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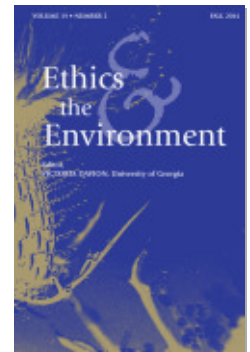
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## **Invasive Species and the Loss of Beta Diversity**

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# INVASIVE SPECIES AND THE LOSS OF BETA DIVERSITY

SARAH WRIGHT

Why should we avoid introducing invasive species? In this paper I argue that in addition to the more ordinary and visible types of harm that invasive species cause, they also cause a reduction in a particular kind of biodiversity—that of beta diversity. Rather than simply measuring the number of species found in a particular region, beta diversity measures the differences in the species found between regions. This difference between regions can be measured by comparing neighboring regions (local beta diversity) or by comparing distant regions (global beta diversity). Both types of beta diversity are reduced by the introduction of invasive species. I further argue that beta diversity is an important part of our concept of biodiversity and of what we value about the natural world. Thus the tendency of invasive species to reduce beta diversity gives us a substantial reason to avoid introducing them.

As I travel the highways of Georgia, I am regularly appalled by the ubiquitous presence of kudzu. It covers trees, telephone poles, open swathes of land, and old houses, making many locations indistinguishable from one another; all I can see from the road is a wave of green covering any formerly distinctive markings. Thinking back to the intentional introduction of kudzu to the American southeast, I recognize that those individuals who encouraged the planting of kudzu made a serious mistake.<sup>1</sup> Their introduction of an invasive species has produced real harms to my local ecosystem.

In this paper I will argue that the introduction of invasive species

should be avoided, not only because it may directly interfere with human interests and local ecosystems, but also because it reduces biodiversity. Rather than focusing on the type of biodiversity captured in species counts and directly affected by extinction and extirpation, I will focus on a type of diversity not often considered in the philosophical literature—beta diversity. Beta diversity is the target of a growing number of studies in ecology, and is the primary measure used to evaluate the phenomenon of biotic homogenization. Biotic homogenization occurs when different local environments become more like their neighboring environments. Beta diversity is a measure of differentiation between environments, and when these areas become more homogeneous, beta diversity is reduced. I argue that this reduction in beta diversity is just as harmful as the reduction of other sorts of diversity. The value of this type of diversity has been overlooked, in part because it is hard to conceptualize and measure, and because what is lost is a pattern, and not an individual entity, or the group of entities that make up a species. Nonetheless, beta diversity is worth preserving.

To begin this discussion, we need to have a clear understanding of what counts as an invasive species. As I will use the term, an invasive species is any non-native species that is flourishing in its new environment, such that it does not need to be continually propagated by humans. Following Ned Hettinger (2001), I define non-native species as any species that are not yet part of the ecological assemblage of a local region—those species that have not yet had an evolutionary impact on, nor been impacted by, the local ecosystem. This definition of invasive species does not require that these species have been introduced by humans; however we will be considering why we ought not to introduce invasive species, and so the human element is contained in the action considered.<sup>2</sup>

Before we deal with the more esoteric harms of invasive species, we can begin by considering the harms that invasive species directly cause to the communities in which humans live. These harms have convinced people to designate some species as noxious weeds and led to prohibitions on the planting of those species. Kudzu is an example of this category. These species are targeted because of the direct harm that they do to human communities and to the crops upon which we depend. The harm here may be as direct as reducing the amount of land available for crop production. Plants that are classified as weeds often out-compete crop species, and

their presence necessitates the introduction of weed control mechanisms.<sup>3</sup> Or an invasive species may be an animal or insect that eats a crop species. Golden apple snails are an example of this. They were introduced into Asia to serve as an additional source of protein. However, they grow on rice plants and have endangered many acres of this crop (Vitousek et al. 1996). The harm caused by an invasive species may simply be that the species is a nuisance to human communities. Kudzu is a clear example here, as it frequently invades areas used for recreation and decoration (like lawns) and its removal requires a great deal of labor. Zebra mussels are another example of a species that has a direct human impact. These mussels are an invasive species in the Great Lakes, and millions of dollars are spent every year scraping these mussels off of infrastructure such as intake ports for water treatment plants (Vitousek et al. 1996; Van Driesche 2000).

