ANABIONTICS I

The Material Governance of Biological Persistence

Hiram Dunn
AstroBiota
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Biological partnerships are usually described by identifying their participants and the resources exchanged between them. In a lichen, a fungal partner associates with a photosynthetic partner. In the eukaryotic cell, mitochondria occupy an intracellular metabolic relationship with the surrounding cell. Microbial communities exchange metabolites, occupy complementary niches, and construct shared environments. These descriptions explain much of how coupled biological systems obtain resources and perform metabolism. They do not completely explain how those systems remain coupled through time.

A persistent biological partnership must solve problems that are different from resource acquisition alone. Its participants must remain compatible despite metabolic fluctuation, oxidative stress, environmental change, injury, growth, reproduction, and turnover. Interfaces must be maintained. Local conditions must remain within viable ranges. Damage must be repaired. The behavior of one partner must remain sufficiently coordinated with the behavior of another that the coupled state does not continually collapse.

Persistence therefore requires regulation. I use the term anabiontics for the material and signaling biology through which that regulation is performed.

The theory begins with a functional distinction between two roles within a coupled biological system. The catabiont is the component disproportionately associated with throughput: acquisition or production of metabolic resources, energetic flux, expansion, growth, and other processes that sustain productive activity. The anabiont is the component disproportionately associated with persistence: regulation of compatibility, buffering of disturbance, maintenance of interfaces, repair, adaptive signaling, and preservation or reconstruction of the coupled state.

These terms describe roles rather than permanent identities. A biological component may participate in throughput at one scale and persistence at another. A mitochondrion, for example, is centrally involved in energetic throughput through oxidative metabolism, yet mitochondrial redox signaling can also regulate stress response, metabolic adaptation, mitophagy, biogenesis, and broader cellular state. The same component can therefore participate in both sides of the polarity depending on the function being examined.

The distinction becomes useful when it is carried from biological roles into material biology. An anabiont does not govern persistence abstractly. It must act through physical means. It produces signals, modifies redox conditions, secretes metabolites, regulates interfaces, constructs polymers, repairs structures, changes local environments, and responds to the state of its partner. These outputs are what I call anabiontics when they participate in preserving the continuity of a defined coupled biological state.

Anabiontics therefore concerns the physical mechanisms through which biological partnership remains possible.

1. Anabiontic Behavior

The first requirement of the theory is to distinguish anabiontic behavior from biological activity in general. A biological effect is not automatically anabiontic. A nutrient may increase biomass. A toxin may alter phenotype. A hormone may trigger development. A metabolite may inhibit a competitor. Each changes biological state, but state change alone does not establish a persistence role.

Anabiontic behavior occurs when the activity of one component contributes to maintaining, regulating, recovering, or reconstructing the coupled state of a biological system.

This can occur through several different physical channels. It may be chemical. A secreted metabolite may alter redox tone, gene expression, immune response, developmental behavior, or metabolic activity in another component of the system. It may be hormonal or hormone-like. Indoles, catechol-derived compounds, phenolics, and other signaling molecules can operate across biological boundaries and couple environmental or metabolic conditions to changes in physiology.

It may be redox-mediated. Reactive oxygen species, antioxidant systems, electron-transfer compounds, and redox-responsive metabolites can act not merely as damaging or protective chemistry but as signals through which cells and organisms coordinate responses to metabolic condition. It may be mechanical or vibrational. A biological structure can transmit physical information between organisms and organize subsequent behavior. It may also become structural. A secreted polymer, extracellular matrix, membrane, web, coating, or conditioned substrate can persist beyond the event that produced it and become part of the physical environment through which the partnership continues.

These mechanisms appear different when classified chemically. From the perspective of persistence, however, they may perform the same higher-order function. They allow one part of a coupled system to alter the conditions under which the other parts operate. That is anabiontic behavior.

The defining question is therefore not simply what a material is or which organism produced it. The relevant question is: what does this output do for the persistence of the coupled state?

2. Signaling as Persistence Governance

This distinction is especially important for signaling molecules. Biochemistry contains many classes of compounds that are normally discussed according to their immediate molecular mechanism: neurotransmitters, hormones, quorum signals, stress metabolites, antioxidants, pigments, secondary metabolites, and redox cofactors. Yet these classifications can obscure a more general system-level function.

