Russell B. Doughty Final
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Earth's Terrestrial Life Support System

"Cursed is the ground because of you; through painful toil you will eat food from it
all the days of your life.
It will produce thorns and thistles for you, and you will eat the plants of the field.
By the sweat of your brow you will eat your food until you return to the ground,
since from it you were taken.
For dust you are and to dust you will return."

Genesis 3:17-19 (NIV; God to Adam after taking from the ***Tree of Life***)

Introduction

The role of earth's biomass and the affects of deforestation upon the biosphere have long been underestimated. Whether their arguments are rooted in concerns for future human recreation or substance, aesthetic values, endangered species, or biodiversity, many philosophers, conservationists, bioenvironmentalists, and foresters have championed their platforms upon a deep-seated notion that our forests are an innately necessary piece of earth's mysterious puzzle. Although these biospherically friendly movements have fueled the creation of state and national bird preserves, game reserves, forests, parks, rivers and lakes; direct action in the form of human protests; and international discourse, they have had little affect upon socio-ecological systems of all scales.

Scientists have been struggling for decades to understand the relationship between forests, their trophic inhabitants, the environment and the future. It hasn't been until recently that science has begun to reveal the role of forests in mesoscale air circulation and biogeochemical cycling, and how perturbations to the structure and function of that cycle affects global climate. It is growingly obvious that the yard stick used to define sustainable forestry is far too short; forests are the single largest natural resource available to sequester atmospheric carbon and volatize the biogeochemical cycle necessary for terrestrial inhabitation.

The goal here is to urge the amendment of forest management techniques and land use policies in light of forests' newly discovered role within the earth system. These new lessons should transform national policy, international dialogue and the trajectory of earth's biosphere.

First, we will review how forests connect local, regional and global cycles beyond traditional models of habitat preservation and biodiversity. Second, we will discuss the formation of the Northwest Forest Plan (NWFP) of 1994, assess the implementation of the plan since its inception, and identify threats to the plan's founding principles. Third, we will explore forests as the foundation of terrestrial inhabitation. Lastly, we will make real-world suggestions on how the United States should approach forestry as the central facet of a larger socio-ecological system, and how international organizations can do the same.

1. The Role of Forests in the Earth System

> *"Through this phenomenon [evapotranspiration], the planetary heat balance, hydrologic cycle, and climate become closely linked."* - Perry et al. (2008 p33)

We will move beyond the historically cherished forest ecosystem services that directly affect organisms, such processes that provide food, habitat, medicinal plants and wood, to identify how forests directly affect the movement and transformation of energy and elements within our biosphere. By doing so, we will provide clues as to how forests affect bioregional and global climate.

First, we will quickly address global leaf area and albedo to illustrate the affect of forests on earth's radiation balance. Second, we will inspect the part played by forests in biogeochemical (BGC) cycling by discussing (1) carbon storage, (2) nitrogen fixation, (3) water cycling, and (4) weathering. Finally, we touch upon what role forests may play in the production of wind and lightning to encourage future research.

Albedo

The average temperature of the earth, for a given level of incident solar radiation, depends chiefly on two factors: atmospheric composition and the albedo of earth's absorbing surface (Perry et al. 2008). Due to their low albedo, forests are the most affective vegetative type at absorbing solar energy.

Even though forests cover only about 30 percent of the earth's surface, it is estimated they account for about 70 percent of the earth's leaf surface area (Perry et al. 2008). It has been estimated that forests reflect up to 25 percent of solar radiation in the winter (Perry et al. 2008 p32) and return as low as 5 percent of solar radiation for some conifer forests (Smil 2002 p103). However, as we will see, the ability of forests to soak up solar radiation like a sponge has more implications than simply affecting the radiation balance of the earth. They put the radiance to work.

BGC Cycling: Carbon Storage

It has long been known that forests are a large source of carbon storage, but to what extent has been hotly debated. Sabine et al. (2004) estimated that forests not only account for 82 percent of earth's vegetative carbon storage, but their soils account for 40 percent of the earth's soil carbon storage capacity. Due to the complexity of forests by type, age, structure, distribution, disturbance history, ownership, and technological limits, it has been difficult to quantify net ecosystem production (NEP), harvest rates (HR) and forest fire emissions (FE) on the bioregional level.