Considering only these harms, we can say that those who introduced kudzu did something that they had a reason not to do. Their action imposed a harm and a cost on future generations. Perhaps we can mitigate this blame to some extent by pointing out that those who introduced kudzu did not know that it would become as robustly invasive as it did. (Though they chose kudzu because it is an aggressive groundcover plant, and so perhaps should have foreseen that it might have harmful effects.) But in cases where it is not known what harm the introduction of a species might cause, a risk is run.<sup>4</sup> Given this risk of harm, there is a compelling reason to avoid introducing new species to an area.

In addition to direct harms to human interests, invasive species also cause harm to the ecosystem as a whole. This happens by way of many mechanisms that are interconnected. One is that invasive species prey on native species, causing extirpation and sometimes extinction. An example of this is the brown tree snake, which was accidentally introduced to the island of Guam. These snakes entered an environment full of bird species that were unused to snake predation; as a result these birds had not adapted any snake-avoidance behaviors. Since the introduction of the brown tree snake to Guam, nine of the thirteen forest bird species native to the island have been extirpated, and the remaining species are severely threatened (Burdick 2005). So invasive species can directly eliminate local populations of native species. Invasive species also endanger local species by causing a change in ecosystem variables and altering the local environment in ways for which native species are unable to adapt. The invasion

of buffelgrass in the Sonoran desert in Arizona is a clear example of an invasive species that has changed an ecosystem function (Niibus 2007; Buffelgrass Working Group 2008). Buffelgrass, having evolved in Africa, is well suited to the desert environment of the Sonoran desert. It grows readily in these harsh conditions, and as a result is pushing out native species, particularly by outcompeting the very youngest of trees and cacti. Buffelgrass grows quickly during the rainy season, but for the rest of the year it is composed mostly of very dry, thin stalks that burn easily and at a high temperature. Buffelgrass's susceptibility to fire contrasts with that of native desert plants, like cacti. During the dry seasons, the cacti, which act like huge sponges, shrink the size of their tissues. But they are not susceptible to fire; in fact the native plant configurations are considered to be "fireproof." The introduction of buffelgrass increases both the chance and the intensity of fires. This increased flammability poses a hazard to people living in these environments, but it also poses a risk to the saguaro cacti in the desert. Buffelgrass fires can scar and kill these very slow growing cacti, and fast-growing buffelgrass vegetation can inhibit new cactus growth. Thus the presence of buffelgrass increases the risk of extirpation of the saguaro cacti from the region. Yet the Sonoran desert is the only place saguaro cacti grow—if they are extirpated from this habitat, they will also be extinct.

These examples illustrate some mechanisms by which invasive species can cause native species to be extirpated from the regions they invade. On a more general scale, it is estimated that the presence of invasive species is one of two major causes of extinctions, the other being the reduction in available land for wild species (Wilcove et al. 1998, 2000).<sup>5</sup> Extinctions are a clear harm to the biosphere, and extirpation is a clear harm to an ecosystem. As evidence that the elimination of species is generally thought to be harmful, we need only look to the endangered species act, which clearly marks the extinction of a species as an outcome to be avoided. In addition, there are many different arguments offered by philosophers to support the claim that the extinction of a species is an outcome that we ought to avoid.<sup>6</sup> If any of these arguments work, we are provided with a reason to avoid importing invasive species, since their introduction tends to lead to extinction.

The two considerations offered so far give us two different reasons not to introduce invasive species. The first reason depends directly on our

human interests. Insofar as we (and our future generations) would like to have cleared fields, we should not introduce kudzu. Insofar as we would like to protect our food crops, we should not introduce invasive species that either compete with them or feed on them. The second argument depends on the way that the introduction of an invasive species can interrupt the functioning of an ecosystem, leading in some cases to the loss of species, either locally or globally.

But what about invasive species that do not have these obvious harmful effects? Some species may thrive in a local environment without either directly interfering with human interests or putting local species and ecosystems at risk.<sup>7</sup> There are other, more complex, ways that invasive species can harm ecosystems, including the reduction of beta diversity.

### **WHAT IS BETA DIVERSITY?**

Beta diversity is best explained by contrasting it with two other measures of diversity: alpha diversity and gamma diversity.<sup>8</sup> Imagine that we are focusing on the trees in a given forest, and within that forest we have many single hectare plots that have been marked off. When we look in the first plot we find examples of six different species of trees, call them species A, B, C, D, E, and F. The second plot also contains six different species of tree, but some are different from those in the first plot. In addition to containing species F, the second plot also contains species G, H, I, J, and K. Finally there is a third plot containing species G, H, I, J, and K, which overlap with those in the second plot, and in addition samples of species L and M for a total of seven species.

