Novel Ecosystems: Concepts and Applications to Forestry

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Introduction

"Novel Ecosystems," a term used first by F. Stuart Chapin III and Anthony M. Starfield in 1997 (Chapin and Starfield 1997), has been used to describe a range of conditions in which an ecosystem has been altered from its historical state. With the recent emergence of this term, several alternate definitions have been offered. In general, the concept includes four parts: (1) new species combinations are present, (2) there has been a significant change in ecosystem function, (3) the change was caused by human agency, and (4) the change is irreversible with current management options (Hobbs et al. 2006). Due to the broad requirements for an ecosystem to be classified as novel, the usage of this term is growing and it is being used to describe a wide range of ecosystem conditions. The seemingly broad application of this idea to ecosystem condition classification suggests that there is no strict definition of the term.

Though usage of the term indeed lacks a single definition and justification, it is clear that since 1997 its presence in relevant literature has increased significantly. Using Google Scholar and searching the keywords "novel+ecosystem," I found four articles when filtering for the year 1997. However, using the same keywords when filtering for articles published in 2014, I found 196 results. Figure 1 shows the number of results returned each year from 1997 through 2014 when searching the keyword "novel+ecosystem." In 1997 the first use of the term by Chapin and Starfield (1997) starts an upward trend with a spike in the number of papers using the term in the year 2000. The next spike in the year 2006 is likely a result of the release of Hobbs et al. (2004), an article defining and characterizing novel ecosystems. The upward trend continues with the publication of Hobbs et al. (2009), titled "Novel ecosystems: Implications for Conservation and Restoration." Finally, with publication of the book *Novel Ecosystems:*

Intervening in the new ecological world order by Hobbs, Higgs, and Hall in 2013, we see a continuing interest in the concept and further increase in the use of the term.

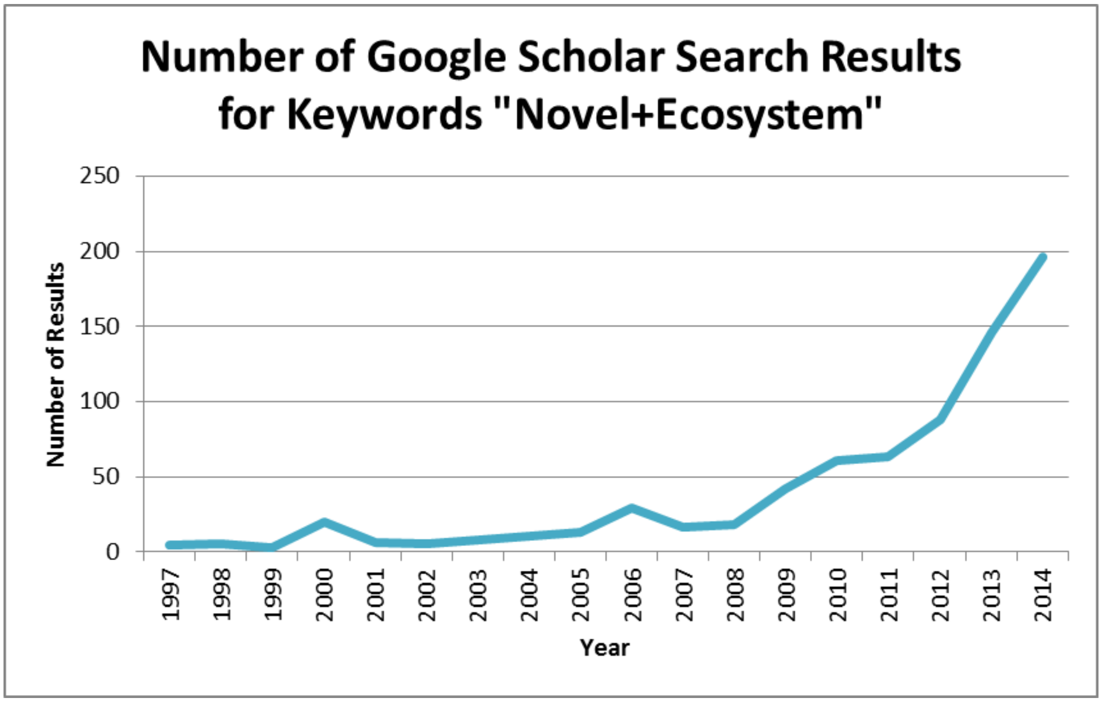

Figure 1. Results per year when searching for keywords “novel+ecosystem” using the Google Scholar search engine. Note the drastic increase in number of citations since 2006. This spike in citations is likely due to the release of the article “Novel ecosystems: theoretical and management aspects of the new ecological world order” by Hobbs et al. (2006). This was the first publication to specifically discuss the concept of novel ecosystems.

This paper has three main objectives which are aimed at improving understanding of the conceptual idea of novel ecosystems and its application to forestry. The first objective is to review current definitions of the topic. The second objective is to review authors’ justifications for using the term in ecosystem case studies. The third objective is to analyze the relevance of the novel ecosystem concept to forestry.

Research Methods

In order to acquire a full and unbiased collection of available literature on the topic, I conducted broad searches using the search engine Google Scholar. Terminology entered included "novel+ecosystem" and "novel+assemblage." Due to the high occurrence of unrelated topics when searching "novel+assemblage", these results were not used in the analysis. I randomly selected 100 case studies to review and subsequently classified each study into a common theme. In order to provide a succinct review of the general themes found in novel ecosystem literature, I have reviewed one case study from each theme that is representative of a subset of the literature. Themes included arbitrary usage, ecological tipping points, change in species composition, land use change proxies, and change in ecosystem function. To understand the relevance of the concept of novel ecosystems to forestry, I have analyzed the interactions of ten examples of novel forested ecosystems on forestry based on the Society of American Foresters' definition of forestry. This definition of forestry has three main parts, including the (1) management, (2) use, and (3) conservation of forests for human benefit. Refer to Table 2 found in in the Index at the end of this document for a complete list of case studies I have reviewed as well as whether each case study meets the four parts of the definition of novel ecosystems.

