamics, but typically do not depend on the dynamics on which they act. When the behavior of a system is sub-specified, as it happens when it depends on variable, contingent local circumstances, boundary conditions related to these circumstances are added to its description for providing the lacking specifications. Boundary conditions are imposed on the laws of physics and chemistry and provide additional specifications by decreasing the

system has become part of its internal dynamics, once it has been subject to their closure, turning from a destructive force into a constraint that is both enabling (e.g., of regrowth processes) and dependent (on fire-adapted plant species) (e.g., Mutch, 1970; Schwilk & Ackerly, 2001; McLauchlan et al., 2020). This kind of process can blur, however, the functional boundaries of the system, jeopardizing the very idea of closure, which depends on the capability of living systems of specifying their functional boundaries from within. This threat to closure may be solved by recognizing the fact that, once an external constraint is *recruited* by a system *A*, it simply becomes a part of that system. Yet, as this was an external constraint, say, initially belonging to some system *B*, we need clear criteria to state whether the constraint is part of *A*, *B*, or both, which will affect which functions may be ascribed to it. That is, as functions are ascribed in the organizational theory to constraints subject to closure, the problem of specifying where the organizational closure of the living system lies will affect functional ascription, i.e., the identification of what can be considered a functional component of the system and what cannot. To trace the precise functional boundaries of a system can be regarded, thus, as a requisite to build functional explanations according to this theory, which is under challenge in other cases than just ecological systems. Yet, as we shall see, the theory has the resources to face this challenge.

Based on the assumption that one could rarely individuate ecosystems as organizationally closed systems, a number of criticisms of the organizational theory of ecological functions suggested that the range of ecological systems to which it applies is rather limited. Dussault and Bouchard (2017), for instance, argue that the organizational theory is too restrictive to accommodate key aspects of contemporary ecology, for instance, related to the biodiversity and ecosystem function (BEF) research program. They go on to discuss cases related to the ascription of functions to biodiversity, abiotic factors, and source-sink populations. We will engage with these cases below. Let us begin, however, by considering a critical appraisal of the organizational theory claiming that the domain in which this theory can be applied is very narrow.

Focusing on the bromeliad example chosen by Nunes-Neto et al. (2014) to illustrate the organizational theory of ecological functions, Lean (2021) argues that organizational closure is an exceptional case in ecological systems, and organizational functions will be less likely as ecological systems scale up in size, complexity, and openness. In this manner, the individuation of ecosystems as organizationally closed systems and the scope of the organizational theory can be seen as

degrees of freedom of the system's dynamics. In this manner, they harness the physico-chemical processes involved in such dynamics (Polanyi, 1968). A constraint is a particular kind of boundary condition, characterized by both its causal role in relation to a particular process *P* under its influence, such that *P* takes place differently under and free from the influence of the constraint, and its conservation or symmetry at the time scale characteristic of *P*, which follows from being locally unaffected by *P* (Mossio et al., 2013). A central difference between living and non-living systems is that in the former part of the constraints/boundary conditions acting over the system are produced by the system itself, and, moreover, the set of internal constraints show mutual dependence, while in the latter constraints/boundary conditions are externally produced.

interconnected issues. Lean argues that one can only take ecological systems to be closed self-maintaining units based on a strong commitment to equilibrium ecology, according to which population interactions would stabilize the composition of communities. Then, if such stabilizing interactions are coupled with stable populations, we would obtain bound self-maintaining ecological systems. However, the problem is – Lean argues – that equilibrium ecology has been extensively criticized in the history of this discipline and ultimately replaced by non-equilibrium ecology, which describes ecological communities as causally open collections of species, and local community composition as a result of path-dependent historical processes and random dispersal of populations from other local communities. The outcome of this picture would be that ecological communities are not closed systems but rather the product of many populations moving around larger biogeographic regions. With the large turnover of species within a local area, there would be changes not just in the populations playing a functional role but also in the overall causal structure of the system. Lean's conclusion is, thus, that the domain in which the organizational theory of ecological function may apply is very limited: organizational functions would only occur in some ecological systems, generally rather small ones, with just a couple of populations in close physical proximity.

Besides organizational functions, Lean (2021) also discusses selected effects, persistence, and causal role functions, concluding that all those that include a normative dimension (i.e., all of them except causal role functions) are sporadic and rare, such that ecological functions would be nearly always dispositional rather than normative. That is, they should be conceived, according to him, as descriptions of causal structure that can be used to identify features that we should preserve. As teleological arrangements of ecological systems would be extremely spotty, with just some “blips of teleological arrangement” (Lean, 2021, p. 9327), founding conservation on teleology would be a misstep. Teleological organization would not include much of what conservation biologists intend to protect and, accordingly, would not provide a strong enough scaffold to support conservation ethics. To deny intrinsic teleological grounding for conservation ethics may limit conservation decisions, however, to anthropocentric reasons, leaving instrumental values in relation to human activities as the major if not exclusive reason that would be relevant for such decisions.⁶

This is related to a key difficulty for causal role functions, which several critics have pointed out: they lack a normative component, just describing the presence or absence of a function, not whether a system's trait is malfunctional or accidental. Even though Lean's position can be described as pluralistic (see Dussault, 2022), we think his conception of ecological functions is more closely related to causal role functions. But, be that as it may, his position shares with the latter the lack of a

⁶This is recognized by Lean (2021, p. 9328) himself: “By deploying [Causal role] functional analysis, we can identify what supports the ecological features that we do, or should want to, protect. These could be features of the environment which have moral utility or preference. While this does not offer us a non-anthropocentric justification for intervening on ecological communities, it does offer a way of identifying which populations make a disproportionate impact on the community.”

normative component. Now, this has been generally regarded as a shortcoming of dispositional theories of function, as shown by the well-known argument that these theories are too liberal for proper functional ascription (e.g., Millikan, 1989; Kitcher, 1993). However, Lean (2021) thinks differently, claiming that this is a positive characteristic of the theory, a flexibility that allows explaining any ecological system's capacity, provided there are constitutive and causal relations in the community at stake. He does not see as a weakness of dispositional theories that the system and capacity of interest are defined by the researcher. This is a defensible view, but not easily so, given the common criticisms of dispositional theories for being too broad and under-specified, incapable of capturing the explanatory force of functional ascription, or making sense of malfunction and differentiating between functioning and mere usefulness, or, else, the criticism that they allow arbitrary, subjective attribution of functions depending on which capacities of a system interest us, and on criteria to identify relevant systems that are entirely dependent on the observer (e.g., Neander, 1991; Mitchell, 1993; Godfrey-Smith, 1994; Moosavi, 2019).⁷

To our understanding, Lean's arguments about organizational functions show two major problems: first, they do not take in due account that non-equilibrium ecology does not exclude ecological interactions and ecological interactions can generate community-level functional organization; second, they do not consider that closure of constraints is not an all-or-nothing property that would necessarily require a strongly cohesive unit to obtain.⁸ As we will argue later, it is sufficient that just part of the constraints exerting influence or control over the system be included in the closed organization, and, accordingly, an organizationally closed system can show different degrees of cohesion or functional integration.⁹ But let us focus, first, on the idea that one might appeal to closure of constraints to individuate ecosystems only if committed to equilibrium ecology.

⁷Lean's approach is to justify conservation decisions based on analyses of the causal structure of ecological systems, in order to identify populations that we are interested to preserve, given their role in supporting ecological features that interest us, and populations we may want to control, due to their role in reducing biodiversity. He does not appeal to any normative reason that could justify treating systems with particular populations (say, invasive species) as malfunctioning. It is clear that these conservation decisions would be mostly based on what we are interested into, and may suffer from the same sort of arbitrariness criticized in dispositional theories. At most, Lean can introduce a justification for conservation decisions based on what "... all prudent agents should want to preserve."

⁸Here we should admit that in our original 2014 paper, we were not explicit about the idea that organizationally closed systems can show different degrees of cohesion or functional integration, such that Lean cannot really be blamed for overlooking it.

⁹This can be related to the view that biological individuality and functional integration come in degrees even in the case of organisms (see, e.g., Queller & Strassmann, 2009; West & Kiers, 2009; Clarke, 2010; Strassmann & Queller, 2010; Godfrey-Smith, 2013; Huneman, 2014a, b; Sterner, 2015; Skillings, 2016; Bich, 2019; Wilson & Barker, 2019).

13.4.1 *Ascribing Organizational Functions in Non-equilibrium Ecology*

Non-equilibrium models resulted from the work of neo-Gleasonian ecologists (e.g., Whittaker, 1951, 1975; Curtis & McIntosh, 1951) who proposed that typical ecological communities are composed of species which have evolved independently and were combined through chance immigration and individual suitability to ecological contexts. As Whittaker and Woodwell (1972, p. 141) argue, “communities are related by a blurred reticulateness of many intersecting strands (*i.e.*, species) relating a present community to many past communities.” But, as Dussault and Bouchard (2017) emphasize, Gleasonian or neo-Gleasonian ecology does not deny community-level functional organization as depicted, say, by Elton’s (1927, 1930) trophic model of ecological communities or as studied by ecosystem ecologists (Hagen, 1989, 1992). Even though Gleason and his followers adopt a population-reductionist stance concerning the migration and establishment of species in a location, they do not deny that these species interact once they are established, and their interactions can give rise to community-level functional organization (Eliot, 2011; Nicolson & McIntosh, 2002).¹⁰ Symptomatically, we find that contemporary ecologists often do not shy away from conceiving communities and/or ecosystems as functionally organized systems, in which organisms, species, or abiotic items fulfil functional roles (e.g., Naeem, 2002a; Schulze & Mooney, 1993).