Alpha diversity is an inventory type measure and it is applied to each small plot. Alpha diversity measures the number of species appearing in each plot—a species count.<sup>9</sup> In the example above, the alpha diversity of the first two plots is the same, since each of these two plots contains samples of six different species. The third plot however has higher alpha diversity, since seven species are represented there. Gamma diversity is also an inventory measure, but it is applied not to the smaller plots, but to the whole forest. In the example above, the forest contains thirteen different species of tree (A–M), and this count determines the gamma diversity of the region.

Beta diversity is a different sort of measure from alpha and gamma diversity because it focuses not only on counting species within a plot but

Species	Plot 1	Plot 2	Plot 3
A	X		
B	X		
C	X		
D	X		
E	X		
F	X	X	
G		X	X
H		X	X
I		X	X
J		X	X
K		X	X
L			X
M			X

also on comparing the species counts between the different plots in the forest. Beta diversity is a between-plots measure.<sup>10</sup> To find the beta diversity between the first and the second plots, we need to look for the species found in the first plot but not found in the second plot (A, B, C, D, E), and the species that are in the second plot which are not represented in the first plot (G, H, I, J, K). We then compare this to the number of species that are found in both the first and second plots, in this case only one, species F. This results in a higher measure of beta diversity than that between the second and third plots—many more species are unique to only one of the two plots than are common to the two plots. When we move to measuring the beta diversity between the second plot and the third, we note that the second plot has only one unique species (F) and the third plot has two (L, M). Compared to the large number of species that the second and third plots have in common (G, H, I, J, K), this yields a low beta diversity between the second and third plots. Thus, the beta diversity between the first and second plots is higher than the beta diversity between the second and third plots. This is true even though the third plot contains more species than either of the other two plots.

Each of these types of diversity can be measured over time. Here we can see the effects of invasive species. Imagine that an invasive species X is introduced into the forest. It takes root and thrives in all three plots. It

competes directly with species A and eliminates it from the forest. Once invasive species X has entered the forest and had its effects, the beta diversity between the different plots in the forest has been reduced. The first plot is now more like the second plot than it was before. They now share another species (X) and the first plot has lost a unique species (A). Thus, even though the number of species found in the first two plots taken together remains the same, the difference between them has been reduced. The beta diversity between the second and third plots has also been reduced, even though neither of these plots has lost any species. While no species have been lost, there is now one more species (X) in common between the second and third plots and this also results in a reduction in the beta diversity between the second and the third plots. When the beta diversity between the different plots in the forest has been reduced in this way, we will also say that that forest as a whole has lost beta diversity. Thus we can characterize this example as an instance in which the introduction of an invasive species reduces the beta diversity of a forest.<sup>11</sup> Call this a reduction in local beta diversity, because the compared plots are local to each other; they are all within the same forest. Looking at change over time, a reduction in beta diversity will also be called biotic homogenization, since this type of change results in a local environment that is more homogenous than it was previously.

Moving from a focus on the plots within a small region like a forest, we can also think about the beta diversity between plots that are far away from each other. For example, we might compare a plot in Japan with a plot in the United States. As the two countries are so far apart and isolated from each other over evolutionary time, it is unlikely that there will be much overlap between the species found in the plots in Japan and the US. However, one species might be found on both species lists—kudzu. Compare this to the species that would be found in each location before the introduction of kudzu as an invasive species. Since these plots now share a species that they did not share previously, the beta diversity between these two plots would be higher in the past than it is currently. Thus we can say that the introduction of kudzu reduced the beta diversity between these two far-flung plots. There is no forest, or other local eco-region that encompasses these two plots, and so we will count this as a reduction in global (rather than local) beta diversity.<sup>12</sup>

When discussing biodiversity, we do not often make distinctions between alpha, beta, and gamma diversity. But philosophical arguments for



the preservation of species and against human-caused extinctions are related to concerns about gamma diversity. In most applications of gamma diversity, the regions considered are local ones. When a species is eliminated from a local region—when it is extirpated—there is a reduction in local gamma diversity. It is also possible to consider the gamma diversity of the whole planet, to consider all the species that would be listed in a global census. I will call this the measure of global gamma diversity. We can then interpret the extinction of a species as a reduction in global gamma diversity—when a species becomes extinct, the species count for the worldwide region is decreased by one. A consideration of this relation between extinction and global gamma diversity allows us to see the arguments that are raised for the preservation of species as likewise arguments against the reduction of global gamma diversity.