However, recent research by Turner et al. (2011) has not only been able to quantify these values to create a net ecosystem carbon balance (NECB) for the Forest Service's Northwestern Region 6, they were able to model how a change in forest management approaches shifted the region's forests from being a carbon source to a carbon sink over time. Later, we will discuss how such methods and simulations will prove extremely useful in the evolution of forest management.

BGC Cycling: Nitrogen Fixation

Although 80 percent of the atmosphere is comprised of nitrogen by volume, the N2 molecule must be split by a process of nitrogen fixation before nitrogen can be readily utilized by vegetation (Smil 2002 p136). Because this process is rare in nature, fixed nitrogen is generally the most limiting nutrient in any ecosystem. Nitrogen fixation generally takes two forms: the abiotic occurrence of lightning and the biotic process of biofixation. Nitrogenase is possessed by only about 100 bacterial genera called diazotrophs, which are able to cleave the N2 molecule (Smil 2002 p137).

So, how does biofixation relate to forests? The largest source of biofixation does not come from free-living diazotrophs, many of which do inhabit forest soils. Biofixation is dominated by a combination of endophytic diazotrophs, which live inside several plant parts, and symbionts, which typically live symbiotically upon plant roots. Together, these diazotrophs are responsible for biofixing 150-190 Mt N per year (Smil 2002 p140).

Biofixation rates are extremely high in leguminous cover, much of which has been shown to comprise a large portion of forest floors, such as in the Ouachita-Ozark Highlands of the American midwest (Kabrick et al. 2006)[1], North American forests of the west (Perry et al. 2008 p357), and tropical forests and savannas throughout the world (Hogberg 1986).

BGC Cycling: Water

Although earth's oceans are the dominant source of water evaporated into the atmosphere, oceanic evaporation accounts for only 34 percent of terrestrial precipitation

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[1] Sparks et al. (1998) identified more than 150 herbaceous species in their prescribed-burn study stands that were generally absent from untreated controls. Among these were some 40 species of native legumes whose nitrogen-fixing activities augment soil fertility, and whose foliage and seeds provide an important source of food for wildlife. Species richness increased in restored stands after both late growing-season and late dormant-season prescribed fires, and was lowest in unburned stands. Overall, herbaceous species richness, diversity, and total forb and legume abundance increased in treated stands as opposed to untreated controls.

(Smil 2002 p125).[2] The remaining two-thirds of terrestrial precipitation is provided by terrestrial biomass in the form of evapotranspiration. Perhaps the most outstanding example of evapotranspiration occurs in the Amazon, where it has been calculated that the trees of the Amazon input more water into the atmosphere in a single day than the Amazon River contains (Nobre 2010). For land-locked forests far from a coastline, it is easy to imagine that precipitation in those forests may be reliant entirely upon terrestrial evapotranspiration or in part to lakes.

Precipitation does not simply provide the H2O necessary for life; it functions to cycle other nutrients necessary for growth. As illustrated by Perry et al. (2008 p348), precipitation is the primary "pathway by which nutrients and other chemical elements are input into ecosystems from the atmosphere." Not only does precipitation input nutrients into ecosystems directly, it has a hand in the two other sources noted for inputting nutrients via atmosphere: dry deposition and clouds or fog. Precipitation provides a vertical movement of nutrients deposited upon forest canopies by dry deposition, water vapor and foliar leaching through stem flow (Perry et al. 2008 p349).

BGC Cycling: Weathering

In addition to atmospheric cycling, weathering of primary minerals from ecosystems with access to fresh rock within the rooting zone constitutes the major source of all nutrients except nitrogen (Perry et al. 2008, p. 351). For example, annual weathering inputs of potassium, calcium, magnesium, and iron were shown to account for from 85 to 100 percent of nutrient inputs in the Hubbard Brook Experimental Forest in New Hampshire (Bormann and Likens 1979). The ability of forests to leech nutrients from stone and put them to use in the earth system can be describe nothing short of amazing.

