

VIEWPOINT

Quantum Conservation Biology: A New Ecological Tool

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Conservation biology is a highly applied discipline, generally concerned with ecosystems perturbed by human activities. It involves understanding statistical distributions, through space and time, of species—often considered to be the discipline's "fundamental unit." An emerging research priority is to formulate mechanistic models that better capture underlying species dynamics, partly for the purpose of informing conservation policy. Mechanistic models that already influence policy might include, for example, those built to capture dynamics for the purposes of assessing population viability in species introductions, or for projecting species' likely responses to climate change.

In improving such models, attention should be given to developments at the frontiers of theoretical biology. Here, I propose applying tools to conservation drawn from quantum mechanics, with the rationale that:

- (1) Quantum mechanics is already being applied in understanding biological phenomena at lower levels of ecological organization;
- (2) Conservationists increasingly focus upon probabilities of species occurrence, not observed occurrence, presenting striking analogies to quantum mechanics.

Quantum mechanics is a core discipline within physics, describing the often counter-intuitive behavior of matter and energy at very small spatial scales. The name derives from observations that certain physical properties vary in discrete amounts (i.e., quanta), rather than continuously. This overwhelmingly successful discipline incorporates strange phenomena, such as matter demonstrating wave-like and particle-like properties simultaneously, and reality being fundamentally probabilistic.

The idea that organisms make use of quantum phenomena ("quantum biology") is not new. Quantum "coherence" may play a role in making photosynthesis more efficient, and biological reactions may involve quantum "tunneling." Studies suggest that birds use "entangled" particles to navigate, and that metabolic scaling results from quantum effects. Physicists have proposed experiments to coerce whole organisms into a "superposition" of quantum states. More contentiously, some have proposed that quantum phenomena play a role in consciousness, and evolution.

But it is levels of ecological organization beyond the organism (e.g., populations, communities, ecosystems) that generally concern conservation biologists, and

quantum biology has not yet been extended to such scales (c.f., Supporting Information). At these scales, one would employ mathematical tools from quantum mechanics to model nonquantum phenomena, rather than expect necessarily to actually observe quantum phenomena. Here, I use the practical topic of barriers to species movement as an example, to outline why the more abstract concept of “quantum conservation biology” is a worthwhile avenue for exploration.

Barriers might be impermeable (e.g., a perfect fence) or permeable, and take many forms, from physical impediments to sensory disturbances (e.g., traffic noise). Barriers are a crucial consideration for many conservation interventions: manmade barriers are used to keep certain species inside reserves and to reduce human-wildlife conflict, or to keep other species (e.g., livestock, artificially hyperabundant native species, invasive, non-natives) out. Equally, an understanding of the influence of either manmade or “natural” barriers to species movements in a given region is crucial in evaluating ecological networks, connectivity, and resilience to environmental change. Barriers consequently play a role across many areas of policy development, including spatial conservation planning, and protected area establishment and management.

The behavior of species encountering barriers to movement is widely studied. A common treatment of barriers—when carrying out environmental impact assessment or designing conservation interventions—would be to assume that all individuals either can or cannot pass through the barrier, or perhaps that some varying proportion of individuals can pass through, between 0.0 (perfect barrier) and 1.0 (no barrier). However, the actual behavior of species near barriers is more subtle and varied than this. Individuals of a given species will pass through barriers that they were not expected to when the conservation intervention was planned (e.g., if a fence was damaged, or somehow circumnavigated). Equally, they might choose not to pass barriers that they are physically able to (e.g., a quiet road)—and even not pass through a barrier using a “green corridor” designed for the purpose, due to some perceived risk. How do policymakers, conservation planners, and project managers model and thereby account for the partially unpredictable, stochastic, and highly variable behavior of species near barriers?

It would be possible to model behavior near barriers using the quantum analogy of “tunneling.” Under classical physics, if a microscopic particle has insufficient energy to cross a barrier of some kind, it never crosses the barrier. But under quantum mechanics, the motion of a particle is captured by the “wave function” of the parti-

cle, and the integral of the squared wave function, over a given range, gives the probability of the particle being observed within that range. A particle's wave function does not drop to zero at barriers, but deteriorates exponentially into them. For sufficiently thin barriers, the wave function can be nonnegligible on the other side, giving a nontrivial probability that the particle passes through. Consequently, quantum particles can “tunnel” through classically insurmountable barriers.

The mathematics of quantum tunneling provides an option for modeling species encountering barriers, such that individuals have some probability of finding a way through, linked to the permeability of the barrier. Then, a variable number of individuals would actually pass through in any given time period. The analogy goes further: an established quantum mechanical phenomenon is that some particles counter-intuitively rebound, even if they have more energy than needed to cross the barrier. This might represent fauna choosing not to cross a barrier they can physically overcome. A mechanistic model is, perhaps, provided for variable and nondeterministic species' behavior near many different barriers. Generally, the wider a range of behavior a model describes, the better—both from a scientific point of view, and in practice.

This is one example of where quantum conservation biology could provide an interesting tool for ecological modeling and conservation policy development. Others exist and are currently under investigation—such as the use of quantum harmonic oscillators to model the behavior of migratory species. Novel analogies for ecological effects on the scale of populations, communities and beyond—which quantum conservation biology provides—could enable the creation of improved and more realistic models (such as mechanistic simulation models for ecosystem dynamics, or species distribution models). In turn, improved models assist policymakers in better determining where species are most sensitive and conservation priorities are most acute, and so, where to target ecological management activities or constrain development impacts (i.e., implement zoning and protected areas), or how best to target species-specific conservation (e.g., species recovery plans). Protected area networks and species recovery plans are examples of conservation policy tools that could directly benefit from abstract concepts such as those contained within quantum conservation biology.

This would not be the first time that conservation policy had been influenced by concepts in other fields. Consider commercial fisheries policy (the study of animal population dynamics incorporates tools from pure mathematics); spatial conservation planning (physics

supplies concepts such as statistical mechanics and entropy); species reintroductions (the derivation of life history parameters, such as carrying capacity, can be derived from basic chemistry via metabolic theory); planning for ecosystem stability (the conceptualization of the 'rivet' model of ecosystems emerges from engineering); and the design of conservation incentives for natural resource users (e.g., game theory, drawn from economics).

Yet, quantum mechanics captures the imagination like few other theories. Decision-makers increasingly seek interdisciplinary science to underpin policy, and quantum conservation biology would be a captivating example of such. Research combining quantum mechanics with a mission-driven discipline like conservation biology would be of enormous popular appeal.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Table S1. Selected research concerning the observation of quantum phenomena, or the use of tools from quantum mechanics, at different levels of ecological organization.