## **HOW DO INVASIVE SPECIES AFFECT BETA DIVERSITY?**

### **Invasive species reduce global beta diversity**

We have already seen one example in which the introduction of an invasive species reduces global beta diversity—that of the introduction of kudzu. The effect of invasive species on global beta diversity is very direct. When a species that is native to one area thrives in a different area where it is not native, the beta diversity of regions containing both areas is diminished. This is true because the invasive species is now present in the two compared areas, whereas before it appeared in only one. When taking a beta diversity measure between these two plots, there is one less species that is unique to a single plot, and thus beta diversity is reduced. When we take the region in question to be the entire planet, and thus consider global beta diversity, we can see that the spread of invasive species will always be a threat to global beta diversity.

This is doubly true when we consider an invasive species that has been introduced to more than one region in which it is non-native. The golden apple snail is native to Argentina. It was originally introduced into Taiwan, but when it failed to take off as a popular food crop there, the same species was introduced in other regions of Asia. It can now be found in regions of the Philippines, Indonesian, Malaysia, Thailand, China, and Japan. If we could compare plots in each of these countries to plots in Argentina, both before and after the invasion of the golden apple snail, we would find that plots in these southeast Asian countries are now more

similar to the plots in Argentina than they were before. This reduces global beta diversity. In addition, since the same invasive species was introduced to each of these southeast Asian countries, they are also more similar to each other than they were before. Thus, when the same invasive species are introduced into a wide range of new locations, global beta diversity will be further reduced.

### **Invasive species reduce local beta diversity**

The relation between invasive species and local beta diversity is a more complicated one. However the overall trend indicates that invasive species tend to reduce local beta diversity, at least once the invasive species have been given time to establish their ranges. At first, the presence of an invasive species increases local beta diversity (McKinney 2004). If a recently introduced species appears only in one plot within the local region, local beta diversity is increased. However as an invasive species becomes more and more pervasive, it reduces the beta diversity of the region. One mechanism by which this may happen is that an invasive species is intentionally introduced. Those species that are chosen for introduction in one region are likely to be the same ones chosen for introduction in another region. The same game fish are introduced in many regions in the US. Thus the introduction of brown trout into a new river tends to make that river more like other rivers in the region and more like other rivers throughout the country. Even without direct and intentional introduction, the same species may tend to thrive throughout the region into which they are introduced. They may spread by natural propagation, or, if introduced accidentally, they may be re-introduced through the same accidental mechanism in multiple locations. Local beta diversity is reduced as the same invasive species are introduced throughout a local region. The effect of invasive species in reducing beta diversity has been noted in freshwater fish (Rahel 2000, 2002), saltwater flora and fauna (Piazzi and Balata 2008), vascular plants (Qian 2005), and North American flora (Rejmánek 2000). A similar effect has been found when considering a more general type of homogenization, a homogenization in traits rather than just a homogenization in species (Smart 2006).

## **BETA DIVERSITY: VALUED AS PART OF BIODIVERSITY.**

Having demonstrated that the introduction of invasive species will tend to reduce both global and local beta diversity, we can now turn to the issue of the value of beta diversity, and questions about why it ought to be preserved. I answer this question by arguing that beta diversity is an essential part of biodiversity, and ought to be preserved.

### **How to define biodiversity**

“Biodiversity” is a term that has only recently entered our language. Despite its recent introduction, it does not have a clear and precise meaning, as some purely stipulated terms do.<sup>13</sup> Rather ‘biodiversity’ is a term that is fixed in part by biological facts and fixed in part by what we value. Bryan Norton has argued that the term biodiversity should be defined in a way that makes it useful both in ecology and in public policy discourse, since the term has an important role to play in each realm. The method he suggests to reach this goal is that

[W]e can state a clear definition for policy contexts: biodiversity should refer to those aspects of natural variety that are socially important enough to obligate protection of those aspects for future generations. (Norton 2006, 53)

This value-oriented approach to biodiversity will have the added feature that it does not require any further arguments regarding the definition of biodiversity in order to show that biodiversity as defined is also something we ought to value. By aiming to include what we value in the definition of biodiversity, we can begin with a term that is already agreed upon as characterizing (at least some of) what we value in the natural world. Developing our concept of biodiversity in this way, we can now focus on beta diversity. Is beta diversity a valued part of biodiversity?<sup>14</sup>