A signal can regulate whether a partnership remains within a viable state. Redox signaling provides a clear example. Oxidation and reduction are not simply chemical damage and chemical protection. Redox state can carry biological information. Changes in reactive oxygen species, electron-transfer balance, redox-sensitive transcription, and antioxidant response can indicate metabolic condition, environmental stress, infection, nutrient availability, or damage. A responding system can then alter metabolism, repair, growth, defense, or developmental behavior accordingly.

Within a coupled biological system, this creates the possibility of regulatory feedback. One component changes the redox environment. Another component detects or responds to that change. The response changes the behavior of the system, which in turn alters the conditions experienced by the first component. The result is not merely molecular signaling. It is coordination of state.

Conjugated redox-active molecules are particularly interesting in this context because many can participate simultaneously in electron transfer, oxidative signaling, photochemistry, polymerization, and biological communication. Indolic and phenolic compounds are distributed across bacteria, fungi, plants, and animals and are involved in a wide variety of regulatory systems. Their individual mechanisms differ, and they should not be collapsed into a single universal function. What matters for anabiontics is that such molecules provide plausible material channels through which organisms can regulate state across biological boundaries.

An indole is therefore not anabiontic merely because it is an indole. A redox-active molecule is not anabiontic merely because it alters oxidation. The classification becomes appropriate when the signal participates in maintaining or reconstructing a coupled state. This requirement keeps the category functional rather than chemical.

It also explains why hormonal and redox signaling are central to the theory. Persistence is not achieved only by physically protecting biological material. Persistent systems must continuously adjust themselves. A coupled state that cannot respond to changing conditions is fragile even if its structure is initially stable. Anabiontic signaling provides a mechanism through which persistence can remain dynamic.

3. Mitochondria and Internal Biological Partnership

Mitochondria provide a useful model because they show why throughput and persistence must be distinguished without pretending that they belong to completely separate structures. At the most familiar level, mitochondria participate in cellular energetic throughput. They oxidize substrates, maintain electrochemical gradients, and support ATP production. From that perspective they participate strongly in the catabiontic side of cellular organization.

But mitochondrial activity also generates regulatory information. Changes in mitochondrial reactive oxygen species, membrane potential, redox balance, metabolic intermediates, and organelle integrity can alter cellular signaling. These changes can influence antioxidant defenses, stress responses, mitophagy, mitochondrial biogenesis, inflammatory signaling, metabolic adaptation, and transcriptional programs.

The mitochondrion therefore does more than process substrate. Its state can help regulate the state of the cell. This is precisely where anabiontic behavior becomes visible. The relevant distinction is not whether mitochondria are anabionts in

every sense. They are not assigned a permanent taxonomic identity by the theory. The point is that certain mitochondrial outputs occupy an anabiontic role when they participate in preserving the adaptive continuity of the larger coupled system.

A redox signal generated by altered mitochondrial metabolism may cause the cell to reduce activity, repair damage, remove dysfunctional organelles, generate new mitochondria, or modify systemic metabolism. The signal carries information about the condition of one component into the regulation of the whole.

The persistence of the cell-mitochondrial relationship therefore depends partly on communication between metabolic throughput and regulatory response. This illustrates a general principle: stable biological partnership requires feedback between production and persistence.

Throughput without regulation can exhaust, poison, destabilize, or otherwise disrupt the system that produces it. Regulation without sufficient throughput cannot sustain biological activity. Persistent coupled systems therefore require an architecture in which productive processes and persistence-governing processes remain coordinated. Anabiontics concerns the material side of that coordination.

4. From Signals to Structure

Anabiontic activity does not have to remain molecular. Biological regulation frequently becomes material architecture.

Biofilms illustrate this transition clearly. Microbial cells secrete extracellular polymers that alter hydration, diffusion, adhesion, mechanical stability, chemical exposure, and spatial organization. The matrix can also retain metabolites and signaling molecules, establish gradients, and modify interactions among neighboring organisms. The resulting material is simultaneously structure and regulatory environment.

