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The rights of microbes

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Over the last forty years, the circle of organisms thought worthy of inclusion within an ethical framework has expanded markedly, in large part in response to Aldo Leopold's 'land ethic'. However, there are still clear limits to the forms of life we are willing to include in such a framework. In this paper I suggest that a strong case can be made for microorganisms to be accorded special ethical status, as they represent the base of all food chains and of the major biogeochemical cycles. Without lions there is life, but without microorganisms there can be no higher life forms. The notion of protecting individual microorganisms may be absurd, but microbial communities and ecosystems nevertheless deserve protection, and offer an example of the merit of a population based approach to environmental ethics. I argue that humankind should assume the position of a moral agent to the microbial world, by formally recognising the intrinsic worth of microorganisms, as well as their utilitarian value to humans and to the rest of life on earth. The practical implications of such an ethic are discussed.

One startling characteristic of ethics over the last four hundred years has been the ever expanding sphere of entities to which we attribute special status. Ethical debate began its long history in Western civilisation with the white male. Ethical status was then thought appropriate for slaves, women, children and coloured persons as the foundations of ethical debate improved. Over the last forty years a more radical stance has been taken, expanding moral and legal rights to animals, plants and even inanimate objects.

The notion that animals, or indeed organisms in general, might have rights reaches as far back as the Romans, with their concept of a *ius animalium* ('law of animals'). The Romans already believed that there were underlying 'laws' that guided the function of the natural world, but to understand how non-human animals fitted within the natural world they believed there must be a separate set of moral laws for animals. They believed that these natural laws essentially gave animals a value of their own. However, this early notion of a law for animals was eventually superseded by a philosophy which viewed animals as the property of humans and available exclusively for their use, a view still very much prevalent in Western societies, and some would say the root of the current environmental crisis.

During the seventeenth century, at a time of accelerating scientific progress and the emergence of the scientific method, scientists and philosophers turned their attention again to understanding how humans fitted into the non-human biosphere. For the first time, the modern Western notion of 'rights' for animals, as opposed to the idea of animals merely having 'value', emerged. Lawyer Nathaniel Ward (1578–1652), botanist John Ray (1627–1705) and philosopher John Locke (1632–1704) established the Western basis of the concept of 'animal rights', and the proposition that animals have some intrinsic right to life of their own, independent of their utilitarian value to humans. They vigorously opposed forms of cruelty to animals. Their ideas were, if you will, the biological equivalent of the Copernican revolution in astronomy: in according rights to animals, they were

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recognising that humans were not the centre of the biological world, and that animals might also have some value of their own. These thoughts would develop slowly over the following three centuries, and in many ways the contributions of these thinkers can be seen as the kindling that would start the fire of the environmental ethical debate in the twentieth century.

Perhaps the most important contribution to this debate was Aldo Leopold's (1887–1948) 'land ethic',[1] which posited that the land and the organisms on it should be considered as a whole and should receive ethical consideration as such. The notion that organisms and even land should be afforded status in an ethical framework is often referred to as 'biocentric', in contrast to anthropocentric ethics which emphasises the utilitarian value of nature to human beings. Leopold's land ethic is a recognition of the intrinsic worth of nature, a recognition that it has some kind of inherent or non-instrumental significance beyond its utilitarian value to humans. One of the most notable developments of this concept is Christopher Stone's call to extend legal and even moral rights to oceans, rivers and other natural objects, expressed in his work *Should Trees Have Standing?*[2] The most recent manifestation of the concept of a biocentric ethics has been the 'deep ecology' movement, the precepts of which were first formulated by environmentalist Arne Naess.

A HISTORY OF MICROBIAL RIGHTS

The notion that microorganisms (or 'microbes'), including all single celled organisms and viruses, might fit within an expanded ethical sphere is not new. Bacteriologist René Dubos (1901–82) was the first to suggest that germs should be allowed to coexist with humans.[3] He never went so far as to claim they should be recognised as having an intrinsic ethical value, but nonetheless he was perhaps the first to see them as an integral part of a biotic community and to treat them as such. The microbiologist Bernard Dixon took this view one step further. He took the case of smallpox and suggested that the ultimate extension of the biocentric viewpoint requires that we protect the virus from annihilation.[4]