### **Interest in local species**

One very simple way to illustrate the value people assign to beta diversity is to look at the species in which they take special pride. Local pride in different areas leads people to value rare species and particularly those that are found only in the local area. This explains, for example, the pride that Tucsonans take in saguaro cacti. Many local businesses in Tucson incorporate the saguaro into their names, and others use the iconic form of the saguaro as part of their logos. Bumper stickers reading “Saguaro you

today?” are found on more than a few cars. Why do locals take pride in the saguaro rather than, say, the more common prickly pear cactus? One reason is that it is a unique feature of the desert surrounding Tucson—the saguaro cannot be found anywhere else. If uniqueness leads Tucsonans to value the saguaro, their value is tracking beta diversity. A plant that is only found in one region increases the beta diversity between that region and all others. Thus the uniqueness of the saguaro serves to increase beta diversity, and the pride and emphasis we place on unique species like the saguaro reflect a value that we place on difference. This reveals an interest both in local and global beta diversity, insofar as people take pride in their region’s differences from both neighboring regions and far distant ones.

### **The anthropogenic blender**

Moving from the case of pride in local species, we can move on to a more general question: what is wrong with an overall reduction in global beta diversity? One way to illustrate this issue is with the idea of the anthropogenic blender and concerns about our movement towards an era of the homogenece.<sup>15</sup> The idea of the anthropogenic blender is that humans, by their repeated introduction of non-native species, are serving as an agent of homogenization in the natural world. The endpoint of this metaphor is to imagine that the ecosystems of the earth are completely blended; this is the coming homogenece that ecologists warn us about. Imagine that there is no differentiation left between ecosystems, but rather all organisms appear everywhere (to the extent that this is climactically possible). This type of completely “blended” world is also what authors are worrying about when they warn that we are moving towards a “planet of weeds,”<sup>16</sup> After imagining this world, we can ask ourselves if this blended world is more or less valuable than our current more heterogeneous world. Even though we might imagine a case in which all species are preserved, the homogenece still seems to be impoverished because it is lacking in an important type of biodiversity. It seems less biodiverse than our world in which there are marked differences from one ecosystem to another; this is because the homogenece lacks beta diversity. Thus truly robust biodiversity is not consistent with the removal of beta diversity. These thought experiments initiated by ecologists lead us to the conclusion that beta diversity matters—it is an important part of the biodiversity that we think ought to be protected. This intuition is shared by ecologists and laypeople alike.

## The role for science in the definition of biodiversity

Norton's suggestion of how to reach a useful definition of biodiversity may start with an exploration of what we value, but it does not end there. 'Biodiversity' also needs to be a scientifically respectable term. To reach this goal, our understanding of biodiversity must be informed by ecological science. Sahotra Sarkar (2004) argues that our scientific concept of biodiversity is not a simple one and there can be no simple metric to measure it. He suggests that, in the absence of a single simple measure, we can understand biodiversity by looking for what ecologists try to preserve and restore. This approach is parallel to a view about the difficult-to-define concept of human health. There is also obviously no single metric to evaluate human health, and the standards that we use for health change over time as we make medical discoveries. Instead of looking for a fixed standard of human health, we might define health as whatever doctors are trying to preserve and restore. We start off with a shared common notion of health, and this notion is evaluative. Doctors, with their specialized medical training, come to better understand what makes up human health, and may add elements that are not in the common conception, based on their medical findings. For example, having a low cholesterol level is not part of our intuitive concept of health. However as scientists discovered the role that cholesterol plays in cardiovascular problems, the concept of health expanded to include low cholesterol levels. Using parallel reasoning, we may ask if ecologists treat beta diversity as an important element of ecosystem health or of overall biodiversity.

What do healthy ecosystems look like? They will tend to have high beta diversity as the result of natural evolutionary pressures. For example, species packing is a natural process that produces beta diversity.<sup>17</sup> Species arrange themselves along any gradient of change. Take, for example, the gradient of available sunlight. For different amounts of sunlight, there are species that are better adapted to that amount. As time progresses, there is a tendency for new species to emerge which are adapted to take advantage of a particular spot on the resource gradient. When this happens the new, specifically adapted species "squeezes" into the resource gradient at a particular place. Thus, over an evolutionary time scale, there will tend to be an increase in species, and also an increase in beta diversity. Since new species will be adapted for more specific environments, they will not be found everywhere, but only where they are most efficient at taking advan-

tage of the resource gradient. This will produce beta diversity as species cluster together in areas that best suit their adaptations.