Wind and Lightning: The Missing Links

> *"Simulation models predict that forests also influence climate (precipitation and temperature) at the scale of regions and the globe."* Perry et al. (2008)

Nobre (2010) demonstrates the affect of the Amazonian forest on mesoscale air circulation by pointing out the absence of cyclones in the equatorial region. He describes the Amazon as a continental forest pump, which speeds the air above the sea, preventing hurricane formation. Furthermore, Nobre illustrates that the breath of the forest is responsible for the importation of ocean humidity, thereby preventing desertification.

Likewise, my own research has revealed a visually interesting distribution and occurrence of tornado activity in relation to the geographic location of forests in the tornado belts of Texas, Louisiana, Oklahoma, Arkansas and Missouri (Sanford 2012a). I hypothesize that the biotic pumps of the Midwestern forests are having a profound affect on mesoscale air circulation in the region, but more research is needed. Such large-scale air movements

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[2] Calculated from Figure 5.1 Annual global flows of the Earth's water cycle (Smil 2002 p125).

may have important affects upon the amount and distribution of precipitation and/or evapotranspiration realized in forested areas and those not forested.

Additional research into lightning, the abiotic form of nitrogen fixation, has revealed that lightning production is overwhelmingly associated with terra firma (Sanford 2012b). More specifically, the terrestrial areas of earth with the most frequent occurrence of lightning seem to be spatially related to the occurrence of forests upon land. Moreover, it was found that N input from lightning might be underestimated. Previous calculations assumed an average of 2 return strokes per flash occurrence, where recent research has revealed that return strokes of 20 were not uncommon (Sanford 2012b).

Such a picture suggests that lightning may not be so abiotic after all, and may well be an important ecosystem service that forests provide. If forests are creating precipitation for themselves via evapotranspiration, doesn't it seem logical they are conducting their own nitrogen fixation regime? There is a lack of lightning in the Pacific Northwest, but for the rest of United States, forests are a hotbed for electric conduction (Sanford 2012b).

2. Survey of the Northwest Forest Plan

Prior to discussing the future of forest management in the face of climate change, we must first have a clear picture of the status quo. Below, we review the formation of the Northwest Forest Plan in reverence to biodiversity and habitat preservation, and then address how the NWFP has actually been adopted and utilized.

The Birth of the Northwest Forest Plan

Pressures to alter forest management goals of "sustained yield"[3] upon public lands in the Pacific Northwest were fueled by the Endangered Species Act (ESA) of 1973, the "viability clause" of the National Forest Management Act of 1976, and mounting concerns over the vitality of the threatened northern spotted owl (Thomas et al. 2006). In response to litigation, the Interagency Scientific Committee (ISC) was formed and charged to find a credible conservation strategy for the northern spotted owl.

Each of the studies published under the direction of the ISC emphasized habitat conservation and biodiversity, an approach that was inclusive of all species within old-growth forests (Thomas et al. 1990; Johnson et al. 1991; Thomas et al. 1993). In short, "old-growth conservation was about more than owls and always had been" (Thomas et al. 2006).

Shortly after attendance at the Forest Summit in 1993, newly elected President Clinton formed the Forest Ecosystem Management Assessment Team (FEMAT) for the purpose of redefining forest management under five new themes: (1) consider socioeconomic

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[3] Defined by the 1960 Multiple-use Sustained Yield Act as, "…the achievement and maintenance in perpetuity of a high level annual or regular output of various natural resources of the national forests without impairment of the productivity of the land."

dimensions of the problem; (2) protect the long-term health of forests, wildlife, and waterways; (3) be scientifically sound, ecologically credible, and legally responsible; (4) produce a predictable and sustainable level of timber sales and nontimber resources that would not degrade the environment; and (5) emphasize collaboration among the federal agencies responsible for land management (FEMAT 1993). In addition, President Clinton proceeded to emphasis terrestrial and aquatic biodiversity within old-growth forests by calling for their conservation and even creation (Thomas et al 2006)[4].

FEMAT responded with 10 options from which the President could choose, and his choice was the one option (Option 9) that included aquatic resources (Thomas et al. 2006). However, before Option 9 became forest plan, "bells and whistles" were added which required land managers to "survey and manage" late stage and old growth (LS/OG) stands prior to harvest. As Thomas et al. (2006) points out, these bells and whistles transformed Option 9 into the "green dream" of Option 1, whereby stands containing old growth were not to be cut. The survey and manage technique shifted the NWFP from a "coarse-filter approach (the occurrence of species is predicted by the occurrence of habitat) to an intense, fine-filter approach (based on actual site-specific data)" (Thomas et al. 2006, p. 281).