According to the biocentric viewpoint, the destruction of smallpox is no more acceptable than the destruction of elephants. It has intrinsic worth independent of humans, it plays a part in ecosystems and so it deserves the right to live. The use of smallpox is a somewhat equivocal choice, because many scientists would argue over whether smallpox (and viruses in general) are 'alive', as they depend upon their hosts to propagate and so do not have the ability to self-replicate usually seen as a defining quality of life. Nevertheless, Dixon could have chosen the anthrax bacterium and the point would have been the same. The ecotheologian Lynn White also defends the rights of smallpox and suggests that because smallpox cannot be consulted on its own imminent extinction we do not have the right to destroy it ourselves.[5] Dixon's and White's arguments are a very good illustration of the fact that often the rights of microbes are used as an instrument for pushing the outer envelope of biocentric ethics and in some ways in this context are merely a tool for ethical debate.

In 1977, Joe Patrouch published an intriguing article entitled 'Legal rights for germs?' in the science fiction and fact magazine *Analog*.[6] The article gives a science fiction view of a future in which germs have legal rights and household disinfectants and mouthwash are banned. The piece is anchored in science fiction, but the story is also presenting a view of a world where environmental ethics has reached its logical conclusion. However, the article follows in the footsteps of Dixon and others by focusing on the detrimental things that microbes do, and describing a specific subset of the implications of an ethical framework

for the protection of microbes. Indeed my dictionary defines a germ as 'a micro-organism, esp. one which causes disease', so the title itself is loaded against microbes. Patrouch's piece was followed by a similar one speculating on a court case between a university medical centre and a pneumonia causing microbe, an article which explores the practical consequences of legal rights for germs.[7]

A problem with all these views is that they focus solely on the destructive roles that microbes play, not on their beneficial and indeed vital roles in the biosphere. The purpose of focusing on destruction is to startle the reader with the idea of protecting something that causes a lethal disease. Though this is a useful angle to take in a biocentric ethical debate, it does not really address the problem of whether microbes should have rights. For example, I would not say that the ethical treatment of tigers should be ignored because there is one species of man eating tiger, neither would I use the man eating tiger as the basis for all ethical discussion of tigers. Smallpox and other microbes that cause human disease are a tiny subset of the microbial world. Although we can argue in great detail about whether such microbes should be preserved and accorded environmental protection, like the man eating tiger they are a distraction from the wider argument about the ethical status we afford microbes in general, and in particular the vast majority that have no influence on human health.

Any concept of protection for *all* microbes that has been put forward in the past has usually been within the context of a statement about the biosphere in general. As early as 1906, John Howard Moore (1862–1916) suggested that an ethical framework should be developed for 'all creatures'.[8] The statement does not recognise microbes *per se*, but by implication in its inclusivity it suggests that microbes should be included within an ethical framework.

In summary, interest in whether microbes should be part of an ethical debate has over the last four hundred years derived either from serendipitous inclusion in general ethical statements about the biosphere, or from their use as tools to trigger ethical debate, usually involving the proposed protection of atypical species that kill humans. These historical points of view have more than just philosophical relevance. Our perception that microbes are inherently bad has enormous practical implications. The US Endangered Species Act, implemented in 1973, was a historic piece of legislation and provided sweeping legislative protection for animals and plants. Although it only protected organisms insofar as they were useful to humans (it did not recognise any independent intrinsic worth), at the time it was still rather radical. However, despite its pioneering status, it recognises no specific protection for microbial ecosystems, defining a species as 'any subspecies of fish or wildlife or plants'. But sometimes there can be more than just ambivalence towards the protection of microbial ecosystems. Rhode Island state law for the protection of endangered species states that 'animals and plants mean any living or dead organism or organisms *other than bacteria or viruses*' [my italics]. Within certain laws there is thus the basis of microbial apartheid. The negative contribution of microbes to human civilisation has made them the nigger of the non-human biosphere.

WHY PROTECT MICROBES?

We live on a planet dominated by microbes. For the first three billion years of life's history on earth microbes were all there was. Although since the Cambrian explosion six hundred million years ago a multiplicity of multicellular organisms have evolved and proliferated on earth, they are still really just a veneer on the microbial world. Just one example illustrates

the point. Today a hundred and forty million tonnes of nitrogen are removed from the atmosphere each year, and fixed by bacteria into forms of nitrogen biologically accessible to plants and ultimately animals. We cannot fix atmospheric nitrogen ourselves. Without nitrogen fixing bacteria there would be a nitrogen crisis on earth and no higher forms of life could exist.