First Usages and Adaptations

As stated previously, the term "novel ecosystems" was first coined in 1997 in an article by Chapin and Starfield titled "Time Lags and Novel Ecosystems in Response to Transient Climatic Change in Arctic Alaska" (Chapin and Starfield 1997). This article describes the time lag that may be seen in dynamic vegetation models of afforestation in Alaskan tundra under predicted warming trends. The article states that the emerging boreal grassland-steppe ecosystem "was common during the late Pleistocene and today occurs south of the boreal forest in continental regions" and was described as a "novel ecosystem" (Chapin and Starfield

1997). In this particular case study, it may be concluded that the authors assumed a novel ecosystem can represent one that is unique with respect to any existing ecosystem in the post Pleistocene period. Also note that this paper does not explicitly define the term but rather suggests that novelty includes novel assemblages in regions previously unoccupied by the species composition. Papers that cite this article are about the following general topics: climate change, species shift modeling, polar ecosystems, Alaskan ecological history, carbon storage, ecoclimate variations, lagging climate effects, and novel ecosystems. Out of the 110 total scholarly articles that cite Chapin and Starfield (1997) from 1998 to 2014, 13 are focused specifically on the topic of novel ecosystems.

The next major refinement of the term "novel ecosystem" was a result of a real-world example documented by Ariel E Lugo in 2004 (Lugo 2004). In this case study, Puerto Rico ecosystem novelty was quantified by the rising percentage of nonnative tree species on the island. This example of a novel ecosystem does not use the specific terminology "novel ecosystem," though it does use "novel assemblages" and "novel disturbance regimes" (Lugo 2004). Though the methods described above do not reveal this paper as a result due to the lack of the term "novel+ecosystem", its large number of mentions in other novel ecosystems literature makes it a prime example of a novel ecosystem. Consequently, Lugo (2004) suggested that novel ecosystem quantification may consider specific assemblages and disturbance regimes. As with the previous article discussed, papers that cite Lugo (2004) include a wide range of topics.

The most significant revision of the term comes from Richard Hobbs, an author who has played a major role in novel ecosystem literature beginning in 2006. Titled "Novel ecosystems:

theoretical and management aspects of the new ecological world order," Hobbs et al. (2006) published the first article about definitions of novel ecosystems.

> *"The key characteristics are (1) novelty: new species combinations, with the potential for changes in ecosystem functioning; and (2) human agency: ecosystems that are the result of deliberate or inadvertent human action, but do not depend on continued human intervention for their maintenance."*
>
> - Hobbs et al. 2006

Since the release of Hobbs' first publication on novel ecosystems, he has published several other articles that will be included in this review. It must be noted that Hobbs et al. (2006) remains the most highly cited article about novel ecosystems, cited by 800 articles between 2006 and 2014. Out of the 800 articles citing Hobbs et al. (2006), 142 are heavily focused on the topic of novel ecosystems.

Critical Terminology

In order to ensure a clear understanding of novel ecosystem examples in the main body of this paper, I must first describe several topics of importance that will be repeatedly mentioned. Specifically, I will review invasive and exotic species, designer and novel ecosystems, and hybrid and novel ecosystems. As stated by Colautti and MacIsaac (2004), "the simple use of terms to articulate ecological concepts can confuse ideological debates and undermine management efforts." This statement, describing the misuse and overuse of terms such as exotic, invasive, introduced, and naturalized, emphasizes that a clear understanding of terms is needed.

Understanding Invasive and Exotic Species

Though “invasive species” and “exotic species” are often used interchangeably, they have differing meanings. Invasive species occur when an organism undergoes a change that allows it to propagate more successfully than surrounding vegetation and spread beyond the area of initial establishment (Callaway and Aschehoug 2000; Rejmánek 2000; Colautti and MacIsaac 2004; Pejchar and Mooney 2009). Changes may include a biogeographical redistribution or an abiotic or biotic change in the plants’ native ecosystem that therefore allows it to become invasive. Exotic species are simply species that are not native to an area (Keane and Crawley 2002; Orrock et al. 2008). Though many exotic species may successfully establish in the area of introduction, a small percentage of established exotics propagate successfully enough to spread and become invasive. Combining these two classifications, I may infer that invasive plant species may be exotic if indeed the invasion is the result of a change in biogeographical location. However, it must also be recognized that plant species can be invasive in ecosystems lacking nonnative species. Exotic species are not always invasive due to the many interactions that may take place between the nonnative plant and the new ecosystem it is occupying. According to the enemy release hypothesis, when a species is moved to a new ecosystem, it is devoid of natural competitors and should be much more successful in reproduction (Keane and Crawley 2002). When a species remains in its native ecosystem, it is exposed to specialist and generalist native competitors. When the species is then moved to a new ecosystem, it often is no longer under threat from specialist species and is therefore released from much of its previous competition. Under certain conditions it is common that the new ecosystem is simply not suitable long-term habitat for the introduced species, thus constraining establishment and spread of the species.

Designer and Novel Ecosystems

Understanding the difference between designer and novel ecosystems is another key to understanding novel ecosystem concepts and applications to forestry. In many cases of ecosystems that are described as novel under the four general criteria listed above, the ecosystems are not "accidental" occurrences but instead were created by design. Designer ecosystems, as described by Hobbs et al. (2009), are ecosystems in which managers have promoted beneficial management practices that involved altering the ecosystem (Hobbs et al. 2009). A general example of a designer ecosystem is tree farms, as they are created by land managers to promote timber harvest and can alter the historical ecosystem significantly. It must be noted that designer ecosystems are always regarded as novel, though novel ecosystems may or may not be designer ecosystems. Designer ecosystems are most often used to repair biological function to previously native ecosystems that have been irreversibly damaged and to introduce ecosystem and commodity services such as agroforestry. For the purpose of this paper, I will not review designer ecosystems; rather I will focus on the idea of novel ecosystems.