Management Under the NWFP

In essence, the fine-filtering, survey and manage approach consumes ample budgetary and personnel resources, thereby dramatically increasing the temporal and monetary costs of timber sale preparation. Thomas (2003a) describes the results of this mutated version of FEMAT's prescription: (1) widespread, "no action" in the old growth matrices[5] that were slated for harvest under the original Option 9; (2) unobtainable harvest goals under the unadjusted predictions determined by FEMAT and expected under the NWFP; (3) constriction of ingenuity, increased risk and lack of funding and framework for Adaptive Management Areas[6] (AMAs) under survey and manage protocols (Stankey et al. 2003; Thomas 2003a); (4) failure to create streamside buffers in riparian reserves[7] (RRs) and implement prescribed silvicultural practices within those buffers; (5) lack of active

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[4] FEMAT was instructed to (1) maintain and restore habitat conditions to support viable populations, well-distributed across current ranges, of all species known or reasonably expected to be associated with old-growth habitat conditions; (2) maintain and/or restore spawning and rearing habitat to support recovery and maintenance of viable populations of anadromous fish species and other fish species considered "sensitive" or "at risk" on federal lands; and (3) maintain or create a connected, interactive, old-growth forest ecosystem on federal lands. (Thomas et al. 2006)

[5] "Matrix lands were those lands lying between the LSRs. These lands were to be managed for multiple-use including timber production. LSFs in the matrix were considered open to harvest following application of Survey and Manage protocols (S&M) and appropriate adjustments to deal with those findings. Whatever harvest of mature timber that was expected under the NWFP was expected to come from this allocation" (Thomas 2003b)

[6] "AMAs were designated to allow innovative approaches to achieving NWFP objectives relatively unconstrained by Standards and Guidelines (S&Gs) and other restrictions applicable to other land designations" (Thomas 2003b).

[7] "Riparian reserves (RRs) were designated along stream courses in Matrix lands to enhance conditions for producing and maintaining habitat conditions for anadromous fish" (Thomas 2003b).

management within Late Successional Reserves[8] (LSRs) in fire-influenced landscapes; and, (6) mounting costs due to risk averse management, rigid regulatory agencies, appeals, and court actions.

To draw the conclusion that the NWFP has met its challenge to foster biodiversity, simply because very little old growth has been harvested, would be a mistake. FEMAT prescribed management strategies for the LSRs based upon historical fire disturbances, lack thereof, and structural factors, which contribute to a desirable habitat for the northern spotted owl, marbled murrelet and other species (Thomas et al. 2006, p. 282). Furthermore, these prescriptions were geographically spaced such that a high number of owl pairs could be hosted in a given stand and young owls could easily move between them. However, due to the lack of active management previously discussed, a growing number of LSRs are at risk for stand replacement fires and do not resemble natural LS/OG structure (Thomas et al. 2006, p. 283).

As shown, the prescriptions and goals outlined by FEMAT in Option 9 have failed to materialize. The ball has been dropped and the buck passed: Adaptive Management Areas have been static, Riparian Reserves ignored, Late Successional Reserves not actively managed, and matrix lands not harvested due to survey and manage protocols and shrinking budgets. Nonetheless, ecosystem management[9] and biodiversity have become the foundation of modern natural resource prescriptions.

***Threats to the Current Forest Management Platform*:**

Genetics

Although biodiversity enhancement and ecosystem management have had profound and beneficial impacts upon our forest ecosystems and their inhabitants, the platform for biodiversity can only go so far in justifying a cessation to the degradation of our forests. For example, recent declines of the northern spotted owl in the northwestern region have been linked to the expansion of the barred owl (Kelly et al. 2003). Unfortunately, the barred owl invasion muffles the discussion over forest management as a means for restoring the northern spotted owl population. The debate now rages over lethal and/or non-lethal removal of the barred owl. Currently, the US Fish and Wildlife Service is accepting comments on 7 alternatives for removal of the owl through June 6th, 2012 (USFWS 2012).