All the cycles of elements from carbon to iron and sulphur are heavily influenced by the actions of microbes. The degradation and decomposition of waste is dependent on them, and in the oceans the food for all animals derives from the photosynthesis of single celled organisms. All higher life forms on earth owe their existence to the microbial world.

The number of microbes that cause detrimental diseases in humans is probably much less than a millionth of one per cent of all microbial species on earth (this is a wild guess as we do not know the total number of microbial species, but when one considers the many hundreds of species that might exist in a single lake and the relatively short list of microbes that cause fatal epidemics or pandemics, then even if this estimate is out by several orders of magnitude qualitatively it makes the right point). However, the ravages of typhoid, Black Death and various other diseases have focused the public mind in a profound way. This overwhelming negative influence in human history, one that has overshadowed the useful things that microbes do for us (for example fermenting wine and beer), has moulded how we view our relation to them.

Since the emergence of the environmental movement in the 1970s, almost all campaigns for environmental protection have focused on multicellular animals. Seals, tigers, various bird species and others too have come into the limelight, but I cannot recall a single high profile environmental campaign directed towards protecting a microbial ecosystem. This alone is sufficient to highlight the underappreciated importance of microbes amongst livings things on earth.

A further reason for the exclusion of microbes from environmental campaigns may well be that we do not think of them as suffering, as we would do in the case of higher animals. This is a discussion of some complexity, since some ethicists might argue that cruelty is not just about the pain inflicted on an animal, but also a reflection of the intention of the human. For example, although a microbial ecosystem may not feel pain, the wanton destruction or draining of a lake is cruel to microbes because it shows a lack of human respect for another form of life, reflecting a cruel trait in the human character. Aside from preventing cruelty, environmental organisations also protect animals to stop their destruction or even extinction, with the purpose of stopping the degradation of the natural environment. Thus, even if we decide that microbes cannot be treated cruelly, they can still take their place within environmental campaigns that seek to prevent degradation of the natural environment.

But why *should* microbes be protected? First we should consider the instrumental worth of microbes. Animals, humans included, all depend on microbes, so when we talk of protecting microbes because of their instrumental worth, this may even be an understatement. The concept of instrumental worth is usually applied to organisms or things of some value. A rainforest has instrumental value to loggers and to the indigenous people who go there to collect nuts, and if the forest is cut down, its instrumental value is lost. However, the people who originally used the forest are not necessarily endangered as a result as they can always move on to new forest (of course if any is left). If on the other hand the microbial world was in large part destroyed, it is unlikely that many multicellular organisms, including humans, could survive for very long. Even on the scale of individual

organisms, microbes can be vital. For example the death of the digesting bacteria in a termite's gut would result directly in its own death, and the death of photosynthetic organisms in a pond might reduce the food supply and so indirectly kill individual fish. So microbes have much more than purely instrumental value.

As humans, we generally do not consider the fact that destroying ecosystems might eventually destroy us. We speak of the instrumental or intrinsic worth of ecosystems, but these terms keep the problem at arm's length, implying that if we destroy something we either lose the use of it or we lose something that had its own value. We rarely consider that we might be killing ourselves. Microbes might therefore be worthy of an entirely new category of ethical consideration. In the case of microbial ecosystems – the basis of all food chains – I would argue that their worth is not just 'instrumental' or 'intrinsic', but that they have 'survival' value to us: without them we simply cannot survive.

What about the intrinsic worth of microbes – the value they have independent of their value to humans? Even arguing from intrinsic worth, microbes occupy a special place. They have dominated the earth for three billion years, and despite many mass extinctions they continue to do so. Some microbial species have gone extinct, but the branches of the tree of life that contain microbes have been extraordinarily resilient. With such tenacity for so long and with such a remarkable evolutionary legacy, is it not the case that the microbial world has a right to be regarded as having its own worth? After three and a half billion years of evolution what right do we have to start destroying this phenomenon? Microbes are the origin of all life on earth. The heat loving microbes that gave rise to all life can be regarded as our (and every organism's) distant relatives. By protecting microbes we are therefore protecting life's family tree, and for this reason alone we might accord them worth independent of their utility to humans.

