An experimental approach to addressing ecological questions related to the conservation of plant biodiversity in China

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ABSTRACT

We briefly introduce and describe seven questions related to community structure and biodiversity conservation that can be addressed using field experiments, and provide the context for using the vast geographic diversity, biodiversity, and network of Nature Reserves in China to perform these experiments. China is the world's third largest country, has a diverse topography, covers five climatic zones from cold-temperate to tropical, has 18 vegetation biomes ranging from Arctic/alpine tundra and desert to Tropical rain forest, and supports the richest biodiversity in the temperate northern hemisphere (>10% of the world total). But this tremendous natural resource is under relentless assault that threatens to destroy biodiversity and negatively impact the services ecosystems provide. In an attempt to prevent the loss of biodiversity, China has established 2729 nature reserves which cover 14.84% of the nation's area. Unfortunately underfunding, mismanagement, illegal activities, invasive species and global climate change threaten the effectiveness of these protected areas. Attention has focused on protecting species and their habitats before degradation and loss of either species or habitats occur. Here we argue that we must move beyond the simple protection of ecosystems, beyond their description, and by using experiments, try to understand how ecosystems work. This new understanding will allow us to design conservation programs, perform restoration of damaged or degraded areas, and address resource management concerns (e.g., agriculture, logging, mining, hunting) more effectively than with the current approach of ad hoc reactions to ecological and environmental problems. We argue that improving our understanding of nature can best be done using well designed, replicated, and typically manipulative field experiments.

1. Introduction

China is the world's third largest country. It stretches 5,200 km from east to west, and the mainland spans 35 degrees of latitude, and covers five climatic zones: cold-temperate, temperate, warm-temperate, subtropical and tropical. China has a great physical diversity. The east and south of the country consists of fertile lowlands and foothills, the west and north of the country is dominated by sunken basins (e.g. the Gobi and the Taklamakan), plateaus (e.g. Qinghai–Tibetan Plateau), and high peaks. The country is dissected by deep river valleys including the Yellow, Yangtze and Mekong Rivers. This wide range of environmental conditions supports a vast biodiversity that is under relentless assault and threat, from both within and outside China. Without proper understanding of how ecological processes act to maintain this diversity, the degradation and loss of China's tremendous natural resource will have significant and far reaching effects.

Biodiversity provides significant ecosystem goods and services to humans (Costanza et al., 1997), and that biodiversity generates considerable economic benefits for humans (Balmford et al., 2002; He et al., 2005). It is these services and the resultant economic benefits that play an important role in ensuring the well-being of people (Xu et al., 2008). Biodiversity is one of China's tremendous natural resources and it must not only be preserved, but it should be promoted. We argue that a productive way to achieve this is to move beyond simple descriptions of nature, and move towards a more comprehensive understanding provided by scientific inquiry.

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We can identify patterns in nature (generalization) and even attribute causal explanations for these patterns in the form processes, mechanism, interactions and conditions. However, it is only by testing these descriptions through controlled, repeatable experiments that we are able to confirm our understanding of nature. This knowledge is essential to help solve conservation, restoration, and resource management problems currently facing China and the world.

1.1. China's plant biodiversity

China's great physical diversity produces a range of environmental (abiotic) conditions that support a vast plant biodiversity. Ni (2001) describes 18 biomes and The Vegetation of China (Editorial Committee for Vegetation of China, 1980) describes 28 vegetation types (see Ni, 2001). These vegetation types range from various types of forest (e.g. cold-temperate deciduous broadleaved, warm-temperate evergreen coniferous, subtropical mixed decid-uous—evergreen broadleaved, tropical rain forest) tropical scrub or coppicewood, Tamarix scrub, montane scrub, various types of grassland (e.g. temperate form—gramineous meadow steppe, temperate desert steppe), to temperate sandy desert, and alpine desert. Within these vegetation types, China holds the richest biodiversity in the temperate northern hemisphere, and China is one of the most biodiverse countries in the world (Harkness, 1998). The country has at least 4357 species of terrestrial vertebrates (Ministry of Environmental Protection, 2015) (world total: ~40,000 named species) and ~32,067 (Wang et al., 2015) species of vascular plants (world total: >368,000; Chapman, 2009). This means that China has slightly <10% of the world's total in terrestrial vertebrates and vascular plants (Liu et al., 2003). Many of China's species are unique. Perhaps half of China's species are endemic and include many archaic and distinctive evolutionary lines such as *Ginkgo biloba* (Ginkgoes), *Wisteria sinensis* (Chinese Wisteria), *Pinus bungeana* (Lacebark Pine), *Magnolia denudata* (Yulan Magnolia), *Juniperus chinensis* (Chinese Juniper), *Cunninghamia lanceolata* (China-fir), *Taxus cuspidata* (Japanese Yew) and *Metasequoia glyptostroboides* (Dawn Redwood), the latter often considered the oldest and rarest plant in the world.