Hybrid and Novel Ecosystems

When classifying ecosystems as novel, it is important to recognize that there is a spectrum of "novelty." As seen in the literature to be reviewed in the following section, many case studies using the term novel ecosystems do not recognize the possibility of a hybrid ecosystem. First published by Hobbs et al. (2009), Figure 1 below shows the theoretical spectrum of ecosystems from historical to hybrid to novel (Hobbs et al. 2009). Take note that ecosystem classification is affected by change in both biotic and abiotic conditions. Also take note that though the figure displays a one way arrow along each axis, Hobbs et al. (2009) clarify that a hybrid ecosystem may be reversible back to a historical state.

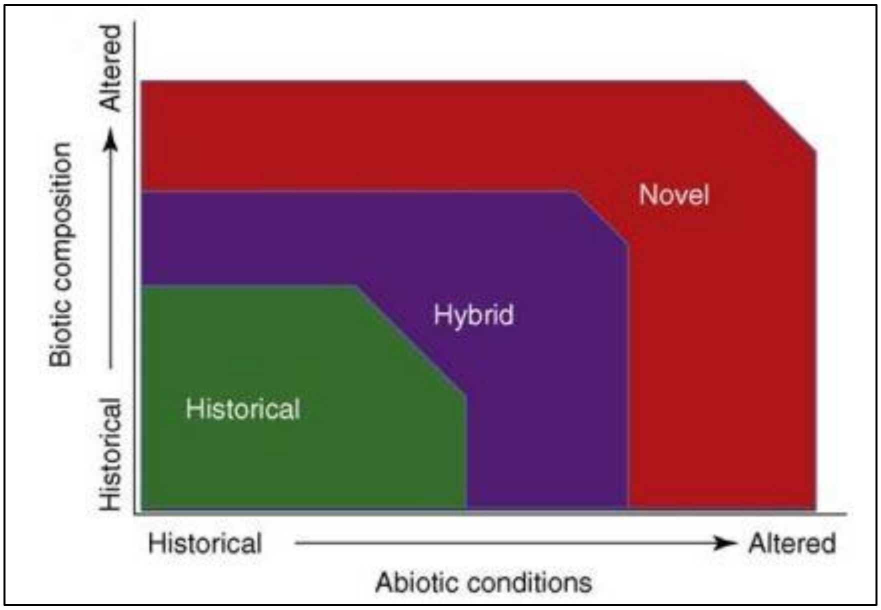

Figure 2. Types of ecosystems that are formed under changing biotic and abiotic conditions from Hobbs et al. (2009).

Common Themes of Classifying Ecosystems as Novel

In this section of the paper I will review general categories regarding the usage of novel ecosystems and support each theme with a representative case study. As described earlier, I reviewed scholarly articles using Google Scholar and identified several general themes regarding the use of the term novel ecosystems. These themes include (1) arbitrary usage, (2) ecological tipping points, (3) change in species composition, (4) classification by population and land use change proxies, and (5) change in ecosystem function. I review an example of each in the next sections.

Arbitrary Usage

Throughout the literature, I found that many examples of novel ecosystem case studies do not include a specific reason for the use of the term. As stated previously a novel ecosystem is generally defined as a novel species assemblage caused through human agency, resulting in an irreversible change in ecosystem function. Though this definition specifies four criteria which must be reasonably fulfilled to describe an ecosystem as novel, there are numerous examples that do not fulfill all criteria. In this section I will review a case study which does not fulfill all four criteria of a novel ecosystem.

In an article written in 2014 by Cabezas et al. on the topic of macronutrient accumulation in degraded fen areas, the authors describe a novel ecosystem which fails to fulfill the criterion of the presence of a nonnative species or novel assemblage (Cabezas et al. 2014). This case study reviews a global change of peatland ecosystems in which fen areas become degraded due to water draining. It may be assumed that the draining of fens fulfills the human agency piece of the definition. In an attempt to restore fens to their previous ecosystem function, these areas were refilled with water. However, this attempt at restoration resulted in shallow lakes where increased amounts of carbon, nitrogen, and phosphorus accumulated. The paper does not specify whether the vegetation has changed significantly or whether the vegetation type creates a positive feedback loop further towards a novel ecosystem. It is because of this lack of specificity that this case study may be classified into an arbitrary usage of the concept. Note that 27% of the papers I reviewed fell into this category.

Ecological Tipping Points

Ecological tipping points may be described as a state shift of a biological system that results in a critical transition or crossing of an irreversible threshold to a new state (Barnosky et al. 2012). Evidence of ecological tipping points may be found throughout novel ecosystem literature, usually including the establishment and spread of a nonnative species that fully alters ecosystem function. According to Barnosky et al. (2012), tipping points may occur on small and large scales. Small scale shifts may occur as a result of biodiversity loss, exotic species introductions, abiotic changes, etc. Large scale shifts are caused by less well-understood mechanisms such as climate change, mass extinctions, and the Cambrian biodiversity explosion (Barnosky et al. 2012).

Though there are no examples of specific ecosystems at a critical transition as the cause of novelty, Brook et al. (2013) states that "up to four-fifths [of ecosystems] globally – have probably already undergone human-driven regime shifts…yielding a biosphere that today is largely characterized by post-transition, hybrid, or novel ecosystems." The lack of specific ecosystem examples in this article makes it also fall into the "arbitrary classification" category described previously. If the article were to select and review specific ecosystems where a tipping point may have been the cause of novelty, it would no longer fall under arbitrary classification. Future research on novel ecosystems should include critical thresholds and tipping points. Note that 12% of case studies I reviewed fell into this category.

Change in Species Composition

As described previously, part of the criteria for an ecosystem to be considered novel is the presence of new species combinations. However, many case studies justify classification as a novel ecosystem purely on the presence of a severely invasive plant. Case studies also justify classification as novel based on the addition or deletion of a plant or animal species. The viewpoint that these case studies take is that the presence of a nonnative invasive or the deletion of a plant or animal species was the underlying cause of initial ecosystem change which resulted in a new ecosystem. In other words, these case studies focus on the idea that the change of species composition is novelty itself.