INDIVIDUALS *V.* THE COMMUNITY

Before the emergence of the science of ecology, the difference between protecting individual organisms and communities was not really appreciated. The German environmental ethicist Albert Schweitzer (1875–1965) was famous for his radical stance on the protection of lower life forms. He helped worms off footpaths and treated mosquitoes with respect. His behaviour and views caused difficulties for the environmental movement as it was patently absurd to spend one's life caring about every insect and worm. On that basis humans could not do any gardening because slicing a worm in two with a spade would be similar to murder of a lower life form. Insects crushed on car windshields would represent a form of mass destruction. Such views were a serious barrier to the notion of expanding ethical status beyond humans, and they played into the hands of those who wished to pour ridicule on the notion of animal rights.

The emergence of ecology and the notion of the 'food chain' in the 1920s brought home the point that the preservation of communities was the important issue. Protecting individual worms was not necessary (provided one did not destroy them with mindless abandon), but if all worms were destroyed there would be a problem. Thus the integrity of the biotic community was the goal. This is the basis of Leopold's 'land ethic', which is summarised in his now oft quoted definition, 'A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.'[9] The land ethic and other similar lines of thinking freed people from the need to protect individual organisms. From this vantage point the expansion of ethical status was made possible.

Microbial communities are a textbook example of the environmental ethical importance of communities over individuals. When we speak of protecting microbes, what exactly do we mean? Each one of us kills countless millions of them every day. Every time we scratch we kill some. When we clean our houses we implement microbial destruction on a huge scale. In terms of the number of individuals killed and the area of potential destruction, a bottle of bleach is more devastating on the microbial scale than an atom bomb is to humans. So clearly the implementation of a microbial ethic that seeks to protect individual microbes is absurd and impractical. If implemented, we would descend into unsanitary conditions, indeed we could not even move or sit down in a chair.

So protection of microbes must apply on a communal scale. But what are we concerned about protecting? Is it the function of microbes, or particular species? For example, if an ecosystem contains a nitrogen fixing bacterium, would we care if we destroyed the bacterium if it could be replaced by another that did the same job? If our concern is with preserving ecosystem function, then the answer would be that we do not care. A good instrumental argument can be made that preserving function is the main objective. Even if we cannot guarantee survival of microbial species when altering an ecosystem, by preserving ecosystem function we have at least preserved the base of the food chain for other organisms.

However if we care about species (or strains as the case may be), then we might care about destroying a particular nitrogen fixing bacterium. An intrinsic worth argument can be made that particular species of microbes have a right to live and so should be preserved even if there are other organisms that can take their place. We do not kill off all wild hyenas, even if we know there are other predators that can do the same job, because we regard hyenas as having their own intrinsic worth.

One problem with the intrinsic worth argument as applied to microbes is the difficulty of defining what a microbial species is, given their huge diversity and their propensity to exchange genetic material amongst themselves. This makes it very difficult from a practical environmental point of view to go around defending individual species. Because of this, we might be inclined to focus more on preserving ecosystem function than specific species of microbes.

MICROBE-CENTRIC ETHICS AND MICROBIAL RIGHTS

A microbe-centric ethic would recognise that without microbes there can be no other life. It would posit ethical and legal standing for microbes equal to that of other organisms; indeed that because of their position at the base of the food chain sometimes even higher priority protection should be afforded to them. To summarise this ethic we might say, 'The protection of the integrity of a microbial community or ecosystem should have equal, and sometimes greater, priority to that of any other organism'. A more naive but no less truthful axiom might be: 'Microbes have a right to live that is equal to that of any other life form on earth.'

An argument against this microbe-centric view would be that many multicellular ecosystems can be destroyed with disastrous consequences. For example, the destruction of rainforests causes major species loss and may even influence global climate. Thus, surely multicellular organisms are very important, independent of microbes? A microbe-centric ethic calls for the protection of microbes in cases where their habitats are threatened and places at least as much emphasis on them as on any other organisms, recognising their importance at the base of food chains. So we should protect the rainforests for the

microbes as well as for the many other higher organisms, the destruction of which would cause negative consequences for the environment. In the case of rainforests, they should be protected precisely because they contain vast and important microbial ecosystems. Microbes grow in trees and soil, and the trees are dependent on them. So there are good microbe-centric reasons for protecting rainforests that complement existing motives for protection.