If we take into account these aspects of Gleasonian or neo-Gleasonian ecology, Lean’s (2021) interpretation that one can only consider ecological systems as organizationally-closed if strongly committed to equilibrium ecology is not well supported. And, if we consider the issue more generally, the current state of knowledge in ecology does not support this interpretation either. It is truly an empirical issue which ecological systems are subject to non-equilibrium dynamics and which are in equilibrium, but it is not the case that closure of constraints would only obtain if community composition was established as depicted in equilibrium models. As in non-equilibrium models community-level functional organization can emerge once the biotic community is formed in the intersection between the distribution of several to many species, closure of constraints can also obtain even if community

¹⁰Here it is important to notice that generic interactions among species are not sufficient for functional ascription. If interactions are generic, it will be difficult to maintain that ecological function bearers contribute to their own maintenance by contributing to the maintenance of the system. Strictly speaking, a species that generically contributes to the maintenance of the ecological system as a whole cannot be convincingly described as contributing to its maintenance *per se*. Rather, it can be said to contribute to the provision of conditions that fulfil the needs of any species with sufficiently similar niches – be it itself or another species. On this issue, see Dussault (2019). For an item of biodiversity or abiotic factor to be functional within a community-level functional organization, it should have specific rather than generic effects. That’s why the proviso that an ecological function amounts to a precise (differentiated) effect of a constraining action on the flow of matter and energy in an ecosystem is very important in the account proposed by Nunes-Neto et al. (2014, p. 131).

composition results from path-dependent historical processes and random dispersal of populations, provided that their interactions once together in the same community give rise to a functional organization.

Vellend's (2010, 2016) proposal of a conceptual synthesis in community ecology offers a case in point about how the role of local species interactions, which can give rise to community-level functional organization, is recognized in ecological models not committed to equilibrium assumptions. He claims that, despite the large number of mechanisms underpinning patterns in ecological communities, four distinct kinds of processes are combined in them, namely, selection, drift, speciation, and dispersal. The focus on these processes resulted from conceptual developments along the history of ecology. In the 1950s and 1960s, equilibrium ecology was consolidated, based on the idea that patterns in the composition and diversity of species in communities were the deterministic outcome of local interactions between functionally distinct species and their environments (importantly including other species). Thus, those patterns could be explained mostly by fitness differences among species, or, in other words, by selection.

Non-equilibrium ecology emerged in the 1980s and 1990s, bringing a more inclusive approach to community ecology, which recognized the importance of processes at broader spatial and temporal scales for understanding local-scale patterns. This does not mean, however, that the latter patterns could be simply dismissed, and, accordingly, it does not entail that local species interactions and their fitness consequences, or community-level functional organization, would have to be simply dropped from the picture. Rather, what was at stake was the need to take into account that the composition and diversity of species at a local scale fundamentally depend on the composition and diversity of regional pools of species, such that speciation is also a process to consider when explaining community-level features.

The next step was the incorporation of drift, with the neutral theory of biodiversity. By "ecological drift" one means random fluctuations in population size resulting from ecological equivalence in the probabilistic sense, i.e., in the sense that individuals have equal chances of reproduction or death regardless of species identity (Rosindell et al., 2012). Pure ecological drift would happen if individuals of different species were demographically identical, a very unlikely situation, but drift will be equally important when it is not the only active process at stake. In any case, there will be ecological drift, and its importance will be greater the more modest is the functional differentiation between individuals or species in a given set, or, to put it differently, the more ecologically equivalent they are. Again, the recognition of drift does not entail a denial of a role for local-scale species interactions and patterns. Finally, dispersal was incorporated into community ecology models in the form of the metacommunity concept, which concerns the influence of dispersal among local communities over community patterns at multiple scales.

As Vellend (2010, p. 185) sums up, "selection, in the form of deterministic interactions among species and between species and their environments, was always recognized as important." Accordingly, in non-equilibrium models, incorporating drift, speciation, and dispersal, local-scale species interaction is recognized, as well as the possibility that community-level functional organization emerges. The upshot

is that we do not need to be committed to equilibrium ecological models to explain ecological functions from an organizational perspective. In non-equilibrium models, organized systems can be also identified, and, accordingly, the domain of the organizational theory is much larger than Lean recognizes. Moreover, it has been argued that the processes identified by Vellend (2010, 2016), which structure species dynamics within a community, can be interpreted as constraints, even though a convincing demonstration that this is really the case is yet to be done (Peck & Heiss, 2021).

Interestingly, Lean (2021) situates his own position between two extremes he identifies in ecological science: either ecological systems would be mere collections of populations, largely independent of each other (Gleason, 1926), or analogous to organisms, possessing functional organization that maintains mature organism-like individuals (Clements, 1916).¹¹ He associates, then, the idea that ecological systems may have functions from which conclusive statements about what is normatively functional or malfunctional can be made with the claim that they are organism-like. However, ecology is not trapped between those two extremes but also formulates an understanding of ecological systems that sits between them. Similarly, we do not need to treat ecosystems as organisms to ascribe organizational functions to their components. On the contrary, there are important differences between ecosystems and organisms, as the former typically lacks the sort of agency and regulation¹² that characterize the latter. Moreover, ecological systems do not show the same degree of stability and cohesion observed in organisms, or at least in many cases of organismality. Accordingly, there is no requirement that one is committed to an interpretation of ecosystems as superorganisms to apply the organizational theory. What is necessary to ascribe function to components of a system based on this theory is just organizational closure, conceived as closure of constraints. Or, to put it differently, what we assume is just that organisms and ecosystems can share the property of organizational closure, despite their several differences. It is sufficient, also, that a self-maintaining, organizationally closed system shows a tendency to closure,¹³ and

¹¹ See Eliot (2007, 2011) for a critical appraisal of the sheer opposition between Clements' and Gleason's approaches to explaining vegetation.

¹² As defined in the organizational theory we take as a starting point. See, e.g., Moreno and Mossio (2015) and Bich et al. (2016).

¹³ We use the expression "tendency to closure" following its usage by Montévil and Mossio (2015). However, this expression may be interpreted in a manner that raises unnecessary difficulties to the theory, since it may suggest that we would be referring to a process showing a tendency that closure emerges as its outcome. This interpretation may lead to a counter-argument that a tendency toward closure would be no guarantee (or support no prediction) of achieving it. Nevertheless, what is meant by "tendency to closure" is that interdependent subsystems (or modules) within a containing system (which is itself organizationally closed) showing a relatively large degree of internal cohesion (i.e., interdependent modules) can be said to tend to be closed, despite the fact that they functionally depend on one another. In this precise sense, organizationally closed systems may come with different degrees of cohesion and functional integration (either diachronically or synchronically), to the extent that it is sufficient for closure that part of the constraints affecting the system's dynamics are mutually dependent such that each of them is involved in at least two different dependence relationships in which it plays the role of enabling and dependent constraint.

even if regarded as closed, this does not mean all constraints or boundary conditions affecting its dynamics should be included within the closed organization.

13.4.2 On the Domain of the Organizational Theory of Ecological Functions

In this section, we intend to reinforce the claim that the organizational theory of ecological functions does not apply only to small ecological systems, with just some limited number of populations in close physical proximity. If the theory applied only to such exceptional cases, its utility would be surely quite limited. We do not think, however, that this is a correct assessment.

In our original paper (Nunes-Neto et al., 2014), we did not present key concepts of the original organizational theory that provide ways to respond to criticisms about the scope of the organizational account of ecological functions (Dussault and Bouchard, 2017; Odenbaugh, 2019; Lean, 2021). Valuable as these criticisms are for sharpening our ideas, there are central aspects of the theory that need to be made explicit to tackle them.

For instance, the concept of constraint has not been given by both Dussault and Bouchard (2017) and Lean (2021) the central role it has in the organizational theory. Organizational closure is explained as follows by the former authors:

... traits have functions relative to what its proponents call the *organizational closure* of a system, which is a causal loop that occurs when the parts of a far-from-equilibrium system contribute to its self-maintenance, and the system, in turn, maintains those parts. (Dussault & Bouchard, 2017, p. 1133)

Lean (2021) also describes organizational closure without considering the concept of constraint in any detail but rather just mentioning it once in the entire explanation of the organizational theory and that as part of a quote from Mossio et al. (2009). In this manner, closure of processes and closure of constraints are not properly differentiated. This differentiation is, however, a key aspect of the organizational theory of biological functions.