It is important to recognize historical geographic range distributions as compared to species distributions after human interaction. Note that another criterion of novelty classification is human agency. With human occupation, plant and animal species often are moved and geographic distributions are changed. Therefore, new species combinations are created and there may not be any one exotic and/or invasive plant, but many. This idea also relates back to ecological tipping points, as one may consider human agency the cause of a tipping point, which creates novel assemblages that are irreversible. Due to the heavy number of case studies regarding change in species composition as the criterion of quantifying novelty, I will review the most highly cited case study below.

Tree invasion in Puerto Rico documented by Ariel E Lugo (2004) is the most widely recognized example of a novel ecosystem. As stated previously, the author uses percentage nonnative tree species to quantify ecosystem novelty. However, it must first be noted that Puerto Rico has undergone several changes in vegetation prior to its current condition. In 1493, the Island was discovered by European settlers. At the time of discovery Puerto Rico was 100% forest cover while in 1950 it had 6% forest cover with 1% of that being original forest. The large amount of farmland created in this time period was then abandoned in the second half of the

20th century, producing a large reforestation event up to the present (Lugo 2004). Currently the island has 50% forest cover, with the most common species being the African tulip tree (*Spathodea campanulata*) (Lugo 2013).

As a method of quantifying and justifying novelty in ecosystems, the proportion of nonnative tree species is one of the most obvious and applicable criteria. It is also reasonable to assume that the state of the ecosystem is irreversible due to the significant barrier to management that may restore the ecosystem to its historical condition. With unlimited funding and public support, it may be possible to remove all nonnative trees, restore the soil, and replant with native trees. Though with current management options, this is not an option in the foreseeable future. Note that 41% of case studies I reviewed fell into this category.

Classification by Land Use Change Proxies

Another approach for justifying and predicting novelty in ecosystems is that of a predictive model based on proxy measurements. Chapter 8 of the book *Novel Ecosystems: Intervening in the new ecological world order* (Hobbs et al. 2013) describes a predictive model that may be used to infer novelty based on land use change and human population. The idea of using models to predict novelty is not found in any literature other than this book to my knowledge. Take note that this theme is not common, though represents a new way of quantifying novelty and thus must be mentioned as a possible common theme in future research. Figure 3 below, found in chapter 8 of Hobbs et al. (2013) and created by Perring and Ellis (2013), summarizes the results of several land use change and population maps and combines them as proxies for the level of novelty. Though this method of classifying ecosystems seems to yield resonable results as seen below, it has not been field tested for accuracy. For example, Figure 3 predicts that the East and West Coasts of the United States are highly novel. Though this is likely the case for most ecosystems in these regions, there are more than likely many ecosystems that are in a hybrid condition and not yet passed an irreversible threshold. The important point to note in this approach is that this model asumes human population drastically affects ecosystems. While this may be true in most cases, this effect is heavily dependant on human behavior and cultural norms of the region. Some cultures may affect ecosystems more than others, and thus cause the creation of a novel ecosystem. Though the model takes into account land use change to aid in regularizing the proxy results, one must note that the model below is still adversely affected by the inseparability of novel and hybrid ecosystems. Attempting to model novelty based on land use change and population proxies does not allow one to predict the presence of full novel ecosystems, rather a condition along a spectrum from native to hybrid to novel as seen in Figure 2.

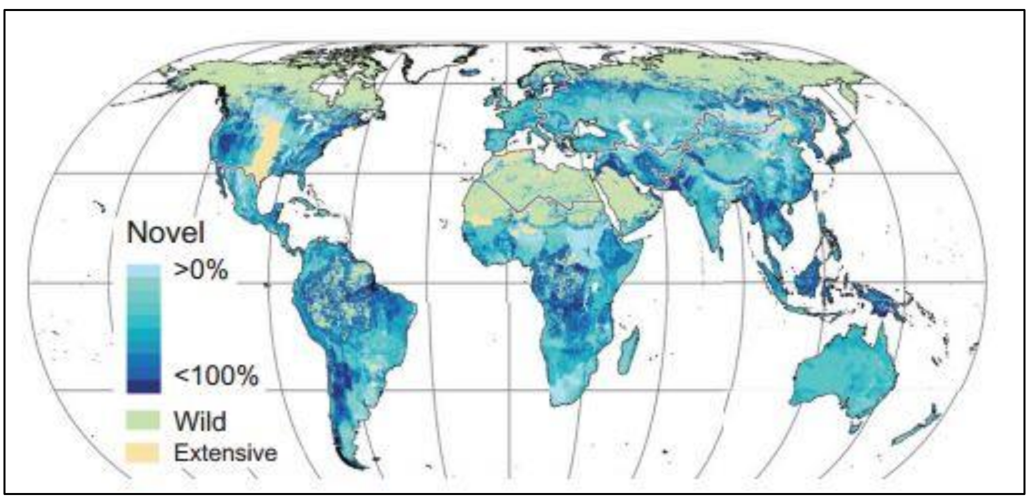

Figure 3. Estimated novelty based on proxy measurements of human population and land use change from Perring and Ellis (2013).

Change in Ecosystem Function

Many case studies throughout the literature classify ecosystems as novel based not on invasive or nonnative species presence, but a change in ecosystem function. Similar to the "Change in Species Composition" section above, I found that there is a significant focus on one of the novel ecosystems criteria rather than an equal focus on all four. The following example leans towards a heavy focus on changes to ecosystem function.

An article published in 2013 by David Doley and Patrick Audet explores the general idea of using novel ecosystems as a rehabilitation alternative for abandoned mine sites. The article is heavily focused on a management decision framework based on mine site conditions, biotic and abiotic integrity, and the likelihood of a holistic assembly (Doley and Audet 2013). Due to its focus on general management, there is no specific example listed in Doley and Audet (2013). In order to create a decision framework that minimizes the necessity to use a full novel ecosystem as a rehabilitated condition, the authors created several questions that guide management. The first question reads "is the abiotic system altered?". This question addresses changes in current compared with pre-disturbance conditions, landform, landscape condition, and soil integrity/stability. The next question reads "is the biotic system altered?" and addresses the biotic components of soil. Specifically, it addresses whether the soil is still capable of supporting native flora. The final and most important question is "are desired ecosystem characteristics achieved?". This question addresses whether rehabilitated ecosystems would provide suitable habitat and ecosystem functions. Overall, the case study reviews a method of recovering a sense of ecosystem function that is favorable to the surrounding landscape and which provides similar ecosystem services as the pre-disturbed site.

