

Conservation Medicine: the Changing View of Biodiversity

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Meffe's (1999) editorial in *Conservation Biology* established a timely point of discussion on the intersection between conservation biology and medicine. As Meffe points out, conservation biology is becoming increasingly multidisciplinary. To that end, the editorial primarily considers conservation medicine, meaning health, both human and animal, considered in an ecological context. But the underlying issue is larger than this. Because human and veterinary medicine is concerned primarily with microbial pathogenic morbidity (i.e., medical microbial ecology), we need more discussion on the issue of biodiversity as it applies to microorganisms, the microbiota, in all environments. Conservation biologists need to consider microbiota as well as macrobiota. In doing so, conservation biology as a science will be poised to embrace the National Science Foundation's (NSF) long overdue and still forming concept, biocomplexity: a multidisciplinary approach to understanding this world's environment and the importance of scale from the micro to the macro (Mervis 1999).

By defining what is known of the microbial world, we can contribute information to human and animal health, evolution, and conservation biology. Considering human health is a good thing, but considering whole-ecosystem health as it is being maintained by the microbiota is a great thing. Without microorganisms, "biodiversity" would not exist. Two of the three domains of life are microbiotic, yet most considerations of biodiversity deal with the visible macrobiotic life, a small subset of the Eukaryotic domain. Colwell (1997) has said that "microorganisms inhabit virtually every ecological 'nook and cranny' in the biosphere," yet the biodiversity of these nooks and crannies remains a mystery.

The classification of life circa 1969 was different than it is today (Fig. 1). "Monera" in 1969 consisted of the blue-green algae and bacteria. Whereas "monera" were

thought to be of minor importance at that time, we now know that Archaea and Bacteria (formerly the monera and more recently known as the prokaryotes) make up two of the three domains of life. They are of great importance in terms of where the majority of the Earth's diversity occurs (Fig. 1). Even in the Eucarya, the third domain, only the crown is macrobiotic in scale. The majority of the Eucarya are microbiotic, but in terms of numbers, macrobiota still dominate "described" biodiversity. If conservation medicine begins to consider conservation biology's ideas as applied to pathogens in human health, why can we not apply these ideas to the full environmental microbiological arena? How widespread is island biogeography in the microbial world? What are the effects of patch dynamics in a microbial ecosystem, either as a subset of a macro-ecosystem or in a pathogen-human interaction? No one knows the actual extent of diversity within Bacteria and Archaea, much less what roles they play in the environment. Arguably, there is more biodiversity in the bacterial world present on the backs and in the alimentary canals of the sea turtles on the cover of the October 1999 *Conservation Biology* than there is represented in the turtles' own macroscopic, visualized ecosystem.

From what I have heard in discussions on biodiversity, biologists tend to assume that biodiversity revolves around macrobiology—the things we see—as evidenced in Fig. 1. Because conservation medicine is an area greatly affected by microbiota, a definition of what constitutes biodiversity is in order. *National Geographic* has provided the publicly accessible definition: the natural array of species along with the processes and interactions that sustain them (representing the microbial world) (Chadwick 1995). This definition has been followed by descriptions of the intricate web of animals, plants, and all other living things that populate the planet, emphasizing not just the number of species but the genetic diversity within species (Swerdlow 1999).

Prokaryotic-eukaryotic interactions are ancient, and this antiquity has heavily influenced biodiversity. For ex-