Its importance is therefore not exhausted by describing it as a scaffold. The matrix changes the conditions under which the community behaves. Previous biological activity has become part of the constraint environment encountered by subsequent biological activity. The same principle can apply to fungal extracellular structures, animal extracellular matrices, mucosal environments, plant walls and secretions, microbial films, and constructed biological materials outside the body.

Spider silk offers a particularly useful extension because it demonstrates how anabiontic behavior may become externalized. A web is initially an output of spider behavior. Once constructed, however, it mediates vibration, movement, prey capture, spatial organization, and subsequent construction. The web becomes part of the behavioral interface through which the organism encounters its environment.

In a multispecies or multi-individual web system, this raises a more specific anabiontic question. If different participants contribute differently to construction and maintenance, does the biological partnership divide labor between throughput and persistence? A large web-building spider may contribute disproportionately to expansion, prey interception, or major structural construction. A smaller associated spider could, in principle, contribute disproportionately to repair, reinforcement, local maintenance, or production of silk with different persistence characteristics.

That specific division of labor must be demonstrated rather than assumed. It is presently a working hypothesis. But the theory tells us what to measure: which organism adds new web area, which repairs damaged sections, which silk persists longest, where each type of silk is deposited, how damage alters the behavior of each participant, whether vibrational interactions coordinate maintenance, and whether the presence of one species increases the persistence of the shared structure beyond what either achieves alone.

These are anabiontic questions because they ask which component governs continuity and through what material mechanism. The web therefore provides more than an analogy. It demonstrates how persistence governance could become physically distributed through architecture, signaling, repair, and division of labor.

5. Symbiosis Requires More Than Exchange

This framework is especially important for symbiosis. Symbiotic systems are often described in terms of reciprocal benefit or metabolite exchange. One organism provides carbon. Another supplies minerals. One partner provides shelter. Another performs photosynthesis. Such exchanges are essential, but they do not by themselves explain how the partnership survives disturbance.

A persistent symbiosis must continuously solve problems of interface. The partners must recognize, tolerate, regulate, and physically accommodate one another. Their metabolic rates cannot diverge indefinitely. Oxidative conditions must remain compatible. Growth must remain spatially coordinated. Competition must be constrained strongly enough that the

partnership does not collapse into exploitation or separation. Environmental fluctuations must trigger responses that preserve the whole rather than merely benefit one component in isolation.

Lichen makes this especially clear. A lichen is not adequately described as a fungus located near a photosynthetic cell. The biological state depends on organized architecture and sustained interaction. The fungal component influences hydration, physical structure, exposure, chemical environment, microbial habitation, and positioning of the photosynthetic partner. The photosynthetic partner supplies fixed carbon and contributes its own metabolic and signaling effects.

The persistence of the lichen therefore depends on more than exchange. It depends on regulation of the coupled state. This is where anabiontics becomes distinct from a generic theory of symbiosis. It asks which materials and signals allow the partnership to remain a partnership.

Candidate anabiontic mechanisms may include redox-active metabolites, indolic signals, phenolic compounds, pigments, extracellular polymers, secretions, structural matrices, hydration-regulating materials, or other compounds produced at the biological interface. None should be classified as anabiontic from chemical identity alone. The classification requires evidence of persistence function.

A lichen metabolite that inhibits unrelated microorganisms may be ecologically important without necessarily being anabiontic with respect to the lichen partnership. The same metabolite would acquire an anabiontic role if its presence helps maintain redox compatibility, protect a shared interface, organize partner behavior, preserve structure, or enable recovery of the coupled state. The system must therefore be named before the role can be assigned. This is an essential constraint of the theory.

6. Persistence as a Governed State

Anabiontics ultimately proposes that persistent biological organization is actively governed. Governance here does not imply intention, cognition, hierarchy, or conscious control. It refers to a simpler physical requirement: a variable biological system must contain processes that respond to changing conditions in ways that preserve the organization of the larger system.

A biological partnership that persists for years cannot remain chemically static for years. Its molecules turn over. Its cells divide and die. Its environment changes. Its interfaces are damaged and reconstructed. Its metabolic rates fluctuate. Its partners encounter stress. Persistence therefore cannot mean permanence of components. It must mean continuity of organization through change.