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[8] "LSRs were designated to contain significant amounts of the "best" late-successional forests (LSFs). The management of the LSRs is to emphasize retention of the extant LSFs and use silvicultural approaches to treat younger forest stands to speed development of structural conditions resembling that of LSFs at the soonest possible time" (Thomas 2003b).

[9] "…the most recent approach to managing is to meet societal goals of aesthetics, game, biodiversity, recreation, and timber fall within the realm of ecosystem management – an approach designed to minimize reisk to species and maximize the likelihood that the approach will be sustainable" (McComb 2008; Meffe et al. 2002)

Complicating the issue further is the fact that the northern spotted owl and barred owls are hybridizing (Kelly and Forsman 2004). Genetically speaking, does hybridization not amplify biodiversity? At what point do we remove ourselves from the evolution of species and ecosystems in response to earth's dramatically altered, human induced landscape?

Such questions are not limited to vertebrates alone. It has been recently discovered that shortleaf x loblolly hybrids not only exist in the wild, but constitute around 14 percent of researched shortleaf pine stands in Arkansas, once thought to be pure (Kabrick et al. 2007). Confusing shortleaf pine management is the inability to identify hybrids in the field, due to their similarity to parental morphology and the fact that hybrid morphology can change over time (Curtis et al. 2012). Moreover, uncertainties regarding hybrid traits, such as growth rates and fire-tolerance, complicate sound silvicultural practice (Curtis et al. 2012).

To the public, it is easy to imagine that ecosystem management may be seen as a smoke screen and the NWFP as a failure to address the decline of threatened and publicly cherished species. One may argue, why protect old growth forests if barred owls will eradicate the northern spotted owl, anyway? After all, it was the concern for the northern spotted owl that set the stage for the NWFP, a call for biodiversity and a halt to the annihilation of old growth forests in the west.

Northern Expansion of Species

The barred owl is not the only vertebrate expanding its range. Most notably, the nine-banded armadillo has been marching its way across the United States from Mexico since the late 1800s, and has been spotted as far north as Illinois (Curry 2007). They are often described as a nuisance, a health threat, and non-native invaders from a foreign territory. However, fossil records reveal that their ancestor from the last glacial minimum, the beautiful armadillo (Dasypus bellus), has been found as far north as Nebraska (Voorhies 1987). These findings beg the question, "Are armadillos invaders from another territory, or are they simply reclaiming their ancient homeland?"

Such a northern expansion is not limited to animals, and has been occurring since the last glaciation 10,000 years ago. Figure 1 illustrates the northern expansion of shortleaf pine since the last glacial maximum. Lessons from the barred owl, armadillo and shortleaf pine illustrate that ecosystems and their inhabitants are not static across long-term and short-term temporal or spatial scales. The success of future land management approaches lies in the ability to adapt prescriptions to biogeophysiological and evolutionary shifts, not constrain natural changes to an idealized status quo.

Biotic Homogenization

Deforestation for the purpose of mono-agriculture is the most fitting example of human-induced homogenization of earth's landscape. Although some ecosystems have recently seen increases in local species diversity, large-scale biodiversity is expected to continually decline (Smart et al. 2006). The drivers behind this loss of diversity include land conversion; the invasion of non-native plants, which often lack natural predators and disease; and, the increasing dominance of native and non-native plants in disturbed ecosystems.

Olden et al. (2008) have identified three forms of homogenization: genetic, taxonomic and functional. Although biotic homogenization can have profound affects on ecological and evolutionary processes, these affects may not necessarily be negative: "there is some possibility that biotic homogenization will promote the origin and diversification of new species, as invasive species evolve in new environments, or as greater hybridization opportunities create new species. Species diversification might indeed be likely, given the many examples of contemporary evolution (i.e. evolutionary changes observable over less than a few hundred years) involving invasive species" (Olden et al. 2008). We have answered the call and already provided two examples on how this diversification may occur as a result of homogenization: barred owl x northern spotted owl and shortleaf x loblolly hybrids.