1.2. Threats to China's biodiversity

Many protected areas are being degraded and destroyed (Liu et al., 2001; Hockings, 2003; Quan et al., 2011) because of poor or overly bureaucratic management. The loss of species, in both species-poor (e.g., deserts) and species-rich ecosystems (e.g., tropical forests), can reduce ecosystem functions such as primary productivity, nutrient cycling, decomposition rates, water filtration, and species interactions such as mutualisms, facilitation, competition, and predation. Ecosystems provide services that support people and societies, and services arising from basic ecosystem functions include forage production for livestock, soil stabilization, carbon storage, climate regulation, pollination of crops, and natural pest control. Thus, the loss of biodiversity imposes a high economic cost.

The current loss of biodiversity has been the most dramatic change humans have induced on ecosystems in the past century, and the current global extinction rate is up to 100× times faster than pre-human levels (Liu et al., 2003; Barnosky et al., 2011; Ceballos et al., 2015). There is a growing concern that this loss of species will have important effects on ecosystem functioning (Cardinale et al., 2012; Hooper et al., 2012), whereby species-poor ecosystems may perform differently or less efficiently than the species-rich systems from which they are derived. As in many parts of the world, China's biodiversity is facing a critical situation, as it is suffering from an increase in the extent and intensity of human activities. Illegal harvesting of plants, overgrazing, vegetation harvesting, soil erosion, agriculture, pollution and firewood collection are some of the primary threats to biodiversity in this region. Overgrazing and desertification have been identified as severe problems (Convention on Biological Diversity, 2010). The great physical and biological diversity of China also makes the country especially vulnerable to the establishment of invasive species. Potentially invasive species from most areas of the world may find suitable habitat somewhere in China. The International Union for Conservation of Nature (IUCN, 2002) has identified the world's 100 worst invasive species. Fifty of them are found in China and 23 have invaded China's natural reserves and threaten the local biological diversity.

1.3. Climate change

Any efforts to preserve biodiversity or understand ecosystem function must be considered in the context of human-caused global climate change. The pollution of earth's atmosphere with abnormal amounts of carbon dioxide will have profound effects on China (IPCC, 2014). Most descriptions of climate change focus on how it will alter the abundance and distribution of abiotic resources in ecosystems. Because of its great diversity these changes will not be uniform across China. Since 1961, NW China has experienced a 0.7 °C rise in temperature and 22%—33% increase in rainfall (IPCC, 2014). There has been an increase in short duration heat waves. While the north has seen a decrease in extreme rains, the south and west have experienced an increase. There has also been an increase in the number of floods and drought (Zhai et al., 2005). Thus, because the climate in China is changing, it prudence demands that we understand how ecosystems work rather than simply describing what we see.

1.4. Protecting biodiversity

Nature reserves receive protection because of their recognized natural, ecological, and cultural values. Nature reserves are essential for biodiversity conservation by providing habitat and protection from hunting or fishing for both common and rare species. Protection also helps maintain ecological processes that cannot persist in intensely managed human dominated landscapes.

Nature Reserves can be used as a baseline against which to compare other ecosystems where degrading and damaging human activities have occured. China has established 2729 nature reserves which cover 14.84% of the nation's area (Zheng and Cao, 2014; Ministry of Environmental Protection, 2015). China has set ambitious goals of increasing the number of reserves. Nonetheless, the nature reserve system faces serious challenges that often involve under-funding, inefficient management, lack of education, size and location of reserves, and illegal activities (Anonymous, 2000; Liu et al., 2003; Quan et al., 2011; Wu et al., 2011). Many research scientists have expressed concern about the effectiveness of nature reserves.