What would be the practical manifestations of a microbial rights movement in instances where microbes are more obviously involved? Let me provide a hypothetical situation to illustrate the possible consequences. Imagine a game reserve in Africa that has a large number of endangered lions. The park also contains some salt flats that have thick microbial mats growing around their edges. The lions are starving and a decision has to be made whether to drain the salt flats to provide extra grass that will attract more prey into the park and give the lions enough to eat. What should we do? Under current ethical frameworks, the decision is predictable. The lions are regarded as having high worth. We associate them with ourselves (they are large and impressive) and they must be protected. They may also have instrumental value to some tourists who take pictures of them. The salt flats have no instrumental value as no one in the park uses them. As microbes are not really regarded, even by the most enthusiastic environmentalists, as having much intrinsic worth independent of humans, the salt flats do not get much of a voice and the decision is made to drain them to save the lions. A great environmental victory is announced for the protection of the lions.

However, the salt flats contain many different microbes. Within a microbe-centric ethic, irrespective of their use to humans, they have their own intrinsic worth and right to continue to exist. The microbes in the salt flats are the descendants of microbes that dominated the earth over three billion years ago; they therefore have a much longer history on planet earth than the lions. They also have instrumental value. Although no person in our hypothetical park is using the salt flats, the microbial mats are the base of an incredible food chain. They feed tiny invertebrates that are food for small fish in the salt pans that themselves are eaten by larger fish and animals. Some of the cyanobacteria fix nitrogen which is used by the salt loving plants there. As the base of a food chain, many hundreds of species depend upon the microbial mats. Thus, under a microbe-centric ethic, the lions must go and the salt flats must be saved. This will maximise the biotic integrity of this particular environment. It will also sacrifice the minimum number of species and protect another part of the base of the earth's food chains. Lions should be saved where and when possible, but only after the integrity of the world's microbial ecosystems is assured.

To provide a more practical example of how a microbe-centric ethic could be useful we might take the example of Butte Lake in Montana, USA. This lake was the site of one of the world's largest copper mines and the waters are now filled with a concoction of cyanide, cadmium, zinc and various other metals. The local authorities woke up to the destruction that was being caused when two hundred snow geese landed on the lake one day in 1995. By the following day they had all died from drinking the poisons in the water. Had the local authorities realised the devastation that was being caused to the local microbial communities by this waste being dumped into the environment, then perhaps attempts to clean up the lake would have begun earlier and they would have been able to control the problem more successfully. Only when large multicellular organisms died did anyone think there was a problem, and by this time it was almost out of hand.

Of course, there is a dilemma in this utopian view of ethics. Many microbes can take advantage of poisonous environments, for example there are algae that can immobilise

toxic metals. In some cases it may even be the case that cleaning up some environments will deny certain species of microbe a home. Microbes are all pervasive and environments that we regard as dangerous can provide their habitats. Some even inhabit the cooling waters of nuclear reactors. So surely the microbe-centric ethic requires us to protect and preserve toxic environments?

The microbes in such polluted environments are rarely the basis of a food chain for higher organisms. In general, environments with fewer heavy metals and other poisons can harbour a greater diversity of species, not just microbes, but higher life forms as well. Of course, some toxic environments are natural (for example acidic volcanic calderas), and they should certainly be protected for their unique microbial ecologies. However when faced with a decision to reverse human pollution, protection of the microbes that have taken advantage of a polluted ecological niche should probably take second place to protecting the microbes that would otherwise inhabit the environment, as they would create a more diverse and extensive food chain (unless an argument can be made that the toxic environment has more utilitarian and intrinsic value than the potentially non-toxic environment that might follow). Thus we can find a resolution to the apparent ethical dilemma of the pervasiveness of microbes in all types of environments.

How does the protection of lethal disease causing microbes fit within this ethical view? In terms of the historic debate about smallpox, we can find reasons to agree with those who might seek to bring this microbe under human control. This may seem hypocritical following the arguments that have just been presented, but it is a question of the relative strengths of different aspects of worth. Like all microbes, smallpox has intrinsic worth in a microbe-centric world simply by virtue of its existence. However, it can kill hundreds of millions of people. Man eating tigers kill only very small numbers of people and so we are happy not to take them to extinction, but I suspect that if they were killing hundreds of millions of people a year, we would quickly lower their numbers in spite of any ethical concerns. In other words instrumental considerations would override the tiger's intrinsic worth under the exceptional circumstances of the vast scale of devastation. Smallpox is in the league of highly destructive agents, and the devastation it can bring to bear on human civilisation might therefore merit its control.