Since these authors do not properly consider the concept of constraint in their arguments, they neglect aspects showing how the organizational theory is less restrictive than it might seem at first sight. Lean (2021), for instance, argues for the rarity of organizational functions based on the difficulty of satisfying the requisite of causal closure in ecological systems since they are rarely, if ever, closed systems. But for properly understanding the organizational theory, it is important to consider that a closure of constraints does not correspond to any set of causal relationships but to a rather specific state of affairs. There is indeed a clear criterion postulated in the organizational theory for constraints to be regarded as part of a closed organization, which is enunciated by Moreno and Mossio (2015, p. 20) as follows:

In formal terms, a set of constraints \mathbf{C} realizes closure if, for each constraint C_i belonging to \mathbf{C} :

1. C_i depends directly on at least one other constraint of \mathbf{C} (C_i is dependent).
2. There is at least one other constraint C_j belonging to \mathbf{C} which depends on C_i (C_i is enabling).

If one takes into account the meaning of closure, not in isolation but within the overall framework of the theory, it will not be difficult to conclude that a closed organization of constraints requires that just some but not all constraints relevant to the system's self-maintenance be included within its organizational closure. Precisely, only constraints that are both enabling and dependent are considered part of the organizational closure. If this is lost from sight, the demand that the system be organizationally closed will seem more restrictive than it is in fact.

As Bich (2019) argues, biological systems should be capable of generating within themselves *some* of the internal constraints that control their dynamics, such that they remain in far from equilibrium conditions by harnessing the thermodynamic flow. Closure is a regime of mutually dependent constraints that determines a subset of its own conditions of existence, not all of them. In these terms, we can tackle the problem posed by the expansion of the functional boundaries of an organizationally closed system that recruits external boundary conditions or extends its network of control interactions. In short, we can do so by considering how this problem follows, in fact, from an incorrect interpretation of the notion of closure of constraints, which conflates the self-specification of the functional boundaries of a system with functional self-sufficiency. Based on how the functional components of a biological organization are wired together to collectively achieve self-maintenance, one can propose criteria to characterize the *degree of functional integration* and, accordingly, the *degree of internal cohesion* of a system, i.e., the different ways and extents in which constraints are mutually dependent and realize closure (Bich, 2016, 2019). When we take into account different degrees of functional integration in organizationally closed systems, we can realize that there is a variety of ecological systems that can be described as such.

A minimal theoretical example of functional integration by means of cross-control (Bich, 2019) is found in Kauffmann's (2000) autocatalytic sets, in which a catalyst A is produced thanks to the action of another catalyst B that controls kinetically its synthesis, while A itself contributes, in turn, to B 's existence by controlling directly its production or some intermediate steps in the production of B . An autocatalytic set realizes a basic form of closure, given that each constraint depends for its production and maintenance on the direct action of (at least) another constraint, and together the components of the autocatalytic set (in the example, A and B) collectively realize self-production and self-maintenance. Autocatalytic sets exhibit closure because each constraint plays a function in collective self-production and self-maintenance, and we can consider the same to be true of ecological systems. Indeed, we find in the literature theoretical treatments of ecological systems as autocatalytic sets (see, e.g., Cazzolla Gatti et al., 2017, 2018). The issues related to

individuation follow from the fact that, like autocatalytic systems, ecological systems are more directly determined by external boundary conditions and material constraints than more complex, autonomous systems, such as organisms. Nonetheless, ecological systems can realize a basic regime of closure, just as autocatalytic sets.

An idea that is quite helpful when discussing the individuation of ecological systems is Montévil and Mossio's (2015) "tendency to closure." Closure offers a clear-cut criterion for drawing the boundary between a biological entity and its environment, providing a fitting solution to the problem of individuation, as the set of constraints subject to closure defines the system, based on the topological property of circularity in the network of constitutive interactions, whereas all other constraints acting on the system belong to its environment. Montévil and Mossio claim that we should ascribe closure to "maximally closed systems," i.e., systems including all mutually dependent constraints in the currently available descriptions (which are, by necessity, incomplete). Thus, in the case of mutually dependent organisms, there still seems to be a fundamental organizational continuity between the interacting organisms. In this case, it seems justifiable to ascribe ecological functions to the organisms constituting the system, even if the system does not show fully-fledged functional integration or constraints closure. Montévil and Mossio were discussing cases in which an encompassing system (say, a symbiotic one) is maximally closed, such that one might say that the symbionts within that system display a tendency to closure. As they depend on each other, they are not closed strictly speaking, but one can say they "tend" to be closed. We think we can extend this notion, however, to conceive of subsystems or modules, generally speaking, which show a relatively large degree of internal cohesion but yet depend on other modules in a given network. Closure ascription can extend in this case beyond each module, insofar as a maximally closed system should include all known constraints showing the topological circular property. Yet, we can claim that the modules containing – in the case of ecological systems – functionally coupled organisms or other items of biodiversity show a tendency to closure, as elements within a hierarchical set or network of modules. That is, in this case we can introduce a somewhat more relaxed notion of internal cohesion that makes it clear how the scope of the organizational theory of ecological functions is substantially broader than just a limited number of cases showing fully-fledged closure. To make this notion more precise, we can introduce a measure of the degree of closure in a system, based on the number of constraints that are both enabling and dependent, and, accordingly, are subject to closure. A tendency to closure points, then, to a specific degree of closure measured by the number of mutually dependent constraints in a system.

Ecological systems realizing closure of constraints can indeed exhibit different degrees of functional integration. They can be rather closed systems like the phytotelmata of bromeliads, chosen by Nunes-Neto et al. (2014) as a case to develop the organizational theory of ecological functions, but not as exhausting all the possible cases to which the theory applies. They can be symbiotic systems or other functionally integrated consortia of organisms, in which control is exerted not only within but also across biological systems (Bich, 2019), as, for instance, bacterial biofilms

in which bacteria exchange enzymes (or DNA sequences coding for enzymes) responsible for the control of the internal metabolic processes in response to nutritional and other kinds of stress (Davey & O'Toole, 2000), or plants integrated by mycorrhizal networks that not only exchange metabolites but mutually affect their physiology and ecology (Selosse et al., 2006). These cases are different from the bromeliad one because a new order of functional integration is realized through the control exerted by organisms upon one another's processes.¹⁴

Ecological systems may show, however, much less integrated and bounded configurations and, yet, realize closure of constraints, as it happens when organisms exert control upon the conditions of existence of one another, either by directly harnessing the external flow of matter and energy or indirectly generating external control constraints in the environment, such as bird nests, spider webs, beaver dams, ant nests, etc. It seems clear, thus, that the domain of the organizational theory is much larger than some critics have supposed. There are plenty of systems in which ecological functions can be naturalistically grounded, in their teleology and normativity, using the organizational theory.

13.4.3 Modularity Analysis and the Identification of Ecological Systems Showing Tendency to Closure

Surely, it is rather challenging to individuate ecological systems not as bounded as phytotelmata or beaver dams. Plant stands integrated by mycorrhizal networks, for instance, are difficult cases. However, we see this not as a fatal conceptual pitfall that the theory cannot deal with. It is rather a methodological challenge that can be tackled with its resources. Even though this is not the space to fully develop a methodological solution to the problem, we can advance some basic ideas on how to pursue it.

An analysis of modularity in ecological networks can provide at least an initial approach to identify ecological systems showing tendency to closure. Modularity – which describes the existence of subcommunities within networks – is currently regarded as a recurrent structure of many types of ecological networks (Thébault, 2013). A network shows modular structure when it consists of interconnected modules, while the extent to which species interactions are organized into modules amounts to the modularity of the network. In turn, a module in an ecological network is defined as a group of species more closely connected to each other than to species in other modules.

¹⁴Importantly, as Bich (2019) argues, the realization of a new order of functional integration does not imply that the organisms involved are not able to realize organizational closure and achieve functional integration by themselves. It just means that, while maintaining closure as functionally cohesive entities, they extend their functional networks of control constraints by realizing nested forms of functional integration that include more than one system and, we add, can also realize closure at a higher order.

In an influential paper, Olesen et al. (2007) provide a good example of the relevance of modularity analysis for understanding the structure and functioning of ecological networks, given that modularity is both a key ingredient of network complexity and plays a critical role in their functioning, e.g., in relation to species coexistence and community stability. Indeed, the modular structure of species interactions in mutualistic networks was shown, for instance, to hinder species loss and promote long-term persistence of ecological communities (Krause et al., 2003; Kashtan & Alon, 2005; Olesen et al., 2007; Guimerà et al., 2010; Stouffer & Bascompte, 2011; Gilarranz et al., 2017; Sheykhalil et al., 2020).

There are several underlying processes that can explain why ecological networks show modularity, all of which can be included in non-equilibrium models: modularity may reflect habitat heterogeneity, divergent selection regimes, and phylogenetic clustering of closely related species (Lewinsohn et al., 2006). It can also result from the convergence of species on correlated suites of traits shaped by similar interaction patterns, as captured by a concept commonly used in studies on plant-animal interactions, namely, that of syndromes (Fenster et al., 2004; Olesen et al., 2007; Dellinger, 2020).¹⁵

Modularity is no exceptional feature of ecological networks but rather a manifestation of a common property in biological networks, which, as Kashtan and Alon (2005, p. 13773) argue, “are modular with a design that can be separated into units that perform almost independently.” We can advance, thus, that modularity analysis can provide a first step to identify highly connected groups of species that may satisfy the requirements for showing tendency to closure.¹⁶ That is, organizationally closed (sub)systems¹⁷ in an ecological network can be searched for through the identification of modules, and the search space for those (sub)systems will be significantly reduced if we focus on modules of ecosystem parts that are more closely connected to one another than to parts included in other modules. After all, within a module, it is more likely that biological organisms/populations/functional groups will show mutual dependence due to their interactions, which are stronger than the interactions with other network components, i.e., it is more likely that they rely on one another for their own maintenance, with at least part of them being possibly both enabling and dependent constraints and, thus, being subject to closure.