2. After description

The high level of physical diversity in China coupled with the enormous level of biological diversity provides an almost unparalleled opportunity to conduct experiments on the processes that maintain biodiversity and ecosystem function. Ironically, the ability to do experiments is enhanced by the altered or degraded state of many ecosystems. This in no way implies that current research is of low quality nor does it question much of the excellent experimental research on biodiversity already being done in China; research such

as by Jiang et al. (2003), Wang and Ba (2008), Gao et al. (2009), Yang et al. (2013), Bruelheide et al. (2014), Zhao et al. (2013) in addition to those cited throughout the paper and many others. However, the protection of China's biodiversity is crucial to both China and the world. Understanding the processes the give rise to and maintain biodiversity is essential if we are to develop a comprehensive and sustainable strategy for the protection of biodiversity. China has made enormous efforts to protect its biodiversity resources and its successes and failures have provided a platform for experimental field research that can advance both knowledge and theory. One of the most fundamental questions in ecology to which we still have no definitive answer is a biodiversity question: How do plant species, which can reach densities of 50 m^{-2} in grasslands and up to 500 tree species ha^{-1} in forests, stably coexist?

Nature Reserves and other protected areas are chiefly designed to protect habitat, and of course, sometimes individual species. Sadly, we need much more than a line on a map, a fence on the ground, or laws banning the transport or sale of species. Even with adequate funding and expert management the existence of a protected area or persistence of an endangered species does not guarantee the long-term survival of biodiversity. A problem with Nature Reserves and other protected areas is the false hope in believing that the enclosed species are protected. However, communities and ecosystems are not static and continually undergo a process of natural change which eventually may lead to the exclusion of the species and habitat that the area was initially designed to protect. In addition, it is rarely practical to protect all species or important ecological processes (e.g., water and air filtration) in protected areas because these processes don't respect the boundaries of the reserve.

Of more critical importance is that we try to understand how the ecosystems work, and if they are broken (i.e., degraded) take steps to restore them. We argue that this can best be done using well designed, replicated, and often manipulative field experiments (Bruelheide et al., 2014), although gradients are useful tools as well. Experiments are conducted for the purpose of answering specific questions about nature. These questions are usually stated as hypotheses about how we think nature works and thereby contain an implied prediction. Confirmation of our predictions is a powerful means to demonstrate the accuracy of our understanding of the biological world. In principle, manipulative experiments are an acceptable procedure, because their planning implies that we are making some level of prediction of the outcome. Biodiversity problems are recognized through observations made in the field, and therefore such observations are vital to the science. But after that observation or description has been made we need to seek explanations, usually by doing experiments. A robust prediction requires a clear statement of outcomes that must occur for the prediction to be confirmed. Therefore, to carry out a satisfactory experiment, one most have full knowledge of the conditions existing before the experiment is begun- and this is precisely what is provided by many of China's protected areas.

Recently Bruelheide et al. (2014) established a major biodiversity experiment in subtropical Xingangshan, Jiangxi Province, China. The mountainous region of Southwest China provides ideal conditions for many of the experiments we will describe. It is a biodiversity hotspot that stretches over 250,000 km^2 of temperate to alpine mountains between the eastern edge of the Tibetan Plateau and the Central Chinese Plain. It has a complex topography, ranging from <2000 m in some valley bottoms to 7556 m at the summit of Mount Gongga and this results in a wide range of climatic conditions. The mountain ridges are oriented in a generally north–south direction. Temperatures range from frost-free throughout the year in southern parts of Yunnan to permanent snow and ice on some of the high mountain peaks of Sichuan and Yunnan. At higher altitudes in Yunnan, annual average rainfall can be >1000 mm on SW slopes, while NW areas of the region rarely receive 400 mm annually. This variability in climatic and topographic conditions results in a wide variety of vegetation types across the hotspot, including broad-leaved and coniferous forests, bamboo groves, scrub communities, savanna, meadow, prairie and alpine scrub. There are of course many other locations scattered throughout China that are perfect for doing biodiversity experiments. These locations include areas such as the extensive scrubland of the high Qinghai Tibetan plateau, and the seemingly endless expanse of the grasslands in Inner Mongolia.