In a microbe-centric world, then, humans act as moral agents for their moral patients, the microbes. Microbes cannot fight court cases and defend their interests with legal arguments, but along with the power to alter and destroy microbial ecosystems that have existed on earth for over three billion years, a thousand times longer than us, we must accept responsibility for acting on their behalf. In exceptional circumstances, because some specific microbes are unusual in their ability to bring global scale destruction to significant percentages of human populations, it may be the case that our own instrumental considerations outweigh the intrinsic worth of a particular species. A microbe-centric ethic provides us with a more mature way of assessing this dilemma in contrast to the prevailing simplistic view of all microbes as being wholly negative.

Finally, I should note that developing a microbe-centric ethic is necessary in the light of our exploration of other worlds.[10] 'Planetary protection' is a phrase that refers to attempts to stop the contamination of other planets with microbes on our spacecraft and more speculatively, to prevent contamination of the earth by extraterrestrial organisms returned from space. The planet Mars and Europa, a moon of Jupiter that has an ocean under an ice layer, are two worlds of very special concern because they are places where scientists would like to seek indigenous life.

The most likely life to exist on these other planetary bodies is simple microbial type life. If we find life on another planet, then we will need a well constructed foundation of microbial environmental ethics to protect it from contamination and destruction and we will need to consider how to deal with the transfer of this other life back to earth. Even if we find no life on these other worlds, we are still faced with the ethically challenging question whether we should disperse microbial life into a lifeless world on our various crashed and successfully landed spacecraft (many spores have already been delivered onto the surface of Mars by landers over the last forty years). A microbe-centric ethic therefore has practical applications elsewhere.

INSTITUTIONAL IMPLICATIONS OF MICROBIAL RIGHTS

Recognition of the importance of microbes and their role in ecological health would result in a series of institutional implications. Here I give some examples.

First, legislation should reflect the importance of protecting microbes. Legislation that is ambivalent on the subject should be changed to recognise microbes. Legislation that overtly opposes the protection of microbes should be reversed. Statements should be constructed that can be used in the formulation of environmental law. One such might be: 'microbial communities and ecosystems are recognised as meriting protection equal in extent to that afforded to all other forms of life'. Lawyers can no doubt refine this.

Second, institutions should be created that protect microbial ecosystems. In the UK, for example, there is a diversity of organisations set up to protect many different groups of organisms. The Royal Society for the Prevention of Cruelty to Animals (RSPCA), the Royal Society for the Protection of Birds (RSPB) and even the British Hedgehog Preservation Society are examples. But, we might wonder, where is the Royal Society for the Protection of Microbial Ecosystems? Where are the environmentalists urging us to 'Save the microbes!'? And where is the microbial division of Greenpeace? Environmental groups, from the most radical to the most conservative, should recognise microbial ecosystems as part of the protected biosphere. The lack of photogenic appeal of microbes (although I invite anyone subscribing to this view to visit the wonderful and highly coloured microbial mats that inhabit the hot springs of Yellowstone National Park) should not remove microbes from the agendas of environmental organisations.

Third, we should consider establishing national parks around important microbial ecosystems, even in cases where there is an absence of larger 'charismatic' fauna for public view. Examples might include lakes that contain unique microbiotas.

Finally, there needs to be a shift in our education system. The negative view of microbes that many people have is partly a function of what we are taught at school about 'germs' and the bad things they do. The importance of microbes in global cycles and their role in the biosphere should be emphasised in biological and environmental sciences curricula from high school to university level.

CONCLUSION

Microbes have intrinsic worth equal to, if not greater than, that of any other species. They have instrumental worth so great that they are vital to our survival and to the survival of all other multicellular organisms on earth. Their place at the base of all essential food chains means that they merit special status in a system of environmental ethics. In this paper I have postulated a microbe-centric ethic. Under this ethic we would seek to

maintain the health of microbial ecosystems as a priority in our environmental stewardship of the earth, recognising that the health of microbial ecosystems allows for the health of all higher organisms.

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