Species packing is the result of changes over an evolutionary time scale. Over a shorter span of time, we might consider the way a local environment responds to disturbances. Floods and fires are examples of disturbances that might be regularly expected in a particular area. After a fire, the first plants to colonize an area will be those that grow quickly and are adapted to growing in areas with high sun exposure. After this first wave of colonization, plants that are not adapted to quick colonization but are more long-lived will move in. Eventually all of the original colonizers may be pushed out of a particular area. This pattern, repeated over time, gives us a picture of what a healthy landscape will look like. Norton summarizes developments in the theory of succession in this way:

The picture that emerges from this modified theory of succession is that of a patchy landscape. Because disturbances occur at irregular intervals and affect areas of varied sizes, and because recolonization will be affected by random factors of dispersal, the result will be a harlequin environment varying in species makeup across space and time. (Norton 1987, 52)

Thus a landscape that has successfully responded to disturbances will have high beta diversity.

Beyond being the result of disturbances, beta diversity also helps an ecosystem respond to disturbances (Norton 1986, 129). To see the importance of beta diversity, imagine an environment that is not patchy, but rather consists only in climax species. These are species that do well in a stable environment, outcompeting their fast-growing rivals over time. If there is a fire in this region, it will not be able to recover from the disturbance quickly. If all of the fast-growing species have been pushed out, then the job of recolonization will have to be carried out by the slow-growing species. But slow-growing species are ill-adapted to colonization, and may also not do well in environments that have not already been inhabited by opportunist species. Thus we can see that beta diversity is both the result of natural processes and an important element that assists those natural processes. In both capacities beta diversity has the kind of value that ecologists aim to preserve. Losing this beta diversity will count as a loss of health of the ecosystem.

Seeing the loss of beta diversity as a loss of ecosystem health also

helps to explain why ecologists hold a restoration in beta diversity as a standard of success for some restoration projects.<sup>18</sup> If the goal of a restoration project is to undo a past harm, then the original loss of beta diversity must count as a harm to the ecosystem in order for the reintroduction of beta diversity to that environment to count as a restoration. Just as doctors often aim to restore the health of their patients, ecologists often aim to restore the health of a local ecosystem. To do this requires the restoration of beta diversity, a central and valuable element of overall biodiversity.

### **A PROBLEM: BETA DIVERSITY IS UNLIKE OTHER TYPES OF BIODIVERSITY.**

The examples above show that both our shared evaluative concept of biodiversity and our scientifically informed developments of the concept of biodiversity include beta diversity as a component. As a result we need to focus on preserving beta diversity and not just on preserving species and combating extinction. However as we include beta diversity in our concept of biodiversity, we may worry that it is not a good fit. For beta diversity is what Norton calls a difference definition of (a part of) biodiversity (2006). We noted above that the measures of alpha and gamma diversity were similar to each other; they are both what Norton calls inventory definitions of biodiversity (2006). As a difference definition, beta diversity may seem too different from inventory measures to be included in and valued as part of biodiversity.

This tension is highlighted when we contrast beta diversity, local or global, with global gamma diversity. A loss of global gamma diversity is equivalent to the extinction of one or more species. Thus when we say that global gamma diversity is valuable, there is an entity that can be the holders of that value—the species that makes up global gamma diversity. However there is no such analogue for beta diversity. Since it focuses on difference, beta diversity is a pattern not an entity. This means that some of the arguments for preserving species (and hence for preserving global gamma diversity) cannot be easily extended the case of preserving global (or local) beta diversity.

One type of argument that is an example here is the argument that Holmes Rolston III (1988) gives for preserving species. Even though species, genus, and family might seem to have the same general structure, Rolston argues that there is something special about species. Rolston

characterizes this difference by saying that species are “real historical entities, inbreeding populations,” and “in this sense, species are objectively there as living processes in the evolutionary ecosystem—found, not made by taxonomists” (Rolston 20001, 407). This conception of species makes them more like individual organisms; they exist for a period of time, in a determinate place.<sup>19</sup> Once we conceive of species as extended historical entities, it becomes more plausible to think of species as having goods at which they aim. Rolston argues that species have their own good that is not simply made up of the good of its individual organisms. Predation by wolves on the weaker members of an elk herd is good for the species, because it helps to eliminate weaker genotypes and makes the species better adapted to its environment. But clearly predation by a wolf is paradigmatically bad for any individual elk. This example shows that species have goods that are independent of the good of their component organisms. Rolston then argues that respecting the good of the species gives us a reason to preserve that species, which is equivalent to preserving global gamma diversity (Rolston 1985, 1988, 2001).