3. Experiments

The number and range of ecological questions that could be asked about biodiversity in China is vast and it is not our intent to be comprehensive in our coverage. We seek to provoke some thought and stimulate more research activates focused on understanding China's biodiversity (Duffy, 2009). Biodiversity experiments currently provide some of the most exciting and timely research options in ecology and addressing these questions in China will provide valuable knowledge to both China and the world. To promote and stimulate more experimental ecological research in China we will highlight seven major questions and hypotheses (also see Bruelheide et al., 2014 'Major questions addressed by BEF experiments'). While many of the experimental designs are quite simple in principle, in practice, many major design decisions have to be made based on the type of vegetation, topography, and availability of appropriate sites (Bruelheide et al., 2014). Perhaps one of the most critical design decisions is the size, or the scale, of the experiment. Multi-scale experimental studies are rare, yet ecologists have long recognized the importance of spatial scale in ecological processes and patterns (Sandel and Smith, 2009). Many patterns have been shown to be, or have the potential to be, scale-dependent (e.g. Crawley et al., 2005; Levine, 2000). The grasslands of Inner Mongolia provide vast areas of relatively uniform conditions that would permit testing for scale-dependency of responses to treatments, specifically animal (grazing) density, productivity (fertilizer addition), and predator additions or removals (Zhang et al., 2013a,b).

3.1. How are natural communities structured?

More than 50 years ago, Hairston et al. (1960) asked a simple question about the fundamental limiting processes in biological communities, and whether they were more likely to come from below (nutrient availability) or above (herbivores or carnivores). Their question was: "why don't herbivores increase in numbers to such levels as to deplete or devastate vegetation?" This question spawned a number of additional questions and hypotheses with fundamentally different implications on vegetation regulation, such as: the "Exploitation Ecosystem Hypothesis (EEH)" (Fretwell, 1977, 1987; Oksanen et al., 1981, Oksanen and Oksanen, 2000), "The World is Prickly and Tastes Bad" (Pimm, 1991), the "Green Desert" (White, 1978; Moen et al., 1993), "The World is White, Yellow, and Green" (Oksanen et al., 1981; Pimm, 1991), "The Cruddy Ingredient Hypothesis" (Hartley and Jones, 1997), and "Large Parts Of The World Are Brown Or Black" (Bond, 2005). These hypotheses address whether ecosystems are structured from the top-down, or from the bottom-up, with much debate and review (Polis, 1999; Crawley, 1997; Sinclair et al., 2000; Turkington, 2009; Shurin, 2015). There are two main schools of thought and these have been reviewed by Turkington (2009), Shurin (2015) and O'Connor et al. (2015).

In the "bottom-up" hypothesis it is assumed that communities are regulated by nutrient availability or environmental conditions from below; higher trophic levels (in our case herbivores) have no regulating or limiting effect on productivity or biomass on the levels below them. In the "top-down" hypothesis, top predators are self-regulating and each level then controls the level below. In the top-down case, plants are not limited by nutrient availability, but rather, by herbivores. Many other models involve variations of the top-down and/or bottom-up hypotheses and there is a growing recognition that both process operate simultaneously in most communities.

Understanding whether communities are structured from the top-down or the bottom-up is not only a theoretical debate, but has management and conservation implications, especially in National Parks, Nature Reserves, and other protected areas. The relative effects of these forces is becoming increasingly important as humans alter ecosystems by overharvesting of consumers, increasing nutrients especially nitrogen over large areas, and an altering the distribution of primary producers by clear cutting of forests, and promoting desertification. These anthropogenic influences are changing the strengths of top-down and bottom-up forces in ecosystems. Therefore, identifying the relative strengths of these forces and how they differ across different types of ecosystems is increasingly important for understanding how communities are structured, and especially how this structure is maintained or changed across different spatial (Sandel and Smith, 2009) and temporal scales. The EEH (Fretwell, 1977, 1987; Oksanen et al., 1981, Oksanen and Oksanen, 2000) makes different predictions for ecosystems having different productivity levels. Turkington (2009) develops three hypotheses leading to 13 testable predictions. This same approach can be extended to ask questions about the role of consumers in ecosystems (see question #7).