It must be noted that the decision framework does not discriminate for or against restoring sites to native conditions; rather it points managers in a direction of the highest chance of restoration of full ecosystem function.

As with the example above, many of the other case studies that focus on a change in ecosystem function are related to management rather than ecosystem analysis. This category is the most applicable to the following section of the paper regarding the relevance of the concept to forestry. Note that 20% of case studies I reviewed fell into this category.

Relevance of the Novel Ecosystems Concept to Forestry

The novel ecosystems concept is valuable in many cases of ecological study and ecosystem science. However, when analyzing its relevance to the field of forestry, one may question whether it makes any impact on the profession. Forestry is defined by the Society of American Foresters as “the profession embracing the science, art, and practice of creating, managing, using, and conserving forests and associated resources for human benefit…” (Society of American Foresters 2008). Due to the field’s focus on utilizing resources for human benefit, it is important to question the relevance of novel ecosystems in forestry. The most important question one may ask regarding the concept is *how is the field of forestry affected by novel ecosystems?*

How is the field of forestry affected by novel ecosystems?

Because forestry focuses on (1) managing, (2) using, and (3) conserving forests for human benefit, I will analyze the impact that a novel ecosystem may have on each of these practices. Depending on the forest type, level of novelty, spread rate of nonnative species, effect of nonnative species on ecosystem function, and many other factors, novelty will affect forestry differently. In order to address the many possible impacts, I will present several examples and their related effects below.

Example 1: Ponderosa pine (*Pinus ponderosa*) forests that have been heavily invaded by cheatgrass (*Bromus tectorum*) likely represent a forested novel ecosystem. The ponderosa pine forests in the Southwest were heavily logged in the early 20th century, yielding a forest composed of mostly small diameter trees (Cooper 1960). With excessive fire suppression after European settlement, ponderosa pine forests began to be exposed to higher intensity and higher severity burns. Prior to European settlement, ponderosa pine forests in the Southwest had a frequent fire regime, with stands burning every 1-25 years. After settlement the fire regime of this forest type shifted to infrequent burning, with stands burning more than 25 years apart (Covington and Moore 1994). As these dense stands burn intensely, the after effects yield a landscape barren of trees which is open to the establishment and spread of highly invasive cheatgrass (Harrod and Reichard 2000). A study conducted by McGlone et al. (2009) quantifies the abundance of cheatgrass in ponderosa pine stands under two management regimes. The first management regime consisted of thinning and the second consisted of thinning and burning. The study concluded that presence of cheatgrass was much higher in the thinned and burned plots than the thinned plots. Due to management constraints such as funding and lack of an effective means of removal, the burn area will likely have little to no regeneration of pines due to the scorched soil and presence of cheatgrass.

In another study by Griffis et al. (2001), regeneration of understory plants was quantified in ponderosa pine stands that were unmanaged, thinned, thinned and prescribed burned, and burned by high intensity wildfire. The study concluded that exotic species abundance increased significantly over time in all conditions. With increased treatment intensity, exotic species abundance and richness increased. The authors conclude that "overall plant diversity was least in the unmanaged stands and progressively increased with intensity of disturbance/stand treatments. Both prescribed burning and wildfire increased plant diversity; however, stand-replacing wildfire also appeared to substantially increase the diversity of exotic plants" (Griffis et al. 2001).

In this example, the novel ecosystem was created by human agency, an exotic species is present, current management options classify the condition as irreversible, and I speculate that ecosystem function is highly altered. The human agency that caused the creation of a novel condition was excessive fire suppression. The most prominent exotic species that changed ecosystem function was cheatgrass. As stated previously, various management options have not had any significant impacts on cheatgrass establishment and spread (Griffis et al. 2001). Therefore we may conclude that the lack of effective management options classify the ecosystem condition as irreversible. Research by Keeley (2007) shows that cheatgrass establishment in prescribed burn areas is most highly correlated with the presence of cheatgrass in the seedbank prior to burning, thus furthering the idea that the ecosystem is in an irreversible condition. Reasoning behind this possible irreversible condition may be found in the diagram of a positive feedback loop in Figure 4. I speculate that ecosystem function is permanently altered due to the change in dynamics between exotics and native understory plants and ineffective management practices. Meeting all four criteria, I consider some areas in the ponderosa pine forests of northern Arizona which have been invaded by cheatgrass to be novel ecosystems.

Justification for an alteration of ecological functions of ponderosa pine ecosystems because of cheatgrass invasion begins with the change of fire risk. Research shows that the presence of cheatgrass alters fire regimes towards greater risk of high intensity fire. An article by Link et al. (2006) concludes that fire risk in ponderosa pine forests has increased with the increasing cover of cheatgrass. According to Keeley (2007), reintroduction of historical fire regimes in ponderosa pine forests significantly increases the presence of cheatgrass. The next step of change in ecosystem function is the change in nutrient cycling due to high intensity fire. A study by DeLuca et al. (2006) showed that the addition of charcoal to soil in ponderosa pine forests "increased nitrification potential, net nitrification, gross nitrification, and decreased the solution concentrations of plant secondary compounds." Furthermore, an article by Vasquez et al. (2008) presents research showing that nitrogen enhances the competitive ability of cheatgrass relative to native grasses. Thus, we may speculate that with high intensity fires there will be increased levels of nitrogen in the soil, lower levels of plant secondary compounds, and therefore a greater potential for cheatgrass to establish and dominate. With the increased success of cheatgrass, a positive feedback loop is created which alters overall ecosystem function permanently. Grass invasions and related fire interactions (e.g., D'Antonio and Vitousek 1992) have been shown to produce the results seen in Figure 4. These authors state that "invasion can set in motion a grass/fire cycle where an alien grass colonizes an area and provides the fine fuel necessary for the initiation and propagation of these grass-fueled fires." The authors go on to state that alteration of fire regimes due to grass invasion represents a significant ecosystem-level change due to invasion (D'Antonio and Vitousek 1992). These interactions are diagramed below in Figure 4.