Turning to a comparison of global gamma diversity with global beta diversity, we will notice a disanalogy. Unfortunately, beta diversity is not an entity surviving across time with its own potential goals, but is rather a pattern of distribution. We can emphasize this feature by noting that beta diversity could be captured in an instantaneous snapshot, and does not depend on the history of a region. Beta diversity captures the current arrangement of species geographically. As a result, beta diversity is not an entity extended over time with a good to be respected. Note that this disanalogy between Rolston’s argument for preserving species and any arguments we can offer for the preservation of beta diversity is a general one. Any argument for species preservation that depends on treating a species as an extended entity will not be applicable to beta diversity.<sup>20</sup> Thus it seems that a number of arguments that might have motivated the preservation of beta diversity are eliminated.

### **THE SOLUTION: THE VALUE OF PATTERNS NOT ENTITIES**

Fortunately there are arguments for species preservation that do not depend on treating species as an extended historical entity and instead show us that we sometimes value patterns, not just entities. Ben Bradley argues that we ought to preserve species because species have what he



calls contributory value (2001). To explain contributory value, Bradley makes a distinction between two different types of relational properties that might confer value. The first is familiar—instrumental value. If we value a hammer instrumentally we do so because that tool has particular causal properties, *vis.* the ability to drive in nails. But causal properties are not the only relational properties. There are also relational properties of a part to a whole, and it is here that we find contributory value. Bradley defines contributory value of a thing as, “the contribution it makes to the overall value of the world, less the intrinsic value of that thing” (2001, 50).<sup>21</sup>

After introducing the concept of contributory value, Bradley focuses on one specific way that a part can make the whole better. That is by contributing to the variety in it. In order for contribution to variety to be valuable, variety itself must be valuable. Bradley makes this case by looking back to Leibniz and Brentano and to the principle of *bonum variationis*. This principle holds that “other things being equal, it is better to combine two dissimilar goods than to combine two similar goods” (Chisholm 1986, 70–71, quoted in Bradley 2001, 51). This principle can be applied to objects of aesthetic appreciation, but Bradley argues that it can also be applied in the natural world. Thus, two worlds with the same number of organisms in each can vary in value. If one has more variety than the other (if it contains more species) then that world is more valuable. This value then gives us a reason to preserve species. For if we destroy a species, we lower the value of the world by destroying a little bit of its variety.

Considering the *bonum variationis* principle, Bradley’s argument is tailor-made to be broadened to explain the value of beta diversity. Beta diversity is good because *all* diversity is good. And this argument does not depend upon a focus on species understood as super organisms. The principle of *bonum variationis* does not focus on the particular organisms or objects that make up the total variety. Instead the focus is on the differences between the kinds of organisms that exist. This focus fits perfectly with beta diversity, which is concerned only with differences. Therefore, some arguments for the preservation of species, such as that offered by Bradley, could be easily extended to include beta diversity as well. These extendable arguments are those that focus on patterns and their values and not directly on the value of entities extended over time.

## CONCLUSION

There are a number of reasons why beta diversity ought to be considered an important part of biodiversity and, as a result, ought to be protected. Some arguments depend on the fact that people already seem to value beta diversity, as is illustrated by their pride in local organisms and the general intuition that the results of an anthropogenic blender would make the world a worse place. Other arguments look at our basic evaluative concept of biodiversity and examine how it is developed and extended by scientific discoveries. By this standard, beta diversity should also be included as an important component of biodiversity. For beta diversity is an essential part of the processes by which the other measures of biodiversity are produced and sustained. Beta diversity is a product of the process of species packing, which produces environments that are maximally biodiverse. Beta diversity is also required in order to protect other kinds of biodiversity—beta diverse ecosystems will be more resilient to catastrophic events, such as fires, and will have the resources to recover more quickly. While there are disanalogies between global gamma and beta diversity, some arguments for the preservation of species can be extended to cover the preservation of beta diversity as well. These are arguments that do not depend on treating species as extended super-organisms, but rather focus on patterns and complexity in nature—such as Bradley’s argument that is dependent upon the principle of *bonum variationis*.

Returning to the specific issue of invasive species, we can see that the preservation of beta diversity gives us a further strong reason to avoid the introduction of invasive species. Beta diversity at both the global and local levels is reduced when invasive species are introduced. This effect can be produced even when there is direct harm neither to human interests nor to the ecosystem in terms of species loss. Thus, because introducing invasive species can harm humans directly, harm the ecosystem through extinction or extirpation, and, as we have now seen, harm the ecosystem through a reduction of beta diversity, we have ample reasons to avoid the introduction of invasive species.