The experimental testing of these hypotheses is quite simple in principle, although forested systems may not be amenable to these tests. The experiments would involve the addition (or reduction) of fertilizer, water, or some other potentially limiting resource combined with a reduction of herbivore or predator density, or their exclusion. The interacting effects of these treatments with other treatments such as warming (using open-top chambers or heaters), water availability (added, or reduced using rain-out shelters) and clipping (simulated herbivory) can be done quite easily, and can be repeated at various points along natural productivity gradients. Potential difficulties with these experiments are in selecting species pools, identifying controls, deciding on spatial and temporal scales, etc.

3.2. How does biodiversity determine the function of ecosystems?

Biodiversity is now the primary focus of both scientists and natural resource agencies because of its potential importance for the adequate functioning of the earth's ecosystems (Isbell, 2014) so that they can continue to provide services to humans. Ecosystem services are benefits received by humans such as food production, pollination, clean water, flood control, carbon sequestration, soil formation and preservation, among other things. Consequently, the preservation of ecosystem function is essential to humans.

Theories about the relationships between biodiversity and ecosystem processes have a long history in theoretical ecology (e.g. Elton, 1958; MacArthur, 1972; Pimm, 1984). Early experimental and theoretical studies focused on building communities and observing changes in function (references in Tilman, 1996; Naeem and Li, 1997; Lawton et al., 1998). These early experiments identified some fundamental issues, such as, which "ecosystem function" is the relevant indicator of ecosystem change (e.g. plant growth, soil fertility and decomposition, or nutrient cycling etc.) or whether we

need to look at ecosystem properties such as "stability" (i.e., resistance to change, or resilience following disturbance) to understand the maintenance of biodiversity. A novel approach to this question is to start with whole ecosystems having numerous plant species and observe what happens to various ecosystem functions when biodiversity changes as a result of manipulative disturbances that resemble human impacts. Simplification of ecosystems through experimentation, such as removing individual native species or groups of species, adding of nitrogenous fertilizer, or subjecting areas to a range of livestock grazing intensities is perhaps the only way to know how declines in species number, loss of functional groups, or absence of whole trophic levels will impact ecosystem functions. Likewise, approaches that simulate nitrification or grazing in controlled replicated experiments are the best way to understand how humans impact ecosystem function. A better understanding of how human activities impact essential ecosystem functions is critical to design either conservation areas or industrial and agricultural practices that preserve the services provided by ecosystems.

Innovation, in either conservation or industrial sectors, comes from examining real, complex systems that have been systematically and deliberately simplified and comparing them with parallel unaltered (natural) systems. This approach allows us to identify which ecosystems functions differ between species-rich and species-poor systems. The results will also indicate which functions are most sensitive to loss of species, the stability consequences that result from loss of species, and the approximate time scale that may be involved. In practice, variables such as primary productivity, decomposition, nutrient cycling, soil development, and soil fertility have, by default, come to represent function and the impact of species loss, nutrient deposition, and land use change on these and other functions should be examined.

We recognize three hypotheses of the possible relationship between biodiversity and ecosystem function (Vitousek and Hooper, 1993). First, is the rivet hypothesis in which each additional species has a constant (i.e. all species considered to have equal effects) additional effect on function (Ehrlich and Wilson, 1991). This hypothesis implies that all species play some role in maintaining ecosystem function. Progressive loss of species, therefore, results in a loss of some function and at some point there is a catastrophic change in function. The second hypothesis is called the keystone hypothesis (Lawton and Brown, 1993) and this is another version of the rivet hypothesis. This hypothesis is asymptotic (i.e. species are considered unequal in their effects) so that each species that is added has a decreasing impact on function. It suggests that some species are keystones, dominants or foundation species and are essential to the structure of the community. The loss of these disproportionately important species results in rapid and catastrophic change in ecosystem function, whereas the loss of other species can have little or no effect on ecosystem function. The third hypothesis, the redundancy hypothesis (Walker, 1992) suggests there should be no impact of biodiversity loss on ecosystem function, until almost all species are lost. This hypothesis proposes that species have overlapping roles in their communities so that the loss of a species is compensated by an increase in activity or density of the remaining species. Only after considerable species loss occurs do compensatory processes break down and function declines. Since each hypothesis makes a different set of predictions in terms of function an experimental perturbation could test which hypothesis is the most relevant.