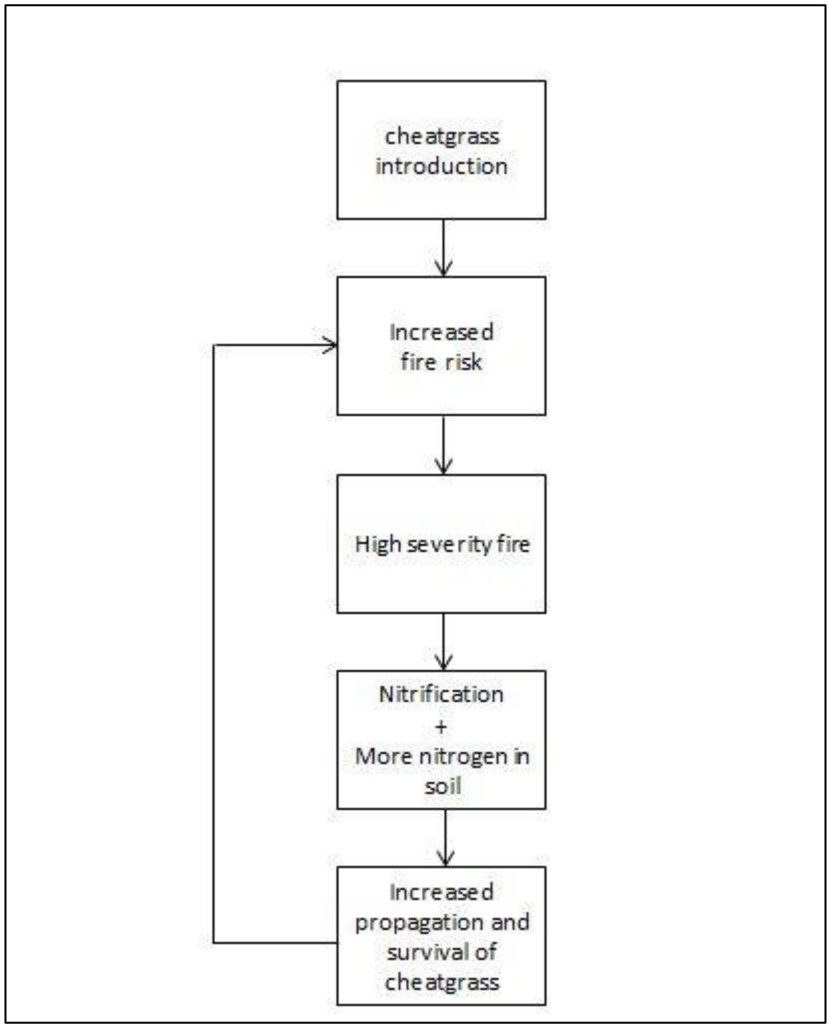

Figure 4. Positive feedback loop caused by the introduction of cheatgrass in ponderosa pine ecosystems. Developed from relationships between cheatgrass, fire risk, fire intensity, soil nitrification, and increased success of cheatgrass.

The example described above affects the three practices of forestry in different ways. First, (1) management is altered. The condition of the ecosystem is so far away from the historical state that management efforts have been altered in order to still provide human benefit. Second, the (2) usage of the ecosystem will also be altered. The previous use of the ecosystem for human benefit such as recreation, logging, and cultural uses may not be applicable. New uses of the ecosystem may still include recreation, but likely do not include logging or cultural heritage. Third, (3) conservation of the forest for human benefit is no longer applicable. Rather than conserving the forest, foresters will likely turn to restoration or alternate land use options that are viable in the novel condition.

Example 2: The temperate forests of the Great Lakes region represent an example of a forested ecosystem that has been drastically affected by the presence of a nonnative species. Though there are many exotic species now present in the ecosystem, there is one in particular that stands out in the literature. Over a century ago, settlers from European countries brought many species of European earthworms into the ecosystems of this region (Hale et al. 2005). According to Lee E. Frelich, a prominent author on this topic, "earthworms reduce the thickness of the organic layers, increase the bulk density of soils and incorporate litter and humus materials into deeper horizons of the soil profile" (Frelich et al. 2006). With the manipulation of the organic layer and bulk density of the soil, the soil food web is affected and thus the understory plant communities are also affected. One of the most notable effects on the understory plant community is the facilitation and exacerbation of invasive plants populations (Nuzzo et al. 2009). Management options are so sparse that there is very little literature available on possible management techniques. European earthworms have existed in the ecosystem for a long time and they cover a large area, thus making removal of earthworms from the ecosystem virtually impossible. Figure 5 on the following page displays a diagram found in Frelich et al. (2006) that describes the effects of this invasion on the ecosystem.