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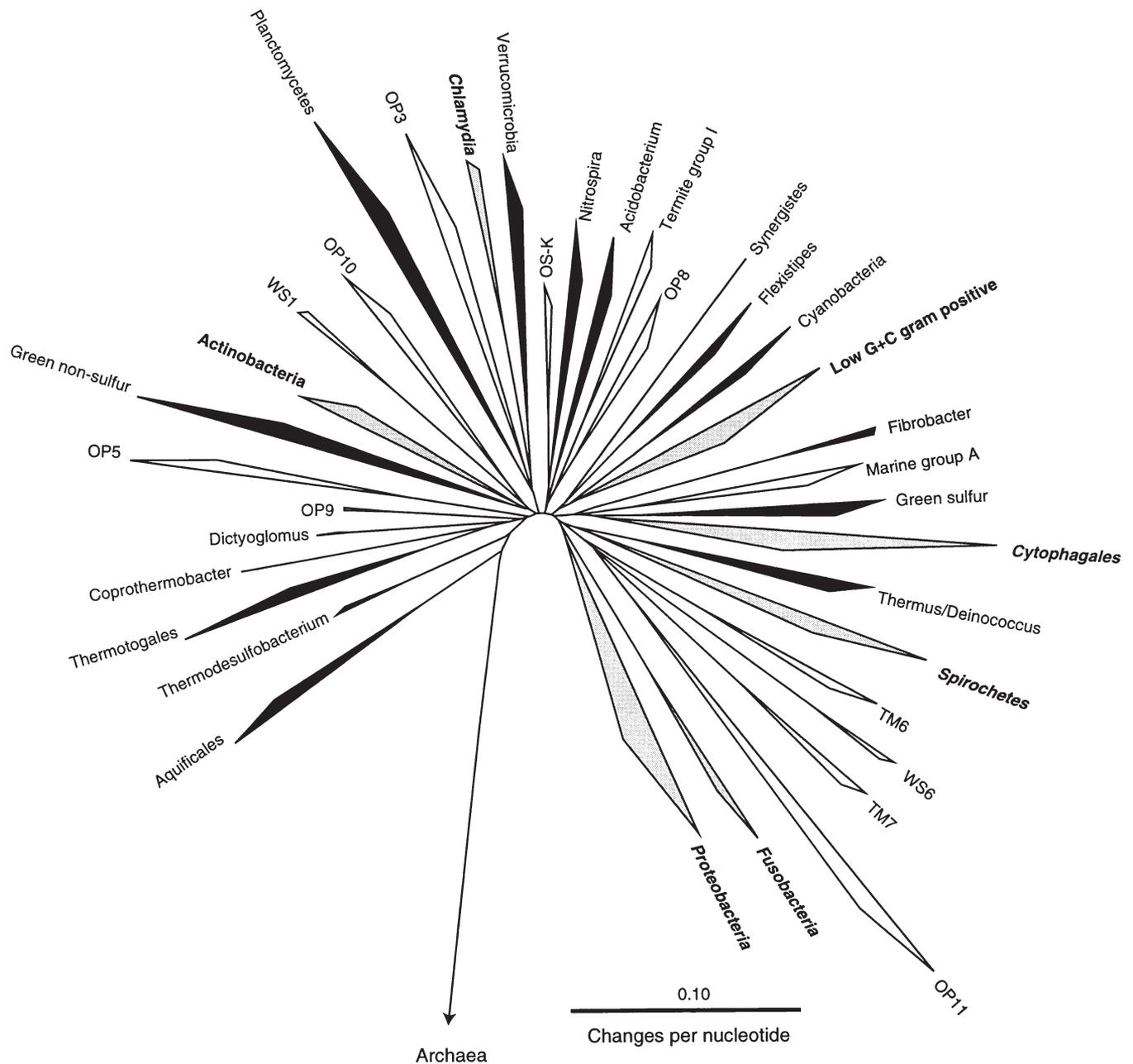


Figure 2. An evolutionary distance tree of the bacterial domain containing known and candidate divisions based on the analysis of the 16S rRNA gene. Depths of wedges represent the branching depth of representatives within a particular division. Widths of wedges correspond to the number of known members. The scale bar indicates 0.1 changes per nucleotide. Solid-filled wedges represent divisions with cultivated representatives, hollow wedges represent divisions only known through their molecular phylogeny, and solid-shaded wedges represent the divisions with known human or animal pathogenic organisms.

between these organisms that dominate the environment (Pace 1997, 1999).

By 1987, in a definitive body of work, Carl Woese (1987) found that the bacterial domain consisted of 12 divisions. In just 13 years the known extent of microbial diversity has increased three-fold, with 16,000 species (by analysis of the small subunit ribosomal rRNA gene or

rDNA sequences) now in the public databases. Similarly, it should be remembered that the eukaryotic domain consists of at least 20 divisions or “kingdoms” (not just plants, animals, and fungi), with most of these divisions comprised of microscopic Eucarya. Bull and Wichman’s (1998) editorial stating that there has been a revolution in evolution is true, and this revolution will take us in

new directions—from ideas for life's origins (Woese 1998), to solutions for how we treat hazardous waste, to how we apply conservation medicine to diverse health issues. Genomics and an increased understanding of the evolutionary picture for all things living will greatly enhance what will be known about all three domains of life in 13 more years. This will be a fascinating measure of biodiversity and of biocomplexity.

I examined recent issues of *Conservation Biology* for studies of where considerations of microbiota could be a positive influence from a conservation medicine perspective, and I found a paper on the "Coexistence between People and Elephants in African Savannas" by Hoare and Du Toit (1999). This study provides a good example of the relationship between people and the macroecological world, but considerations of the microbiological crossover between species could play a role in understanding human and animal health—conservation medicine. A second report by Bevill et al. (1999) examines the effect of herbivorous enemies on the threatened Pitcher's thistle. The report describes positive outcomes when enemies are minimized. Such a study could also be considered from a microbiological perspective by asking what microbiota are present on the surfaces of these plants that could themselves be fending off the attack. This example contributes to the idea of conservation medicine: the interplay between species providing for the health of the organisms involved.