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#### NOTES

1. For information about how the planting of Kudzu was encouraged in the American south, see Blaustein (2001).
2. I will only consider the ethics of introducing invasive species. The complex interplay between the policies that would best prevent their introduction, the present methods to best control those invasive species, and the harm to those methods might impose is a task that goes beyond my present purposes. For a public policy approach to the benefits and costs of prevention, eradication, and biological control of invasive species see van Driesche and van Driesche (2000), Mack et al. (2000), and McNeely et al. (2001).
3. Invasive species may tend to out-compete native species because they have the advantage of having escaped their native biotic constraints, including native parasites and predators (Mack et al. 2000).
4. Simberloff (2005) argues that this risk is substantial, and we should form our policies to respect it.
5. This assessment of the causes of extinction has been questioned by Gureitch and Padilla (2004), however their methodology in raising this objection has been criticized by Clavero and Garcí a-Berthou (2004) for counting as cases not involving invasive species all the instances in which there was no determined cause of extinction in the database.
6. Including Gunn (1980), Varner's (1987), Johnson (1992), Callicott (1986, 1987), Rolston (1985, 1988, 2001), and Bradley (2001).
7. It is the general claim that invasive species are harmful that is questioned by Sagoff (2005). Here he considers the possible harms to the environment to be only extinction and the reduction of local productivity. I argue below that there is another measure of harm that is missing in Sagoff's arguments.
8. These terms were introduced by Whittaker (1960, 1972), and developed by MacArthur (1965). This figure explaining the difference between them is adapted from an example in Meffe (2002).
9. Different measures of alpha diversity will be concerned not only with the number of species found but also with their relative distributions. While this more complex measure is clearly of ecological importance, I will focus on the simpler measure of species presence/absence because, as we move up to the level of gamma diversity, it more adequately captures the concerns about extinction. We are concerned with a species ceasing to exist, not with its relative distribution (except to the extent that the number of organisms may predict future extinction).

10. Norton (2006) characterizes alpha diversity as an inventory definition of diversity since it focuses on the inventory of species in a given area. He classifies beta diversity as a different definition, since it focuses not on pure inventories in a given area but on differences between areas. Gamma diversity (defined below) also turns out to be an inventory definition.
11. Even though the gamma diversity, or the number of species found in the whole forest, stays the same. Beta diversity is independent of alpha or gamma diversity.
12. There is some inconsistency between the way that beta diversity was originally defined by Whittaker and the way this concept is now used. Whittaker defines three measures of difference between plots, depending on the size of region that contains those compared plots. Whittaker defines these to be pattern, beta, and delta diversity. The only difference between these three is scale. Yet the scale that Whittaker gave does not really limit the way that ecologists talk about beta diversity today. Beta diversity is far more often used as a general measure of difference between plots regardless of the size of the region that contains them. So in this paper I will address only beta diversity.
13. See Takacs (1996) for an extensive survey of the way that the term 'biodiversity' developed and the many different meanings it has taken on.
14. Wood (1997, 2000) also answers this question in the affirmative, but his arguments do not depend directly on the value that we assign to biodiversity.
15. See Olden et al. (2004) and Olden (2006) for the original characterization of the anthropocentric blender. The terminology of a coming homogeocene was introduced by E.O. Guarrant (1992).
16. David Quannen (1998) coined to term "planet of weeds."
17. This process is explained in Whittaker (1972).
18. See, for example Aronson et al. (1993), Finegan and Delgado (2001), Leanne Martin et al. (2005), and Lepori et al. (2005).
19. It may be difficult to determine the exact boundaries of a species—when one species ceases to exist and another species begins, which exact organisms make up the species. But similar concerns about organisms, and particularly about ourselves as humans, don't stop us from saying that the organisms, or ourselves, are discreet entities. See Johnson (1992) for a consideration of ways in which species, like organisms, are entities, despite having vague boundaries.
20. This will be true of a wide variety of arguments for the preservation of species including Gunn's (1980) argument based on the rarity of those species, Varner's (1987) and Johnson's (1992) more legalistic arguments that species have standing, and Callicott's (1986, 1987) argument for the value of species on the basis of bio-empathy.
21. This, of course, can't be quite right, since we should also eliminate the instrumental value that the thing brings to the world, so as to focus on contributory value alone.

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