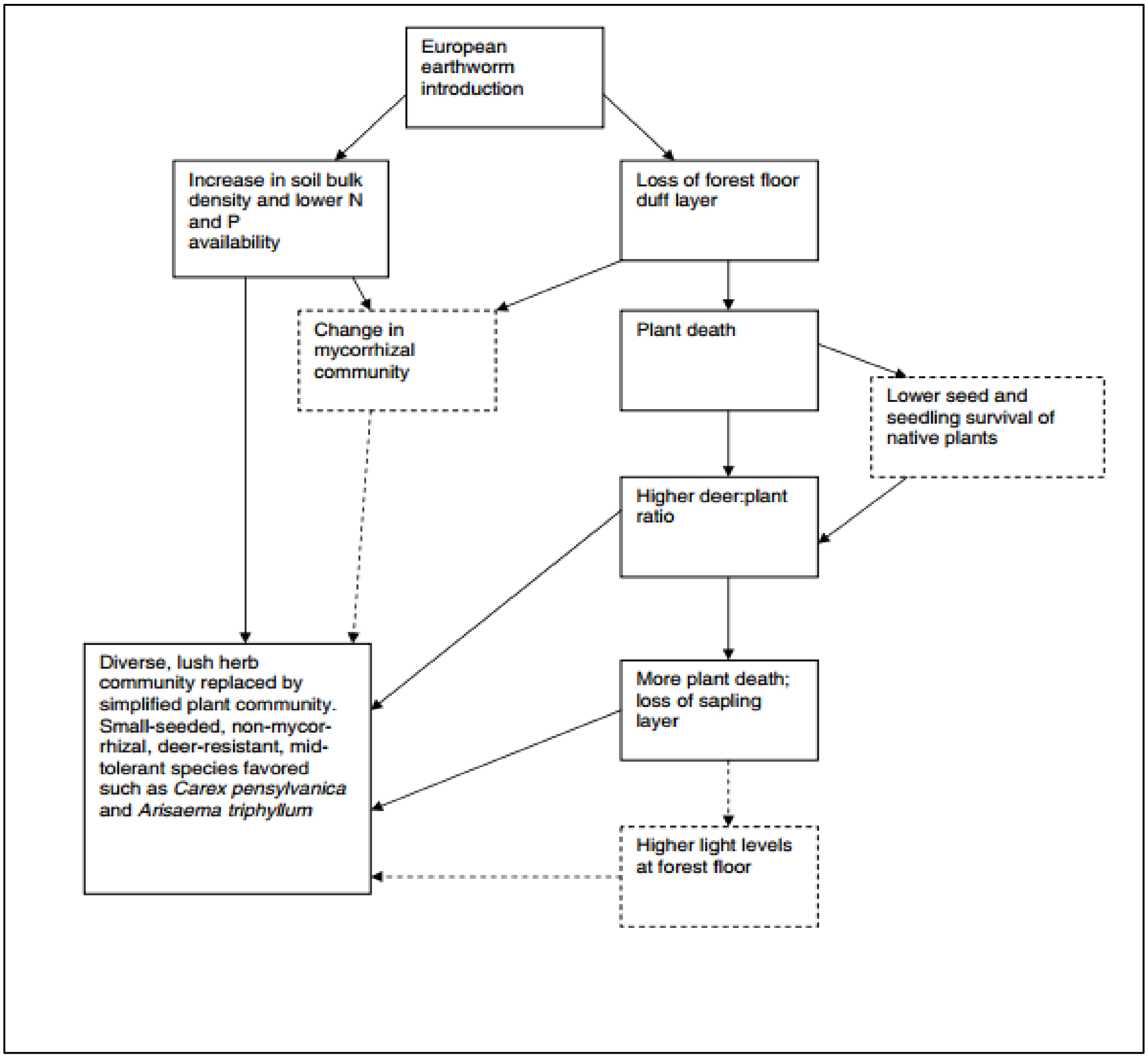

Figure 5. From Frelich et al. (2006), plant community composition changes caused by European earthworm invasion. Dashed pieces of the diagram indicate hypothesized interactions that have not yet been proven with scientific methods.

In this example of a novel ecosystem, it is clear that all four criteria of the novel ecosystems definition are met. The ecosystem condition was created by human agency (the movement of earthworms from Europe to the Lake States region), an exotic species is present, ecosystem function is highly altered due to the change of soil food web dynamics, and current management options classify the condition as irreversible.

With regards to forest management, this case study is very different from that of Example 1 described previously. This novel ecosystem represents a new ecosystem characterized by a change in understory plant composition. Though there are likely subsequent effects on the overstory composition due to a change of seedling attributes, they are not yet quantified or documented (Frelich et al. 2006).

Management, use, and conservation are affected by the new condition of the novel ecosystem. First, managing this region may refer to manipulating the understory plant communities to better suit the publics' views of an aesthetic forest. The current presence of a less lush understory is likely to be described as "unaesthetic" by the public. However, when viewing management from a timber harvest perspective, the overstory is not highly affected by presence of earthworms. Using and conserving forests are both subsequently affected in similar ways. Second, recreational use may decrease due to the less aesthetic understory. However, use for timber harvest is likely unaffected by the novel ecosystem condition. Third, conserving these forests for complete native understory and overstory plant composition is drastically affected by the condition of the ecosystem due to the loss of its past understory composition. Conserving the overstory species composition has not been highly affected, however.

The ways in which this novel ecosystem affects forest management practices are variable and dependent on the land manager's perspective of management itself. If the land manager views the entire ecosystem condition as critical to forest health and composition, then forest management and use are affected. However, if the land manager views the ecosystem as purely a timber harvesting opportunity, management has not been affected, at least yet.

The two examples listed above represent opposite scenarios of novel forest ecosystems and their related impacts on forest management practices. In Example 1, it is clear that forestry is drastically affected by the new condition of the ecosystem. With the high density of small diameter trees and the slow process of succession of healthy stands to an intermediate or old growth condition, forest harvesting and land use are both highly altered. In this example, forestry is proven to be affected by the novel condition of the ecosystem. Example 2 represents an ecosystem in which the effects on forestry vary depending on the viewpoint of the land manager. If the manager is focused on timber harvest, then the unchanged overstory species composition yields a forest management plan dissimilar to the previous historical ecosystem. However, if the manager is focused on aesthetic, recreational values and biodiversity the changed understory composition is likely to affect forest management practices.

The process used to assess the impact of these two examples of novel ecosystems on the field of forestry was repeated for 10 examples and results are in Table 1 below.

Table 1. Ten case study examples of novel ecosystems and their impacts on forestry. Y = there is an impact, N = no impact, and D = dependent on management goals.