There is a growing understanding that the effects of biodiversity loss require recognition of the non-random nature of species loss (Wardle et al., 2011; Estes et al., 2011). But, it is important to note that "species" may not be the best unit by which to discuss ecosystem function, and the classification of organisms into

functional groups (e.g. nitrogen fixers, perennial grasses, forbs, trees), guilds, or even whole trophic levels (e.g., top predators, herbivores) may be more relevant ecologically. It may be that the identity of a species, or group of species, may play an even larger role than that of the diversity of the species themselves. Despite this realization, virtually no studies specifically examine the independent effects of species composition and species diversity on the functioning of ecosystem processes such as productivity, decomposition rates, and nutrient cycling. In addition, different measures of ecosystem function may fit different hypotheses (see question #6 below).

3.3. How does the loss of biodiversity alter the stability of ecosystems?

A potential problem with National Parks, Nature Reserves and other protected areas is the false hope in believing that the enclosed species are protected. However, communities and ecosystems are not static; they undergo a process referred to as the exploitation, conservation, release and reorganization cycle (Holling, 1986). This process is not continuous and in the mature successional stages most of the nutrients and energy are locked-up in biomass, and the system gradually becomes more vulnerable to disturbances. Until recently, most disturbances were natural and included fire, wind storms, pest outbreaks, etc., but now human activities such as excesses of harvesting, exploitation, grazing, and exploitation are more common, intense and operate over larger spatial scales. The intensification of disturbance can lead to progressively faster processes of release and reorganization (Holling, 1986).

An important question here is whether the stability of a community (defined by variance in some factor such as biomass) is related to biodiversity. This is not a new debate (e.g. Elton, 1958), but recent work suggests statistical averaging of variances across species inevitably leads to a joint community variance that declines with increasing biodiversity. This is the "portfolio effect" (Doak et al., 1998). Therefore the question: How does the loss of biodiversity alter the stability of ecosystems? May be reworded as: Does decreasing biodiversity lead to more variability in community biomass (i.e. less stability)? In effect, we can predict that a greater number of species, functional groups, feeding guilds, or trophic levels will lead to greater stability if: (i) variance of individual species biomasses increases more than linearly with mean individual biomass (portfolio hypothesis); or (ii) there is compensation between species through interspecific competition (competition hypothesis). Monitoring community biomass in perturbed and intact systems over time can test these predictions (see question #6 below).

3.4. How does the loss of biodiversity alter the integrity of ecosystems?

Ecosystems are complex systems and thus have a number of important properties (May, 1977; Kay, 1991). These properties include: (1) non-linearity in that the whole system behaves as a unit more than the sum of its constituents; (2) multiple scales since local and regional processes differ but affect each other; (3) multiple states, the combination of species, and population sizes, can switch as a consequence of disturbance; (4) dynamic stability in the sense that systems fluctuate around potential stable points that are rarely observed; (5) resilience in that within a range of environmental perturbations they maintain their characteristic species assemblages and rate of return from a given intensity of disturbance; (6) fragility as measured by the limits that a system can tolerate perturbations (resistance); (7) catastrophic behaviour

meaning that they exhibit sudden change if disturbances push the system beyond the limits that determine the system's fragility (Regier, 1992). These properties emerge because ecosystems are thermodynamically open systems that are never in equilibrium (Kay and Schneider, 1992). Therefore our question: How does the loss of biodiversity alter the integrity of ecosystems? May be reworded as: What features of ecosystem integrity change as biodiversity changes? Some of the measurable factors are those listed above. Again, a comparison of unaltered natural systems with systems showing varying degrees of degradation or simplification can provide an adequate field situation to test these hypotheses (see question #6 below).