Jamie Rappaport Clark's article (Clark 1999) concerns the ecosystem approach from a practical point of view. She mentions two real-world constraints: (1) that minimal knowledge exists of ecosystem function (referring to macro-ecosystems, but equally applicable to understanding all ecosystems, micro and macro), and (2) the immediate human demand on landscapes, which cannot be ignored. She goes on to say that scientists need to understand that there is a lack of knowledge about ecosystems and that this lack affects the management of those systems. This lack of knowledge is greatly magnified in the microbial world.

The concept of conservation medicine can be a starting point in the understanding of microbially induced disease in animal and human models. By viewing disease as a complex process between host and microbial pathogen in a complex ecosystem, conservation biologists can apply principles of the field gained in the study of macro-ecosystems to aid in the treatment and prevention of disease. In addition, it may be possible to find new models from which to learn as-yet-unknown principles. Biomedically understanding host-microbiota ecosystems through principles of applied conservation biology principles will allow for future understanding of how disease can be treated in humans and animals. Goldstein (1999) brings up the point that *community*, *habitat*, and *ecosystem* are terms used interchangeably

in the literature and discusses the concept of ecosystem management. Based on the results of current studies on macrobiota, ecosystem management needs to be altered to encompass the whole ecosystem (micro and macro) to further our understanding.

The integration of conservation biology with microbiology, forming the subset conservation medicine, will benefit all parties. How can the concepts of conservation biology be applied to a microbial pathogenic infection in humans or animals? A *Staphylococcus* spp. infection is more complex than one species dominating the opportunistic infection: it is an ecosystem out of balance. Can the principles of conservation biology be applied to such an ecosystem to enhance and implement a more effective and rapid treatment? Comparative studies in the microbiological literature consider the coexistence of people with *Escherichia coli* in the human gut and the death of this microbiota upon exposure to appropriate antibiotic. Conservation medicine could play a role in examination of the coexistence of *E. coli* and other Bacteria under the continual exposure to antibiotics, allowing for increasing antibiotic resistance, which is a huge, looming problem. Exposing Bacteria in the body to an antibiotic is equivalent to exposing a tropical rainforest to slash-and-burn agriculture. We wipe out everything, the good and the bad, but all were arguably beneficial to the ecosystem considered.

What has been learned in macrobiology has often been applied to microbiology. For example, Hahn and Höfle (1999) provide an excellent example of predator-prey relations between a nanoflagellate and a complex, mixed bacterial community in which the bacterial cell sizes decreased in the presence of the predator and other bacteria formed large floc-like aggregates. Both of these responses are a reaction to size-selective grazing or predation by the nanoflagellate. Evolving to a smaller cell morphology, which allows for the continued survival of the community against a size-selective predator, and the strength-in-numbers approach are two strategies for continued survival seen in a macroecosystem.

Lessons from the micro world also can be applied to the macro world. For example, interspecies translocation of DNA through lateral gene transfer has relevance to conservation medicine. Applying the tools of molecular biology (e.g., molecular phylogenetics) allows us to open the black box of a microbial ecosystem and determine what members are present. Lessons learned from the short generation times of a microbial ecosystem could be rapidly applied to larger ecosystems on an exponentially different temporal scale. Can habitat fragmentation and alteration be better studied with a microbial model? What can be learned from a microbial ecosystem out of balance (e.g., an opportunistic infection) can in turn be applied to a macroecosystem threatened by deforestation, pollution, or human encroachment.

To achieve an enhanced understanding of what is possible for biodiversity, the field of conservation biology must encourage diversity in those who participate and are interested. Ecologists, sociologists, conservation biologists, hydrologists and geologists, environmental engineers, economists, and physicians need to think about the bigger picture: not just what can be visualized in an ecosystem, but what microbiota are present in the equally complex microscopic ecosystem, which is what NSF's biocomplexity initiative seeks to achieve. Evolutionary biologists can interact with environmental engineers, molecular biologists, and field ecologists to discover, for example, what kind of microbial diversity lies within the beetles that fell out of Erwin's tree (Erwin 1982). A molecular phylogenetic analysis of the microbiota inside just one of those beetles could yield a wealth of information on microbial biodiversity.

As a science, conservation biology has been concerned with biodiversity. Science and medicine have been compartmentalized into a number of equally important categories over the past 100 years. This has allowed for the in-depth examination and subsequent understanding of widespread human and environmental questions. In this new millennium, it will be those who link the ideas of diverse fields who will solve the complex questions. Meffe's proposal of embracing conservation medicine is such an example. What needs to be done to meld the compartmentalized fields of microbiology and conservation biology? To propagate Meffe's idea of conservation medicine, we all need to widen our focus, educate others, and think small, as in microbiota. To make this world a better place for future generations of all things living, we need to understand the concept of biodiversity beyond a macro level. Meffe quotes Aldo Leopold, stating that a person with an ecological education "lives alone in a world of wounds" and that maybe conservation medicine can heal those wounds. We also must not forget that the microbiological ecosystems healing those wounds in us, on us, and around us are in need of further understanding.

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