3. The Terrestrial Life Support System

> *"The economies of the earth would eventually grind to a halt without the services of ecological life-support systems, so in one sense their total value to the economy is infinite."* – Costanza et al. (1997)

The global cycle that exists between land, air and sea has created an environment in which terrestrial inhabitation is possible. Without sun's energy, precipitation or the availability of nutrients that are the building blocks of DNA and cellular structure, terrestrial life simply would not exist as we know it.

As discussed, forests dominate the earth's terrestrial albedo by its radiation absorbing leaf cover and production of reflective clouds via evapotranspiration. At least 66 percent of rainfall on land can be attributed to the ability of biomass to return precipitation into the atmosphere. Trees not only take and return nutrients from their soil; they liberate minerals from rock itself for use within ecosystems. Forests aid in meso-scale air circulations that help protect continents from desertification. And, further research may illuminate the indirect role of forests in the formation of lightning, which may be earth's largest source of fixed nitrogen (Sanford 2012b).

Suddenly, the term "*ecosystem services*" falls short when attempting to describe the benefits forests provide. Undoubtedly, earth's current terrestrial cycle cannot exist without forests. Indeed, forests are earth's ***terrestrial life support system (TLSS)***.

The TLSS Approach

Notions that forests are at the foundation of life are not new (Genesis 1:11). However, scientific research is just now beginning to reveal what we knew all along. Remote satellite monitoring and simulation models are helping us quantify the carbon storage capacity of forests in space, time and history (Turner et al. 2011). As humanity now struggles to understand the technobiosphere we have created, and the climatic perturbations we have induced, the implications of such modeling are outstanding.

The reality of climate change is becoming more widely accepted by individuals, nations and international bodies, and many are working to reduce CO2 and other greenhouse gas emissions (GHG). Moreover, we are attempting to predict how climate change will affect earth's biotic community. As seen in Figure 2, simulations of the year 2095 reveal that as climate changes, forests of the United States are expected to take over much of our crop lands: Iowa and the Great Lakes region becomes completely forested, and the agricultural states of Oklahoma, Kansas, Nebraska and the Dakotas are invaded by both deciduous trees and conifers. As previously illustrated, the expansion of these forests has been happening since the last glacial maximum.

However, it seems that current anthropogenic disturbance in these areas reduces such simulations to hog wash (especially in Iowa). Due to the confines of America's current agricultural system, the bioregion will not be able to respond naturally, as simulated. More specifically, the TLSSs these forests establish are a dream without a dramatic shift in the way public and private lands are managed.

As previously illustrated, current forest management and restoration policy based purely upon biodiversity and ecosystem services may fail when external constraints work against goals of maintaining or increasing biodiversity or those services, especially under the NWFP. ***Therefore, we assert that the trajectory of earth's biosphere and the provision of terrestrial inhabitation relies upon the ability of national and global policy to adapt a TLSS approach to natural resource management.*** Such an approach should not ignore biodiversity and ecosystem services, but embrace them in a coupled method of sustainable management.

Conclusion

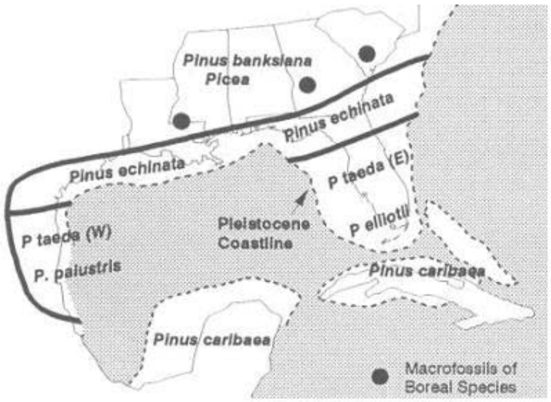
The purpose here is not to provide "tree-huggers" and bioenvironmentalists more ammo for political banter, nor to chase loggers out of the forest. Without earth's TLSS, humanity may face extinction. Afforestation is a must. To further develop a sustainable approach to nurturing earth's TLSS, research is urged in the following areas:

1. Modeled simulations of climatic and atmospheric responses to large-scale afforestation, and without
2. Modeled simulations of biodiversity and ecosystem services in response to a reduction in landscape fragmentation from afforestation, and an increase

3. An inventory of lands currently ripe for afforestation
4. Methods for shifting timber harvest from difficult to access public lands to easily accessible, afforested lands
5. The creation of a socio-ecological partnership between private landowners and public land managers
6. Establishment of markets and the economic relationships necessary to make afforestation a possibility

The problems that earth's swelling human population now faces are numerous and global in scale. The adoption of the TLSS approach is only one answer to many of humanity's conflicts. However, it seems obvious that without realizing the necessity of earth's forests for terrestrial inhabitation, solutions to our other problems may not much matter.