Novel Ecosystem Impacts on Forestry				
Case Study	**Management**	**Use**	**Conservation**	**References**
Cheatgrass-invaded ponderosa pine	Y	Y	N	Cooper 1960; Harrod & Reichard 2000; McGlone et al. 2009); Griffis et al. 2001)
Earthworm invasions in Great Lakes Region	D	D	D	Hale et al. 2005; Frelich et al. 2006; Nuzzo et al. 2009
Norway maple Invasions on the East Coast	Y	Y	Y	Martin 1999
Hawaii Nonnative Forests	Y	N	Y	Gardner & Davis 1982
Puerto Rico Nonnative Forests	N	Y	Y	Lugo 2004
Deforested Cerrado in Brazil	Y	Y	Y	Klink & Machado 2005
Chestnut blight Introduction	Y	Y	Y	Anagnostakis 1987
Black locust Invasion in Italy	Y	Y	Y	Nascimbene & Marini 2010
Black cherry Invasion in Belgium	Y	Y	Y	Deckers et al. 2005
White pine blister rust invasions in the Pacific Northwest	Y	Y	Y	Samman et al. 2003

When viewing the 10 examples of novel ecosystems in the table above, note the trend that generally all three practices of forestry are impacted by the new condition of the ecosystem. Also note that there are several exceptions to this trend. One exception is the earthworm invasion example discussed previously. In this example, the impact on forest management and use depends on the goals of the land manager. In the example of nonnative forests in Hawaii, I chose the "no impact" option for forest use because of the huge diversity of species now present on the islands. With the larger diversity, it is logical to assume that diversity of land uses have also increased. With a greater plant and land-use diversity I may classify the ecosystem as "impacted positively". In the Puerto Rico example, I chose the "no impact" option for forest management because there is currently no management being conducted to attempt to reverse the forest to its previous condition, nor was there management to prevent the establishment of the new ecosystem. In fact, managers have chosen to let the nonnative species continue to grow due to soil stabilization properties of the plants. All other examples listed in the table have valid literature concluding that all three of the main forestry practices are affected in some way by the new condition of the ecosystem.

Summary and Conclusion

The concept of novel ecosystems was first published by FS Chapin and AM Starfield in 1997, AE Lugo in 2004, and RJ Hobbs in 2006. Since the publication of these early papers on the topic, over 900 papers have been published with the term "novel ecosystem." With the continued development of the idea, the definition of the term has changed over time and now includes four general criteria: (1) new species combinations must be present, (2) there has been a significant change in ecosystem function, (3) the change was caused by human agency, and (4) the change is irreversible with current management options. Under these criteria, researchers may identify case studies on ecosystems not yet classified as novel. Throughout the literature, there are also case studies that have already identified the ecosystem as novel.

In the first part of this paper, I reviewed literature to find the most common themes of justification for the author's use of the term "novel ecosystem." Many of these case studies either did not fulfill all four criteria of the definition or did not explicitly state how the case fulfilled all 4 criteria. In the cases that all four criteria were not met, the case studies were classified as "arbitrary usage." Other common themes found throughout the literature were "ecological tipping points", "change in species composition", "land use change and population proxies", and "change in ecosystem function". The most common theme found throughout the literature was the presence of an invasive or exotic plant or animal species that has affected the ecosystem significantly. I have presented one example from each of these common themes in the first part of this paper.

The second part of this paper sought to answer whether the concept of novel ecosystems impacts forestry. Results suggest that in general, the three practices of forestry (managing, using, and conserving forests for human benefit) are indeed affected by novel ecosystems. Though some exceptions exist, general consensus suggests that forestry practices in the future will need to account for novel conditions in order to maximize human benefit and sustainability of forests.

The overall usefulness of the concept of novel ecosystems for land managers is highly dependent on the land manager's goals. As stated previously, a designer ecosystem may be classified as novel. In the case that a land manager creates a designer ecosystem that is novel and the ecosystem meets all of the land manager's goals, concerns about ecosystem novelty likely will be secondary to the value of the designer ecosystem. However, in an example such as ponderosa pine forests invaded by cheatgrass, land managers should fully take into account the concept of novelty and how irreversibility may come into play with future management practices. Thus, understanding and utilizing the novel ecosystems concept represents an opportunity that, when used under the right circumstances, may be used to manage forest ecosystems more effectively.

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Index

Ecosystem Case Studies

Case Study	References	New Species Combinations	Change in Ecosystem Function	Caused by Human Agency	Irreverisble Condition
Degraded Fen Areas	Cabezas et al. 2014	Unkown	Yes	Yes	Yes
Ecological Tipping Points	Barnosky et al. 2012	N/A	N/A	N/A	N/A
Puerto Rico Tree Invasion	Lugo 2004	Yes	Yes	Yes	Yes
Land Use Change Proxies	Perring & Ellis 2013	N/A	N/A	N/A	N/A
Abandoned Mine Sites	Doley & Audet 2013	Yes	Yes	Yes	Yes
Cheatgrass-invaded Ponderosa Pine	Cooper 1960; Covington & Moore 1994; Harrod & Reichard 2000; McGlone et al. 2009; Griffis et al. 2001; Keeley 2007 D'Antonio & Vitousek 1992)	Yes	Yes	Yes	Yes
European Earthworm Invasion	Frelich et al. 2006; Hale et al. 2005; Nuzzo et al. 2006	Yes	Yes	Yes	Yes
Norway Maple Invasions	Martin 1999; Anderson 1999; Wychoff 1996	Yes	Yes	Yes	Maybe
Hawaii Nonnative Forests	Hobbs et al. 2006	Yes	Yes	Yes	Yes
Deforested Cerrado in Brazil	Hoffmann & Jackson 2000; Klink & Machado 2005	Yes	Yes	Yes	Yes
Chestnut Blight Introduction	Evans & Finkral 2010	Yes	Yes	Yes	Maybe
Black Locust Invasion in Italy	Benesperi et al. 2012	Yes	Yes	Yes	Maybe
Black Cherry Invasion in Belgium	Deckers et al. 2005	Yes	Yes	Yes	Maybe
White Pine Blister Rust in Pacific Northwest	Kinloch 2003	Yes	Yes	Yes	No

Table 2. This table lists all of the case studies used to represent each theme found in novel ecosystems literature as well as the case studies used to describe the relevance of novel ecosystems in forestry. For each case study I state *yes*, *no*, *mayb*e, or *N/A* for whether the case study meets each part of the novel ecosystems definition based on literature found on the case study.