The identification of modules in an ecological network can provide, thus, a first step to model organizationally closed ecological systems but needs to be complemented by an approach to investigate the within-module connections in order to

¹⁵In fact, many pollination studies implicitly assume modularity when they focus on groups of interacting species sharing a syndrome.

¹⁶Although we cannot develop the argument in the confines of this chapter, we advance that the approach described in the body of the text may provide a way of implementing the procedure to delimit organizationally closed systems through the drawing of their spatial boundaries derived by Montévil and Mossio (2015) from the quantitative assessment of the tendency of constraints to be “packed together” in space.

¹⁷We write “(sub)systems” to accommodate the fact that the whole ecological network or more inclusive parts of it may be also described as systems in a number of cases.

establish whether they take place between constraints and, moreover, between constraints that are both enabling and dependent. A possible way to model modules in ecological networks as organizationally closed systems is to ascertain whether they can be treated as ecological autocatalytic sets, as proposed by Cazzolla Gatti et al. (2017, 2018). Another way, which we are currently investigating, is to show that systems of differential equations used to describe coupled dynamics (e.g., consumer-resources, predator-prey) can provide a mathematical framework to model ecosystem closure of constraints. Surely, these two approaches can be integrated, as they offer descriptions of the same dynamical system, with networks describing the topology of the interactions, and differential equations, the dynamics of the interactions.

Olesen et al. (2007) analyzed a total of 51 pollination networks, encompassing almost 10,000 species of plants and flower-visiting animals and 20,000 links, and found that 29 of them (57%) were significantly modular.¹⁸ In particular, all networks containing more than 150 species were modular, while all those with less than 50 species were nonmodular. The modular networks had, on average, 8.8 ± 3.7 modules, ranging from a maximum of 19 to a minimum of 5 modules. Most links in such networks were among species within the same module (on average 60% of all links), reinforcing how modularity analysis may allow us to identify organizationally closed (sub)systems in an ecological network, despite the intricacy of ecological relationships and the relative openness of such systems. Individual modules in the networks differed in size and shape because of both the variation in species number and the ratio between pollinator and plant species. A module contained on average 32 ± 34 species (on average, 26 pollinator species and 6 plant species). This suggests that the set of organizationally closed modules or (sub)systems in ecological systems may not be as small as some critics think. It was even the case that 36 (14%) of all 254 modules identified in the networks were isolated species groups without any links to the remaining network. However, this finding concerns the ecological interactions between plants and animals modeled in the networks, and there is no reason to assume that if other kinds of ecological relationships were at stake, those same species groups would be equally isolated. Only 21 of these isolates, i.e., 4% of all identified modules, were small 1:1 modules, consisting of only one pollinator species interacting with one plant species. That is, just a minority of the modules were the sort of small ecological systems, with just a couple of populations, that Lean (2021) argued would exhaust most of the domain to which the organizational theory could apply. Twenty-nine (11%) of all modules were star-shaped, consisting of one generalist hub species, most often a plant species, showing no links to other

¹⁸Olesen et al. (2007) treated all flower-visiting animals as pollinators, which, of course, is not necessarily true as several species may visit flowers without being involved in pollination but in other processes, such as nectar robbing. As the role of a species in an ecological network is defined by its topological position compared to other species, it is not central to functional ascription based on modularity analysis if the species at stake is a pollinator or not, since it may constrain the flow of energy and matter in a variety of ways and, thus, play different ecological functions according to the organizational theory.

modules, while it was linked to a range of 3–51 peripheral pollinator species connected only to the hub. Most of the hubs (189, i.e., 74%), however, varied a lot in size and shape, showing the diversity of arrangements possible in plant-pollinator networks. Some modules contained a set of species with convergent traits related to their pollination biology, i.e., to pollination syndromes, or which were closely related taxonomically.

Considering functional analysis, a rather interesting aspect of the study carried out by Olesen et al. (2007) lies in the topological analysis of the role played by each species in the networks. This role is defined by its position compared with other species in its own module and how well it connects to species in other modules. Accordingly, the analysis considers the relation between each species' within-module degree z , i.e., its standardized number of links to other species in the same module and its among-module connectivity c , i.e., the level to which the species was linked to other modules. Eighty-five percent of all species showed low z and c and were peripheral species or specialists, showing only a few links and almost always only to species within their module (72% of them had $c = 0$, with no links outside their own module). Species with either a high z or a high c value were generalists (15%), including module hubs (3%), i.e., highly connected species linked to many species within their own module (high z , low c), and connectors linking several modules (low z , high c) (11%). Species with high z and high c were network hubs or super generalists (1%), acting as both connectors and module hubs. Plants were the strongest module hubs. Connectors were mainly beetles, flies, and small-to-medium-sized bees, and most network hub pollinators were social bees, especially *Apis* spp. and *Bombus* spp., or large solitary bees, e.g., *Xylocopa* sp. and a few *Diptera* species. Even though generalists not only contribute to pack peripheral species together into modules but also connect modules together into networks, blurring in this way module boundaries, it is possible to extract modules from networks using the appropriate analytic approaches, as shown by several studies (e.g., Olesen et al., 2007; Fortuna et al., 2010; Thébault & Fontaine, 2010; Schleuning et al., 2014; Grilli et al., 2016; Sheykhal et al., 2020). This is instructive when one seeks to consider how system openness does not entail that organizationally closed systems cannot be identified.

Some ecological networks may show a greater tendency toward modularity than others, since this property is expected to increase with link specificity (Lewinsohn et al., 2006).¹⁹ One may expect, for instance, that modularity is stronger in insect herbivory or host-parasitoid networks, which show high link specificity, than in

¹⁹Link specificity concerns the degree of specificity of the ecological interaction represented by a certain edge in a network. For instance, in a food network, the more specialized the trophic relationship considered, the higher the link specificity, while the reverse is true for generalist trophic relationships. Link specificity is related to another key concept in the literature on ecological networks, namely, interaction intimacy (i.e., the degree of biological integration between interacting individuals; see Pires & Guimarães, 2013), such that the decision on specificity does not merely involve an analysis of the links in a given network.

pollination and seed-dispersal networks, characterized by lower interaction specificity, and in traditional food webs (Olesen et al., 2007).

Important consequences for conservation may follow from the combined use of an organizational theory of ecological functions and modularity analysis, as it may allow us to ascertain key groups of taxa that need to be conserved for an ecological network to persist, based on the implications of losing them to the network functioning *per se*, not just on the choices of a scientist in relation to where to focus his or her attention. This is so because such a theoretical-methodological approach can provide us with normativity criteria that can underlie conservation decisions, for instance, about the conservation of biodiversity items that constrain the flow of matter and energy in the ecosystem in such a manner that its resilience and persistence – as aspects of its stability and, accordingly, of its intrinsic teleology – be maintained. These are criteria that depend on the natural normativity of the system and cannot be offered by accounts that fall short from grounding the teleology and normativity of functions. Consider, say, how the network consequences of species extinctions depend, among other factors, on the species role in the topology of the network. For instance, the extinction of a module hub may cause its module to fragment with no or minor cascading impacts on other modules, whereas if connectors are extinct, this may cause the entire network to fragment into isolated modules but with minor impacts on the internal structure of individual modules (Olesen et al., 2007). Accordingly, we can derive criteria, for instance, for choosing conservation priorities from the ascription of functions to different species depending on their topological roles in relation to the modularity of the network, which may be properly captured by interpreting ecological functions in terms of the organizational theory. To briefly mention a central topic discussed by Lean (2021), this will have normative consequences to decisions in invasion biology: for instance, alien invaders of a network may cause, as they are often highly generalist, fusion of modules in an ecological network, with profound, long-term effects on network functioning and selection regime (Olesen et al., 2007). This would be a reason, then, to choose to avoid the establishment of highly generalist invaders in ecological systems.

By considering the modularity of ecological networks, we can conclude, first, that it may provide a first step in the identification of organizationally closed systems individuated as modules in a network (if complemented by approaches to establish that the nodes in a module form a closure of constraints), which do not necessarily correspond to a small set of small networks; second, that if we consider the modularity of entire ecological networks, say, all species interacting through ecological processes such as pollination in a given area, many networks will likely include many modules, and, then, the fact that it may not be possible to describe the whole network as a single organizationally closed system may not hamper functional ascription based on the organizational theory within identified modules; and third, that several different functional roles can be described based on modularity analysis, such as module and network hubs, and that it may be possible to interpret them based on the organizational theory, as related to the constraining actions of biodiversity items on flows of matter and energy through, say, trophic or pollination

relationships.²⁰ Even connectors, which link several modules, can be ascribed functions based on the organizational theory. In particular, this will be so if we consider coupling between modules as a functional role, something that will be possible if these connectors establish a form of mutual dependence between modules, due to their stable connecting interactions, such that one can say the self-maintenance of the modules is related to these interactions. Finally, the roles played by different species in the topology of ecological networks have conservation implications that are not at the discretion of scientists' decisions only but also depend on the nature and structure of the networks, as modularity can even be said to spontaneously evolve in them (Kashtan & Alon, 2005).