Figures



Projected Range of Southeastern Pines at Last Glacial Maximum
(Kabrick et al. 2007)

Current Range of Pinus echinata (shortleaf pine)
Source: USFS
http://www.na.fs.fed.us/pubs/silvics_manual/Volume_1/pinus/echinata.htm; Retrieved 3/18/2012

Figure 1 – Comparison of the range of shortleaf pine (Pinus echinata) at last glacial maximum and today.

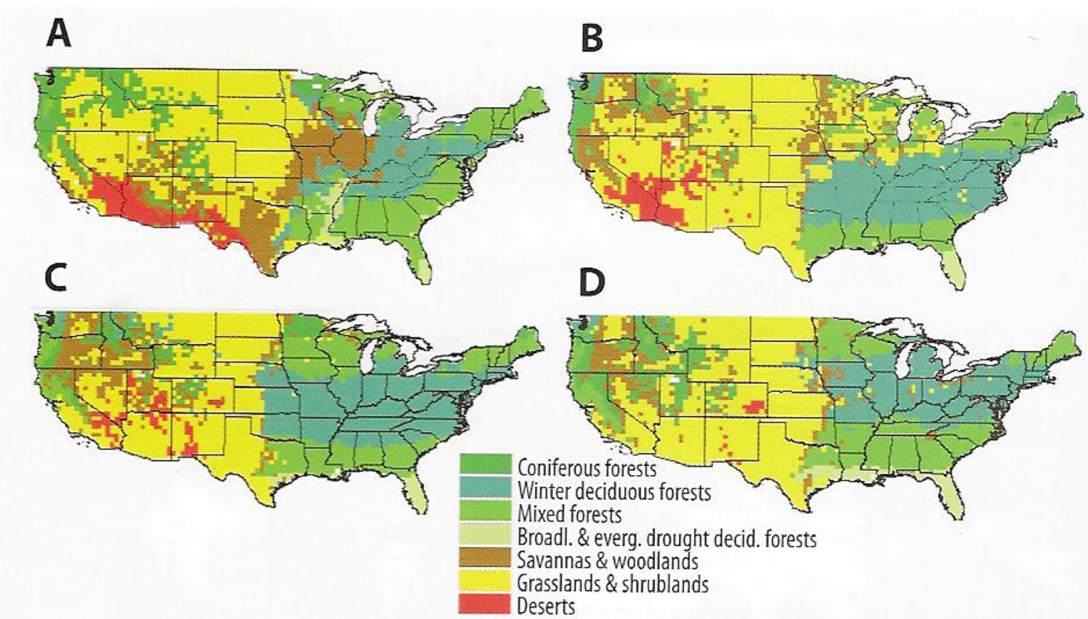


Plate 15. Current and simulated distribution of aggregated vegetation classes in 2095 for the United States. A. Current distribution according to the Kuchler classification. B. Current distribution as simulated by the dynamic vegetation model, MC1. C. Distribution in 2095 as simulated by MC1 using a moderately warm scenario (up to 2.8°C increase in average U.S. temperature by 2100) predicted by the HADCM2SUL General Circulation Model of the Hadley Climate Centre. D. Distribution in 2095 as simulated by MC1 using a warmer scenario (up to 5.8°C increase in average U.S. temperature by 2100) predicted by the CGCM1 general circulation model of the Canadian Climate Center. Both general circulation models assume a continuous increase in the atmospheric CO_2 concentration from 295 ppm in 1895 to 712 ppm in 2100. (Adapted from Bachelet et al. 2003)

Figure 2 – Current distribution and simulated expansion of forests in the US. Source: Perry et al. (2008).

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