The anabiontic role is the role by which that continuity is regulated. This makes repair an especially revealing behavior. Repair demonstrates that persistence is not simply resistance to disturbance. A structure can be displaced from its previous condition and nevertheless return toward it.

The same logic applies to biochemical regulation. Oxidative stress can move a system away from its previous state. Redox signaling, metabolic reorganization, antioxidant response, repair processes, and structural reconstruction can subsequently move it toward recoverable organization. In both cases the relevant phenomenon is not immobility. It is regulated return.

Anabiontics therefore concerns both the maintenance of an existing coupled state and the mechanisms by which that state can be reconstructed after ordinary disturbance. This provides a stronger criterion than survival.

Two organisms can remain alive while their partnership disappears. A tissue can remain viable while losing its previous organization. A microbial community can preserve biomass while reorganizing into a different ecology. Persistence of components is therefore not equivalent to persistence of state. Anabiontic function should instead be evaluated by asking whether the defined coupled organization remains recoverable.

7. A Material Theory of Partnership

The theory can now be stated precisely. A coupled biological system is a system in which two or more biological components participate in an organization whose behavior cannot be adequately described by considering each component independently.

Within that system, a catabiontic role is disproportionately associated with metabolic throughput, energetic supply, productive activity, or expansion. An anabiontic role is disproportionately associated with maintaining the conditions under which the coupled organization remains viable, coordinated, recoverable, or reconstructable.

Anabiontic behavior is signaling, regulation, buffering, repair, interface management, or structural activity that performs this persistence-governing role. An anabiontic is a material, signal, polymer, secretion, structure, conditioned environment, or other physical output through which anabiontic behavior is executed.

These categories are relational. The same material can occupy different roles in different systems. The same organism can participate in catabiontic and anabiontic functions simultaneously. The same signal can stabilize one partnership while destabilizing another.

The unit of interpretation is therefore not the molecule or organism in isolation. It is: system -> role -> material -> effect on persistence.

This sequence also establishes an experimental discipline. The first task is to define the coupled system. The second is to identify the relevant state whose persistence is being examined. The third is to determine which components disproportionately provide throughput and which regulate continuity. The fourth is to identify the materials and signals through which that regulation occurs. Only then can a material be meaningfully classified as anabiontic.

This approach converts a broad intuition - that some biological partners help maintain other biological partners - into a testable materials biology. It predicts that persistent biological partnerships should contain identifiable asymmetries of maintenance. Some components should contribute disproportionately to repair. Some should dominate interface regulation. Some should produce signaling molecules that coordinate stress response. Some should construct more persistent extracellular structures. Some should regulate redox conditions. Some should help reconstruct the coupled state after disruption.

In many systems, several of these functions may be performed by the same biological component. The theory therefore generates a simple empirical question across scales: who governs persistence, and through what material means?

That question can be asked of a lichen, a biofilm, an intracellular organelle system, a microbiome, a tissue, a synthetic consortium, or a multispecies spider web. The answers will not necessarily share chemistry. They may nevertheless share biological role. That shared role is the foundation of anabiontics.

8. From Persistence to Biological State

The immediate subject of anabiontics is therefore not every material that affects biology and not every structure that happens to persist. Its subject is the physical regulation of continuity in coupled living systems.

This distinction also creates the next problem. If anabiontic signaling and structure can help a biological system maintain one organization rather than another, then those same mechanisms must influence more than persistence alone. They must influence which states the system can enter.

A redox signal can change developmental behavior. A hormone can reorganize metabolism. A conditioned interface can permit a partnership that was previously unstable. A persistent structure can change what interactions become possible. A previous exposure can alter how the system responds to the same signal later.

The theory of persistence therefore leads naturally to a theory of biological state accessibility. That transition requires care. Anabiontics I establishes the simpler claim: biological partnerships contain persistence-governing roles, and those roles are executed through identifiable signals, materials, structures, and feedback systems.

The next question is what follows when those same persistence mechanisms are used not merely to preserve an existing state, but to move a living system toward a state it has not previously occupied. That is the subject of Anabiontics II: The Navigation of Biological State.