13.5 Organizational Functions and Evolution

Dussault and Bouchard (2017) argue that the organizational theory dissociates the concept of ecological function from evolutionary considerations. It is true, on the one hand, that there is much work to be done in order to develop the connection between the causal loop by which functions explain the presence of the function bearer in an organization-based account, which has self-maintenance as its *telos*, and an evolution-based causal loop, which refers to the (past) natural selection of fitness-enhancing traits. But, on the other hand, the organizational theory has the resources to further develop this connection to the etiologic dimension, which is part of its elaboration since its inception. The organizational theory proposed by Mossio and colleagues (2009; see also Moreno & Mossio, 2015; Saborido et al., 2011, 2016, among others) aims at accounting for the *explananda* of both etiologic and dispositional theories of function. Moreover, in the theory of biological organisms under construction by the ORGANISM-group, which is also an important theoretical framework for our proposal, the concept of function is connected to the principle of organization, and this is in turn integrated with evolutionary thinking through the principle of variation (Montévil et al., 2016; Mossio et al., 2016). This means that in this framework evolutionary changes in organization along time, both qualitative and quantitative, are necessarily integrated into the understanding of biological phenomena, including ecological ones.

Ecological functions have been recently conceived as central for integrating evolutionary and ecological perspectives on ecosystems. As a consequence, even though the concept of function has played an important role in the whole history of ecology, it has become increasingly fundamental to the development of ecological and conservation research in the last three decades (Nunes-Neto et al., 2016a). This happened as a consequence of the biodiversity and ecosystem function (BEF) research program, which aims at establishing a better understanding of the

²⁰In this sense, our arguments are not affected by the fact that not all flower-visiting animals in the pollination networks are truly pollinators but play different roles, for instance, as nectar-robbers, as observed above.

relationships between biodiversity and the functioning of ecosystems (e.g., Naeem, 2002b; Loreau, 2010a, b). To account for these relationships, this research program attributes to functional diversity the role of a conceptual bridge between community and ecosystem ecology, i.e., between the understanding of biotic communities and, accordingly, of biodiversity, including the interactions among their constituting components and their effects, on the one hand, and their contribution to ecological processes that maintain ecosystems and their properties, on the other. This unification of ecosystem and community ecology is often recognized as an important goal both for the development of ecological knowledge and for meeting the challenges of the current socioenvironmental crisis (e.g., Pickett et al., 2007; Dussault & Bouchard, 2017). They are sought after by BEF researchers through the investigation of how specific traits of organisms and other biological items contribute to the maintenance and functioning of ecosystems. This requires, however, that the understanding of ecological functions be connected with how organismic functions are conceived in evolutionary theory, which is a central component of the theoretical framework in community ecology (Dussault & Bouchard, 2017). Not surprisingly, BEF researchers stressed that a synthesis of community and ecosystem ecology demands that evolutionary considerations be reintroduced into ecosystem studies (e.g., Loreau, 2010a, b).

It is at the purview of the organizational theory of ecological functions to deliver an understanding of functions that is both ahistorical and evolutionarily grounded. To do so, it will be necessary to elaborate more on the relations between the evolution of organisms and the emergence of ecological interactions and functions in organizationally closed ecological systems.²¹ A key aspect to bear in mind is that, as ecological systems emerge from interactions (at least part of them functional interactions) between populations that have been selected to a considerable extent, an integration between evolution- and organization-based accounts is a *sine qua non* for understanding ecological functions. But how should this integration take place? A fundamental requisite is to consider how to prioritize functional approaches in organisms or ecological systems. At the level of organisms, an evolution-based functional and teleological understanding should be grounded on an organization-based functional and teleological conception of self-maintaining organisms capable of survival and reproduction (Mossio & Bich, 2017). However, at the ecosystem level, it seems to be the case that organization-based function and teleology should be grounded on the interrelations among organismic functions (and also accidental or fortuitous effects) that emerge in evolution at the population level. That is, at the ecosystem level, organization arises from interactions among populations that have been selected for at the population level, as a kind of by-product of organismic functioning to achieve self-maintenance and increase fitness. After all, other populations are always a relevant part of the environment of any population at stake.

²¹A dialogue with the persistence enhancing propensity (PEP) account proposed by Dussault and Bouchard (2017) can be helpful in this effort.

Functions in ecology are relational and contextual, as emphasized by Dussault and Bouchard (2017). They emerge from current interactions between populations that are, at least partly, associated with organismic traits exhibiting functional roles that evolved historically, before a particular ecological system has been formed. This does not mean, however, that such functional traits have evolved for the sake of the ecosystem; rather, they partly evolved due to their fitness-enhancing consequences at the population level, partly due to other evolutionary processes than natural selection, and have been coopted for functional roles in ecological processes within the ecosystem when subject to its closed organization of constraints. For example, in plant-pollinator networks, different populations mutually stabilize each other (allowing for an account in terms of closure of constraints and organizational functions), but it is the evolution at the population level that explains the spread and eventual fixation of functions that are entangled with one another in the ecosystem closure of constraints (e.g., Patiny, 2012). Moreover, the historical constitution of ecosystems involves a “fine-tuning” of functional relations as a result of evolutionary paths, reinforcing the need to integrate evolutionary and organizational perspectives on ecological functions.

13.6 Ascribing Functions to Abiotic Items

For Dussault and Bouchard (2017), the PEP account accommodates the ascription of functions to abiotic components of ecosystems better than the organizational theory, as it allows function ascription to abiotic factors like disturbance regimes and habitat heterogeneity (e.g., Pickett et al., 1999; White et al., 1999). A similar argument is proposed by Odenbaugh (2019) but in a defense of a systemic approach, which is one version of a dispositional theory. But consider how we recently broadened the range of functional items that fall under the umbrella of the organizational theory in order to include abiotic items, provided they are under the control of biodiversity items (El-Hani & Nunes-Neto, 2020). From this perspective, factors like disturbance regimes (say, related to fire) and habitat heterogeneity (for instance, due to the construction of a beaver dam) only play a functional role in an ecological system if they are products of constraints subject to closure in that system and are themselves involved in the production of constraints. If they are not so, then they are not truly functional but just boundary conditions that affect the maintenance of populations and ecological communities in that system (even though they can be functional if we are rather modeling an ecological system at a higher scale). If, say, habitat heterogeneity and disturbance regimes are not under the control of components of an ecological system, they do not have a functional role according to the organizational theory precisely because they are not under the control of the system and do not enable the conditions of existence of other constraints. But this does deny their relevance to the system’s dynamics, as external boundary conditions. This relevance seems to be the reason why ecologists ascribe in a number of cases functions to such external entities and processes. A philosophical analysis can offer,

then, an important clarification about a conflation between the functional contribution from a system's component and the dynamic relevance of external boundary conditions (at a given scale). To describe the interaction of an external entity or process not controlled by a system but influencing its dynamics in terms of a broadened regime of functional integration is incorrect precisely because in this case the system is not exerting any influence upon the generation of the boundary condition (Bich, 2019). If we consider some ecological systems as showing the same kind of regime of closure as autocatalytic sets (see, e.g., Cazzolla Gatti et al., 2017, 2018), it will be also clear why one should not, from this perspective, ascribe an ecological function to entities or processes external to the system and not under its control. This conflates being a boundary condition to the system's dynamics with playing a function, which is an important drawback, since functions are attributed to components of a given system.

If an external entity or process is under the control of the system, as disturbance regimes or habitat heterogeneity in a number of cases are, then it has a functional role defined in accordance with the closure of constraints defining the system, since by being under the control of the system, it becomes subject to closure, being both a dependent and an enabling constraint. Consider, as a case in point, how fire (as a disturbance regime), when integrated into the dynamics of an ecological system, say, through fire-adapted plant species exhibiting traits that promote flammability and, thus, influence fire frequency (e.g., Mutch, 1970; Schwilk & Ackerly, 2001), is not merely destructive but rather enabling, leading to regrowth processes that are crucial to the system's dynamics. In these cases, vegetation is a driver of fire regimes, and one can even talk about coevolution of fire and biota (McLauchlan et al., 2020).

Dussault and Bouchard (2017) consider, in fact, precisely the argument we are advancing here but refuse it because it would, they argue, run counter to the tendency in contemporary ecosystem ecology to include disturbance regimes into the dynamic of ecosystems irrespective of whether they are under biotic control or not. However, we think there is no real problem in this case, because boundary conditions are part of the dynamics of the system no matter if they are within the closure of constraints or not. This is a clear case in which the concept of closure of constraints is not properly expressed, since it only demands that part of the constraints exerting influence on the system be internal to closure. A boundary condition that affects the system without being within closure is still part of the system's dynamics.