3.5. Diversity and species composition

Many studies have concluded that in addition to the role that diversity plays in controlling ecosystem function, stability and integrity, the identity or type of species may play an even larger role than that of diversity (number of species) itself. There are almost no studies that specifically examine the independent effects of species composition and species diversity on the functioning of ecosystem processes such as productivity, decomposition rates and nutrient cycling. However, there is good evidence that functional diversity, especially in plants, is an important predictor of ecosystems function (Díaz and Cabido, 2001; Díaz et al., 2003).

Climate change, one of the drivers of biodiversity loss, is likely to have different effects on different functional groups, resulting in the loss of some functional groups before others. For example, the loss of predators can have pervasive effects on lower trophic levels (Schmitz et al., 2010) and have even been shown to indirectly increase carbon sequestration in plants (Strickland et al., 2013). Likewise, herbivores can play a major functional role in ecosystems altering nutrient cycles in ways that change with abiotic conditions (Metcalfe et al., 2014). Different functional groups can have compensatory effects, as trophic processes such as herbivory compensating for the negative effects of nitrification on diversity and subsequently function (Borer et al., 2014). By understanding the role that each group (functional groups, feeding guilds, or trophic level) plays in determining how the entire ecosystem responds to this change, we can predict with greater accuracy the overall effects of climate-changed induced species loss.

3.6. How does the loss of species determine the ability of ecosystems to respond to disturbances?

The frequency and intensity of fires, storms, drought etc. will undoubtedly change with current global warming trends and with increased human pressure encroaching ecosystems. A likely outcome of these changing disturbances for both flora and fauna is a loss of species or changes in species composition. The objective here is to test whether the loss of some of the plant species will result in significant changes in ecosystem processes and whether the remaining species will be able to compensate. This question is a natural follow up to some of the previous questions and is a comparison of degraded ecosystems. Two or more ecosystems could be degraded to an "equal" degree in that both may have lost the same percentage of their biomass, species richness, or functional diversity of their undegraded natural state. However, those losses may have come about in the degraded ecosystems by losses of different species or species functional groups. In other words, one system may have lost many graminoids, another may have lost mostly forbs, and another may have lost representatives of both groups. This question now investigates the role of plant functional groups by asking how these different degraded ecosystems respond to imposed stresses or disturbance.

The essence of this experiment is to remove different plant species or functional groups, then compare the stability, productivity and other functional properties of this degraded system under experimental stresses (e.g. fire, nutrient addition, drought), with systems that have their full biota. Recent reviews (Hooper et al., 2005, Hooper and Vitousek, 2011; Spehn et al., 2005) and meta-analyses (Balvanera et al., 2006; Cardinale et al., 2006) provide clear evidence that biodiversity has significant effects on ecosystem function, and research is shifting to exploring the underlying mechanisms (Díaz et al., 2003). If the traits that determine extinction risk are correlated with the traits that control ecosystem function, the order in which species are lost may have critical effects on ecosystem function and services. Therefore, we need to predict the effect that the loss of particular species or groups of species will have on ecosystem function.

This question is of particular interest in China. The Hohhot Declaration (Peart, 2008) stated that "temperate indigenous grasslands are critically endangered and urgent action is required to protect and maintain the service they provide to sustain human life." This is especially critical because drought and over-grazing are threatening much of the world's grasslands, particularly those in China. In addition, anthropogenic disturbances, including climate change (most models predict that temperate grasslands will experience increased temperatures, drier summers, and wetter winters), are expected to cause an increase in nitrification and nitrogen deposition, increased levels of CO_2, produce longer growing seasons, and potentially cause many species extinctions, all of which have the potential to drastically alter grassland communities. However, a theoretical basis for decision making on conservation and management policy in grasslands is often lacking and many decisions are based on expediency, politics, and on a case-by-case basis.

3.7. How does food web complexity and productivity influence the relative strength of tropic interactions, and how do changes in trophic structure influence ecosystem function?