Another argument presented by Dussault and Bouchard concern the difficulty of determining whether a disturbance regime is under the control of the ecological system, since it may lie on a continuum between being biotically controlled and uncontrolled (Pickett & White, 1985, pp. 8–9). First, this is an empirical problem that does not challenge the organizational theory: it is quite common in scientific research that the stipulations of a theory pose empirical challenges for their application to real-world processes. Second, the organizational theory can accommodate through the idea of tendency to closure a situation in which an external process or entity (say, fire) is somewhere on a continuum between being biotically controlled or not. In this case we would in fact ascribe function to fire if it is at least to some extent under biotic control.

Differently from Dussault and Bouchard (2017), who intend to follow ecologists' ascription of ecological function to abiotic entities and processes, no matter if they are under the control of the ecosystem or not, we rather think to be preferable to conceptually clarify the case from a philosophical perspective. It seems to us that – revisionist or not – the philosophical analysis at stake drives home a relevant distinction to ecological research, which we exemplify using fire as an example. If fire is under control of constraints internal to the ecological system, it can be both enabling and dependent, being part of the ecosystem closure of constraints, and, thus, being ascribed function, but if it is not under the control of those constraints, even if fire may be eventually enabling, it will not be dependent on internal constraints, and, thus, it will be just an external boundary condition, which should not be described as functional within that ecosystem, despite their significance to the system's dynamics. We do not see a problem in adopting a “revisionist stance” (as Dussault & Bouchard, 2017, p. 1133, calls it) in relation to some attributions of functions by ecologists. After all, epistemological studies would be quite limited in their utility and contribution to scientific research if we assumed that philosophical analysis could never clarify the uses of concepts by scientists themselves.

It does not matter, then, if some abiotic process has the same effect on an ecosystem as a biotic process to which an ecological function is ascribed, as in the example of nitrogen fixation by lightning or volcanoes. Contra Odenbaugh (2010, p. 251), this does not mean that those abiotic processes should be ascribed a function as well, since what they have in common with the biotic process at stake is just that they are both boundary conditions. Nevertheless, the crucial distinction between being a boundary condition under control or deprived of control by the system still applies and is, in our view, crucial to keep in place the distinction between what is truly functional and what merely affects the system's dynamics. From the perspective of the ecological system, nitrogen fixation by a lightning is merely a boundary condition (which, by accident, can fortuitously affect an ecosystem's dynamics, or eventually become stable enough to affect the dynamics on a steady basis²²), while the same process carried out by bacteria has an ecological function.

Another case that does not bring as much trouble to the theory as Dussault and Bouchard (2017) think concerns source-sink dynamics (e.g., Pulliam, 1988; Pulliam & Danielson, 1991; Amarasekare & Nisbet, 2001; Loreau et al., 2003), which explains the maintenance of “sink” populations, i.e., populations which would run locally extinct if not maintained by constant immigration from “source” populations, as well as of “source” populations whose abundance would often inflate considerably if there was no emigration to “sink” populations. They correctly argue that the effects of source-sink dynamics are often indistinguishable from those of more conventional density-dependent regulation processes (as discussed by Sterelny, 2006, pp. 219–220) and would thus warrant ecological functional ascriptions just as

²²In this case, it may be that the dynamics of the system eventually turns the boundary condition subject to closure, meaning that the abiotic process become a functional part of that system. This does not affect, however, the core of our argument.

in the latter case. True. But there seems to be no problem, however, in ascribing ecological functions to sink and source populations based on the organizational theory. It is only necessary to describe a higher-level entity of which those populations are part, playing functions within its closure, such as a metacommunity or metapopulation, depending on whether we are dealing with multiple or single species. Therefore, in the case of both density-dependent regulation processes and sink-source dynamics, the closure criterion can be met, and function can be ascribed according to the organizational theory.

13.7 A Word on Pluralism About Ecological Functions

It is worth saying here a few words on pluralism about functions. In the overall literature on biological functions, pluralism has been often regarded as an attractive option. For instance, a number of authors supported a pluralistic solution to the problem of function by advocating that the etiological and dispositional theories offered two complementary concepts (e.g., Millikan, 1989; Amundson & Lauder, 1994; Allen & Bekoff, 1995). Godfrey-Smith (1993) called this solution a “consensus without unity.” Currently, one cannot advocate for pluralism about functions without considering also organizational theories, in their several versions, as one of the key players in the debate. Specifically in the ecological domain, Garson (2018) has also defended within-discipline pluralism about functions.

But, when we are dealing with some specific problem, it seems to us that pluralism should be the conclusion we reach once we did our best to find a single, unifying theory. It should be the outcome of an investigation that justifies the principled impossibility of a unified account. If we think that a certain theory about function, ecological or otherwise, cannot be the unique one, a proper justification should be offered. Why is it the case? Moreover, to avoid empty pluralism, we need to identify which kind of phenomena can be accounted for by which models, such that we may in the end reach a theory unified as a family of models, as proposed in a pragmatic view of theories in ecology (Travassos-Britto et al., 2021).

To our understanding, we are not yet at a point in the investigation that allows us to settle the case and conclude for a pluralistic perspective on theories of ecological function. The jury is still out. Thus, rather than assuming pluralism, we will leave for now this possibility open and continue inquiring into the application of the organizational theory to different uses of functional explanations and ascriptions in ecological and conservation research. This does not mean that we are claiming that normative functions will be properly attributed to each and every ecological system. Also, this is not the same as exclusively defending organizational functions as an overarching account for all functional ascriptions in ecological research, as Lean (2021) claims to be our intention. We are simply continuing to pursue our avenue of inquiry, extending the theory as much as we can, but open to the possibility that it may not apply, eventually, to a number of functional ascriptions made by ecologists.

The organizational theory of ecological functions remains expandable to new cases, and we really do not know if the latter may be the case.

As an example of how the domain to which the organizational theory is applied can be extended, we can consider two mechanisms proposed to explain how biodiversity enhances the maintenance and resilience of ecosystems, namely, sampling and compensation effects (e.g., Sterelny, 2005).²³ In the former mechanism, the increased resilience of species-rich ecosystems is attributed to the statistical fact that they have more chances to contain species whose functional performance will not be affected by a range of environmental variations. In this case, the functional contribution to ecosystem maintenance is attributed to items of biodiversity rather than to biodiversity as a whole, and no difficulty is posed for the organizational theory. Compensation effect is, however, a different matter, as the increased resilience of species-rich ecosystems is related in this case to response diversity, i.e., the presence of many species that respond differently to environmental variation but are able to perform similar functional roles in the ecosystem. Response diversity entails, thus, that the species may show compensatory dynamics, i.e., when an ecosystem is subject to variation in its interaction with other systems that leads a formerly dominant species to decrease in abundance, the functional consequence for the ecosystem dynamics can be buffered by the compensation of another species that is functionally equivalent but shows a differential response to the variation at stake. Thus, the likelihood that a variation leads to impacts that may disrupt ecosystem functioning and harm its capacity of maintaining itself is reduced, and, conversely, ecosystem resilience before that variation is maintained or even enhanced.

Compensation effect illustrates a case in which more work is needed to extend the domain of the organizational theory. In the definition of organizational function proposed by Saborido et al. (2011), function is ascribed to a *trait* that exerts a constraint subject to closure in an organization of a given system. Mossio et al. (2013) characterize a constraint as a *configuration* and Moreno and Mossio (2015) as an *entity* that exhibit a symmetry with respect to a process (or set of processes) under its influence. Nunes-Neto et al. (2014) consider *items of biodiversity* as objects of functional ascription in ecology, while El-Hani and Nunes-Neto (2020) recently broadened the set of functional objects in the theory to include *abiotic items*. Biodiversity is a global property or, to put it differently, a distributed feature of an ecological system. The question that arises is as follows: Can a global property be a constraint, such that the organizational theory justifies the ascription of ecological function to biodiversity *per se*? At this point, we do not see any fundamental blockage for formulating the notion of constraint in such a manner that this justification can be done. While it may stretch the concepts too far if we treat biodiversity as an entity in an ecosystem, the use of categories such as trait and configuration in the organizational functional discourse paves the way to encompass biodiversity as an object of functional ascription. This will need some reworking of the notion of

²³The arguments in this paragraph benefited a lot from the discussion made by Dussault and Bouchard (2017, pp. 1133–1134).

constraint in order to include under its extension global properties such as biodiversity, but this will not be some far-fetched conceptual operation. Therefore, while there is still work to do, the organizational theory can be applied to explain both the specific functional contributions of many items of biodiversity to the overall functioning of an ecosystem and the collective stabilizing function of response biodiversity.

13.8 From Organizational Functions to an Integrated Scientific and Ethical Approach to Sustainability

The fortunes of teleological accounts of ecological functions, such as the organizational theory, may have important consequences to conservation ethics. If we show that ecological systems are structured in such a manner that their parts are functional for the whole, we may be able to provide support to the claim that they possess a type of natural value on a naturalistic basis. Such a natural normativity can facilitate objective judgments about the role of populations within ecosystems and about conservation measures, as well as mediate debates in conservation ethics and provide guidance for thorny environmental ethical questions.

What does the idea that ecological (and, possibly, socioecological²⁴) systems realize closure of constraints entail, then, for an ethical perspective on such systems? Recognizing that biological systems include constraints that perform functions is to recognize a normative dimension of the very existence of these systems. In this sense we can differentiate between two kinds of systemic state, namely, between organized states, which exist according to the norms of the system's behavior, maintaining conditions of existence that allow its persistence and resilience, and states that work counter to the system's organization, deviating from the norms of its behavior and disrupting its conditions of existence (Moreno & Mossio, 2015; Cooper et al., 2016; Montévil, 2021). That is, the functionality of certain biological features concerns not only a current performance of an ecological system but a performance that the system must do in order to continue to exist. It seems, then, that we may be able to discern in a normative way between *good* and *bad* functioning of ecological systems (Cooper et al., 2016). It is at this point that the descriptive language of biological organization touches on ethical and axiological aspects.

Notice, however, that this is a more demanding normative dimension than that that play when we just speak of functions. If we consider, say, a pumping heart, this organ will be fulfilling the biological norms involved in the performance of its function even when pumping poorly, with consequences to the organism's health. To consider the performance of the heart's function in a healthy condition demands, thus, a second, additional set of norms, establishing that the heart is not only

²⁴For a brief and initial discussion of the application of the organizational theory of functions to socioecological systems, see Nunes-Neto et al. (2016b).

functioning but also functioning *well*. Accordingly, one thing is ascribing normativity to ecological functions based on the intrinsic purposiveness associated with the realization of closure by an ecosystem, as a causal regime maintaining its own conditions of existence. Another thing is considering whether an ecosystem is functioning poorly or well, as this requires a second source of normativity. What should this source of normativity be is one of the issues to be tackled by an environmental ethics theory.

There are important differences, however, between proposing an organizational view of ecological systems and functions (which is mostly an epistemological stance) and developing an ethical perspective on them (which entails an interpretation based on moral philosophy). Let us begin, thus, by appreciating an important conceptual difference in moral philosophy which is important for our arguments, namely, that between moral agents and moral patients (Warnock, 1971; Goodpaster, 1978; Nunes-Neto & Conrado, 2021). A moral agent is a being capable of emitting moral judgments, which can be – as a consequence – held responsible for its actions. In turn, a moral patient is a being that matters in relation to actions and, accordingly, should be taken into consideration in moral judgments about the latter. When dealing with ecological systems, we are primarily talking about moral patients, rather than moral agents, who could have any kind of moral duty, obligation, or responsibility. When we refer to what an organism or species (say, a bee species) should do in relation to the norms of an ecological system's behavior (say, in a pollination network), we are surely not considering any moral duty, obligation, or responsibility but just manifesting an expectation that a given behavior must happen if those norms are to be observed and conditions needed for the system's resilience and persistence are to be fulfilled. But this expectation may also offer criteria to distinguish between what is good or poor working of the system, providing an ethical perspective on its organization and functioning.

But would we not be committing a fallacy – namely, the naturalistic fallacy – by constructing an ethical perspective on ecological systems from an organizational theory of functions? We cannot simply make inferences from purely factual claims to moral ones, or, to put it differently, *normative claims* about what *ought to be true* can never be validly inferred from *factual claims* about *what is true* (e.g., Kitcher, 1993; Sterelny & Griffiths, 1999). This means that the use of good, bad, well, poorly, or other normative terms in an ethical context does not entail merely an expectation about the natural behavior of systems but also about what we consider that we – human beings as moral agents – *must do* in relation to others (humans or nonhumans), to moral patients, in our everyday life. There is a central difference between developing an organizational theory of ecological functions and an ethical perspective on ecological systems: while the normative language in the organizational theory expresses facts (even if dispositional), the normative language in the ethical field expresses values. The kind of normativity that stems from the organizational theory does not come from the same sources than those at play with ethical and moral human judgments. When we consider an ethical view about ecological systems, we must also recognize, thus, our own (human, thus ethical) perspective, which – at least from our point of view – cannot be reduced to a naturalized

outlook about organizational functions only. In this sense the difference between ethics and natural sciences is of central relevance, even if a dichotomous view of facts and values is avoided:²⁵ ethical issues concern, preponderantly, matters of value, while the natural sciences deal, mainly, with matters of fact, but matters of value and fact, albeit not entailing one another, do interact.

This difference does not mean, however, that it is not possible to build an integrated perspective combining the organizational theory and an ethical theory. It only means that we should not do so by committing a naturalistic fallacy, since one thing is an epistemological (naturalistic) outlook on organisms and ecosystems, and another thing is an ethical standpoint. But these stances are not necessarily in contradiction; they can interact with one another, and, perhaps, in some cases be even conceived in a kind of continuity or complementarity. As Sterelny and Griffiths (1999) argue, even if moral principles cannot be inferred from purely factual biological premises, we can discover morally relevant facts through biological research, which can interact with existing moral principles to produce new practical policies.

In what follows, we are not going to talk about ethics in general, but rather talk about environmental ethics, since ecological systems are our main focus here. As soon as environmental problems gained notoriety (around the 1970s), a new field of ethical reflections was consolidated, environmental ethics, as a way of dealing with a whole range of new issues that could not be well grasped by more traditional ethical frameworks. This was so because those issues concerned a series of beings and processes that had not been commonly considered in previous ethical studies. In its emergence, environmental ethics differed from previous views, which were generally anthropocentric (i.e., focused on human beings). In this sense, environmental ethics broadened the scope of ethical study and reflection to include other natural entities and processes such as animals, plants, rivers, mountains, ecosystems, etc. This was an expansion of the scope of moral considerability (i.e., concerning which beings or entities should be morally considered in our decisions and actions). What was at stake, in short, was which among all the natural beings should we humans (as moral agents) accept as moral patients (Warnock, 1971; Goodpaster, 1978; Vaz & Delfino, 2010).

Kant [1785] 2007) differentiated between direct and indirect moral considerations, depending on the moral status we recognize in other beings. We consider something to be under the purview of indirect moral consideration when its value is not final but rather justified by reference to something else, which is external to it. For example, the value of a hammer comes from the act of hammering, which is external to the hammer itself. In this case, the value of a hammer is merely instrumental. In turn, we generally accept – in accordance with Kant's view – that the importance of a human life is final, in the sense that it has value in itself, without

²⁵ Following Putnam (2002), we do not endorse a dichotomy between facts and values (as assumed, for instance, by logical positivists), but this does not mean that we cannot differentiate between them. Every fact is value-laden, as well as values are connected to facts in the empirical domain. Here, we assume a non-dichotomous difference between facts and values, as well as between science and ethics, recognizing at the same time that there are mutual influences between them.

requiring justification in terms of anything else. Accordingly, a human life cannot be grouped generically together with other entities that might supposedly replace it in fulfilling some external value (as is the case of a hammer, which, when broken, can be replaced by another one, with no harm to the satisfaction of its value). This means a human life is irreplaceable and shows intrinsic value, i.e., a value that is justified in itself. Direct moral consideration results from the recognition of this type of value (Warnock, 1971; Goodpaster, 1978; Vaz & Delfino, 2010).

For Kant ([1785] 2007), only human beings – as rational beings – should have their intrinsic value recognized, being fundamentally different, in ethical terms, from things and other beings. However, the appraisal of this humanist position has changed with the emergence of environmentalism, among other developments. This view came to be regarded as a form of anthropocentrism. Environmental ethics translated moral perceptions that came to the fore with environmentalism into the proposal of expanding moral theories in such a manner that recognition of intrinsic value in other beings could be justified (Warnock, 1971; Goodpaster, 1978).²⁶

This expansion of moral theories resulted in a variety of different positions. The sentiocentric current,²⁷ for instance, attributes intrinsic value to all sentient beings, i.e., to all those that can experience their own life (including humans and a range of nonhuman animals). The biocentric current, in turn, recognizes the intrinsic value of all living beings, whether they are sentient or not (also including, say, bacteria, fungi, etc.). The ecocentric current, finally, ascribes intrinsic value to ecosystems and cannot be regarded as a mere expansion of other moral theories, due to its more holistic character (Vaz & Delfino, 2010; Nunes-Neto & Conrado, 2021).

In the wake of this theoretical expansion, one of the main tasks has been to justify the intrinsic value of nonhuman beings. This means to offer reasons to justify which of these beings (if any) have a purpose of their own. As the organizational theory discussed here naturalizes the concept of function in living systems, it offers a possible contribution to the understanding of this purpose (see, e.g., Holm, 2017; Moosavi, 2019). Biocentrism offers a case in point. In the case of this stance, the justification for ascribing intrinsic value to all living beings stems from the idea that the intrinsic teleology associated with organisms provides a criterion for objective recognition of a good of its own, a good that does not originate from subjective attribution of value (e.g., Taylor, 1986; Varner, 1998).