This question extends question #1 by asking if predators can initiate a trophic cascade whereby predator effects propagate downward through the food chain, crossing a number of trophic levels and ultimately influencing the biodiversity of the plant or soil levels. The effect of predators may cascade through ecosystems to impact disturbance regimes, the prevalence of diseases, soil nutrient cycling, water quality, species invasions, and biodiversity (Estes et al., 2011). The recognition that predators can have important effects on species, communities, and ecosystems even in systems with strong resource-control is increasing. Though a classic trophic cascade is not the only way predators affect ecosystems, food webs, or biodiversity, it is a clear outcome demonstrating the role predators can play in ecosystems. We have good examples of ecosystem-level (energy, nutrients), community-level (biomass), and species-level (diversity) cascades in many ecosystems (Dyer and Letourneau, 2002, 2013) and our understanding of ecosystem-level cascades is continuing to grow (Schmitz et al., 2000; Strickland et al., 2013).

Consumers can exert indirect control on ecosystems through a variety of mechanisms, resulting in very different impacts. The classic example of top-down control is how the removal or addition of predators can change the distribution of biomass between trophic levels (community-level cascade). This occurs through either changing herbivore abundance or behaviour. Second, the addition, removal, or alteration of the predator community composition can change the composition, diversity or behaviour of herbivores resulting in changes in the biomass, biodiversity, or composition of the producer community (species-level cascade). A third way that consumers can exert control is through changing the function of ecosystems. There is growing recognition that predators can exert control on ecosystems processes such as decomposition rates, nutrient flux and storage (including carbon), primary productivity, and water cycling without obvious visual changes to the herbivore community (Strickland et al., 2013).

We propose that by adding or removing predators from an ecosystem we will see changes in the productivity, diversity, and function of both herbivores and primary producers. In addition, we propose that human-caused changes to the distribution and abundance of resources can change the strength of consumer-control in any particular ecosystem and possibly elicit unwanted trophic cascades. We suggest that it may be possible to bring about a trophic cascade not simply through the addition or removal of predators in a system but by changing the amount, distribution or quality of resources in an ecosystem. Likewise, changing the number of species that occupy lower trophic levels (through invasions, extinctions etc.) could alter the transfer of energy through the food web making ecosystems either more or less susceptible to inherit instability of trophic cascades. Understanding that trophic structure can be altered in indirect ways, ways other than direct perturbations, harvesting, or exotic invasions, is important when we think about conserving and restoring ecosystems.

4. Conclusions

We have briefly introduced and described seven questions that could be addressed using the vast geographic diversity, biodiversity, and network of Nature Reserves and other protected sites in China. The aim of the account is introductory and thus it is not a comprehensive list or literature review. Our goal is to stimulate experimental research into how ecosystems function and how to preserve and promote biodiversity. For example, each of the seven questions we outlined can be asked in at least five different contexts:

(1) How do the observed responses change across the 28 vegetation types in China identified by the Editorial Committee for Vegetation of China (1980)?
(2) How do the observed responses change from the low productivity grasslands of the Qinghai Plateau to higher productivity grasslands in other parts of China, or temperate steppe versus Alpine steppe, or along a transect across any of the major biomes?
(3) How do the observed responses change along a gradient in the intensity of human-use or degradation.
(4) How long should an experiment be conducted given that the immediate results are seldom indicative of longer-term outcomes?
(5) How does the scale of the experiment influence treatment responses?

China is one of the world's biodiversity hotspots, and not unlike many parts of the world much attention has been focused on describing, listing, legislating and protecting habitat and species in various types of protected areas including Botanical Gardens, National Parks, and Nature Reserves. While this is both necessary and commendable we have tried to make the case that understanding how these habitats and ecosystems work, how they function and how they respond to both natural and anthropomorphic perturbations, is the next important level of investigation. Simply containing ecosystems in preserves will not help protect them. We must understand how ecosystems function, first to know what components are essential to preserve, second to ensure that ecosystems continue to function and thus provide humans services.

China's diverse physical geography, its 18 biomes and 34 vegetation types, vast biodiversity and network of protected areas provides an ideal opportunity to test many of these vital questions because these areas can provide the contrasts necessary to examine how human impacts influence ecosystems.

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