Holm (2017) investigates whether the biocentric claim can be well justified by the organizational theory in response to what he calls the scope problem. According to this problem, for the biocentric justification to correspond with the moral

²⁶We chose here, for simplicity, a Kantian way of describing the changes brought about by the emergence of environmental ethics. However, there are other equally important moral theories, such as utilitarian and virtue ethics theories, that would describe the research tradition of environmental ethics differently.

²⁷Sentioethical ethics can be understood not as an environmental ethics *per se* but as an animal ethics, with its own research agenda. However, it is part of the same movement of questioning and overcoming the anthropocentric position and that is why it is described here within the same tradition of environmental ethics.

intuitions of biocentrists, it is necessary that the teleology identified in living beings encompasses all types of possible organisms and be exclusive to them, i.e., not shared with non-organisms (e.g., artifacts and inanimate objects in general). Holm argues that the organizational theory, to a large extent, locates the scope of teleology in the domain of living systems, except for the theoretical possibility that some dissipative systems, such as candle flames and hurricanes, also show a rudimentary sort of constraint closure, resembling the intrinsic teleology described by the organizational theory. He considers, then, that this possibility poses a problem for the defense of a strict view of biocentrism, as it more appropriately points to a defense of a teleocentrism, which acknowledges that beings that are not organisms can also (albeit arguably) be targets of direct moral consideration whenever they show intrinsic teleology.

Moreover, the naturalization of the ascription of functions to biological items, as articulated by the organizational theory, is regarded by Holm as suggesting a potential empirically testable criterion for the biocentric claim. That is, as any system realizing self-determination by means of a closure of constraints will exhibit intrinsic teleology and, hence, a good of its own, the organizational theory enables biocentrists to turn the claim that living systems show such a good into an empirical thesis, without appealing to the contested concept of “life.”

Holm’s proposal of a teleocentrism points to the possibility that a supraorganismic system be regarded as having a good of its own, provided it shares the same kind of orientation toward the end of self-maintenance exhibited by organisms (which awakens the moral feelings of biocentrists). Once we consider that this is the case of ecosystems, the path is open for an ecocentric argument, such as that developed by Rolston, III (1987), who understands nature as a set of teleologies, ranging from human self-legislation to ecosystem self-maintenance, passing through organic autonomy.

Nunes-Neto et al. (2014) support this understanding by showing how an ecosystem can be treated as an organizationally closed system in which the items of biodiversity (and abiotic items, see El-Hani & Nunes-Neto, 2020), acting as mutually dependent constraints on the flow of matter and energy, give rise to intrinsic teleology, just as we observe in organisms, even though ecosystems typically lack other distinctive features of the latter, such as agency. Once one accepts the organizational theory of ecological functions, it might seem that a strictly biocentric position could not hold, since the same criteria for the good of organisms may be also valid for ecosystems. However, it is not really the case, to our understanding, that the teleological grounding of ecocentrism on the organizational theory of ecological functions denies the epistemological legitimacy of biocentrism. Looking more closely, we must notice that, as Nunes-Neto and Conrado (2021) argue, biocentrism and ecocentrism are not contiguous perspectives on the scope of moral considerability but, instead, are focused on different kinds of entities. While biocentrism lies in the same spectrum as, for instance, sentiocentrism and anthropocentrism, ecocentrism is a response to the lack of moral considerability of nature in general, arguing that holistic entities such as ecological systems should be morally considered as having

intrinsic value. This means that biocentric and ecocentric perspectives are not mutually exclusive, even though in some situations there could be tensions between them, such as in the classical example of hunting wild animals for maintaining ecological attributes of ecosystems (see, e.g., the debate between Regan, 2013, and Callicott, 2010) or the example of cutting and removing a tree in order to produce organic matter to maintain an agroforestry system (Miccolis et al., 2019).²⁸

Following the argument above, if an ecological (or for that matter, socioecological) system realizes closure of constraints in a similar way to organisms, then it will be also a candidate for the recognition of its own good. What does that mean? Namely, that each and every ecological (and socioecological) system would have its own good, considering only the criteria provided by the realization of closure of constraints and intrinsic teleology. However, this conclusion would lead to serious moral conflicts since, if we dissociate the whole from the parts, it will be possible to conceive the well-being of the whole, even if there is no well-being of one or more parts. For example, it would be possible to think that a socioecological system including slavery might have a good of its own if it showed organizational closure. However, just as ecosystems are formed by items of biodiversity that exhibit their own individual good, so are socioecological systems and, accordingly, the claim that a socioecological system including slavery might have a good of its own would not hold. Rather, we would be facing in this case a conflictive state of affairs. This is analogous, in fact, to a dilemma discussed above: just as there may be conflicts between biocentrism or sentiocentrism, on the one hand, and ecocentrism, on the other, the same is true in the case of socioecological systems. These conflicts will happen whenever there are tensions between the intrinsic goods of individual

²⁸Another example of tension between biocentric and ecocentric perspectives concerns the implications of redundancy to conservation decisions based on considerations about role functions. For instance, if two species play the same role function in an ecosystem and the extinction of one of them does not impact sustainability (because of redundancy), functional considerations may fail to provide a rationale to preserve it. This is a relevant problem for conservation decisions justified on functional grounds, which does not go away when we propose, from an integrated scientific and ethical point of view, a conception of sustainability that entails our duty as moral agents to support the self-maintenance of ecological systems (see below). This is not the space to engage with this issue in the depth it deserves, but let us just briefly state that, first, pluralism about functions may play an interesting role in this respect, since conservation decisions that seem attractive, but are not justified by some theory of ecological function, may well be justified by another one. Second, that the problems entailed by redundancy for conservation decisions have been recognized and debated in the scientific literature for a while, and one of the outcomes of the discussion has been the requirements of more fine-grained descriptions of ecological role functions, such that what at first may seem to be a redundancy may eventually be shown to be a case of functional complementarity between the roles played by two or more species in relation to ecosystem processes (e.g., Rosenfeld, 2002; Oliver et al., 2015). An ecological community can only be maintained if there is functional complementarity among several anatomic, physiological, behavioral, and other attributes of the populations composing it, as it has been shown, for instance, in several studies on pollination systems (e.g., Brittain et al., 2013; Fründ et al., 2013). Surely, in the case of complementarity, the conservation of all species at stake will be justified.

organisms (humans or not) and the intrinsic goods of whole ecological or socioecological systems. It seems to us that these dilemmas can be avoided by an understanding of the system's well-being as integrated to the well-being of its parts, which seems reasonable, once the system is composed by the parts and their interactions. Cases of conflict between the system itself and its parts may generally involve some kind of malfunctional behavior. However, a more complete evaluation of this problem is out of the scope of this chapter, and we shall leave it for future investigation.

What does the recognition or ascription of intrinsic value to an ecological (or socioecological) system mean? First, that we consider that system as important in itself, that is, as having a purpose of its own, or a value of its own. Second, that we judge we have a duty to the system with regard to its self-maintenance. In short, we must promote the resilience and persistence of the system, and not its destruction. This is equivalent to saying that we must sustain the system, i.e., that we must act toward its being a sustainable system. In short, sustainability, from this perspective, is the realization of the duty to promote the good of an ecological (or socioecological) system that has its intrinsic value duly recognized by virtuous moral agents integrated into a worldview of respect for nature. This new conception of sustainability provides an alternative to the usual anthropocentric and economically based version, associated with the management of natural resources, (social, economic, or ecological) capital, and/or ecosystem services. By combining intrinsic valuation with the self-maintenance of ecological (or socioecological) systems, this new conception allows us to use a common "grammar" to refer to respect for nature and responsibility (see Larrère, 2013) in such a manner that the values of technological progress, capital, and the market can be subordinated to what Hugh Lacey (2014, 2016) calls "viable values," associated with the sustainability of socioecological systems, social justice and participation, and universal well-being.

The organizational theory of ecological functions offers a promising way not only to further develop important positions in environmental ethics but also to integrate fields of ethical knowledge hitherto pursued in a relatively independent manner. This does not mean – it is important to notice – that the organizational theory can ground by itself an ethics. This theory, applied to organisms or ecological systems, offers a naturalized epistemological perspective on their organization and intrinsic teleology, which is not sufficient, in our view, to ground ethical aspects related to the interactions between human beings (as moral agents) and other beings or systems (as moral patients). These ethical aspects demand a consideration, both in theory and practice, of properly ethical and moral perspectives (for instance, theories providing criteria to ground the value of moral actions, or differences in value ascription), which cannot be reduced to a naturalized approach. Nonetheless, there is much to gain from an interaction between morally relevant features of a naturalized approach to the intrinsic teleology of organismic and supraorganismic systems and principles provided by ethical and moral theories.

13.9 Concluding Remarks

We further developed in this chapter the organizational theory of ecological functions by responding to some criticisms that allowed us to sharpen the theory. We argued about the individuation of ecosystems as organizationally closed systems, to which the theory can be applied, provided some comments on how evolutionary considerations may be integrated into an organizational understanding of ecological functions, and took additional steps for elaborating on how functions can be ascribed to abiotic items according to the theory. We expect to have shown how the organizational theory provides a convincing basis for naturalizing the teleological and normative dimensions of ecological functions, as well as for making contributions to the construction of an integrated scientific and ethical approach to sustainability that can avoid an anthropocentric perspective.

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