Novel Landscapes: Challenges and Opportunities for Educating Future Ecological Designers and Restoration Practitioners

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EDUCATION

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ABSTRACT

In the context of changing climate regimes, new and modified chemical inputs, and introduced species, the interactions between biota and abiotic processes are being reconfigured. These new interactions result in novel communities, which are compositionally unlike communities observed previously, falling outside the conventional gradient of pristine to degraded ecosystems. For educators in college and university faculty in the ecological and design fields, two primary questions emerge in teaching restoration: how can design education engage landscapes not previously encountered, and how can educators and students acquire the necessary knowledge and experiences to be successful practitioners in no-analog communities? I first provide background about and examples of novel landscapes. I then describe the key complexities associated with novel systems made evident through research in the ecological sciences in order to understand the pedagogical challenges facing educators. I propose five pedagogical strategies that can facilitate exposure to and experience with the uncertainty and ecological dynamism that characterize novel systems. These changes include: making uncertainty central to the learning experience through creating future scenarios; using visualization and quantification technologies and playing digital game exercises; providing research opportunities for students through collaborations with municipalities and other experts, including natural and social scientists; and facilitating deliberations with ethicists, designers, and scientists about the political and ethical dimensions of interventions in hybrid and novel systems. I conclude with brief descriptions of three courses that integrate some of these pedagogical strategies while investigating novel systems.

Keywords: landscape architecture and design, novel ecosystems, pedagogical strategies

Now is a provocative and exciting time for educators of future practitioners involved in ecological restoration efforts, including the ecology disciplines and design fields (i.e., landscape architecture and landscape design). We are witnessing unprecedented global transformation of landscapes (Foley et al. 2005, Parmesan 2006, Williams and Jackson 2007, Lugo et al. 2012, Lurgi et al. 2012), characterized by the decoupling of historic ecological relationships and interactions, resulting in the emergence of communities not seen before (Hobbs et al. 2006, Williams and Jackson 2007, Lindenmayer et al. 2008, Higgs 2012, Suding and Leger 2012, Hobbs et al. 2013). In the context of changing climate regimes, new and modified chemical inputs, and introduced species, the interactions between biota and abiotic processes are being reconfigured (Seastedt et al. 2008). Novel communities, also referred to as non-analogs (Williams and Jackson 2007), are compositionally unlike communities observed previously, falling outside the conventional gradient of pristine to degraded ecosystems (Lindenmayer et al. 2008).

Novel communities are not a unique contemporary phenomenon; over the last 18,000 years, plant species have moved at different rates and directions during interglacial transitions (Overpeck et al. 1991), resulting in unique plant communities that lacked historic precedents (Lindenmayer et al. 2008). Paleoecologists characterize the Quaternary Period as one novel system (Bloom 2002). Recent estimates claim novel landscapes constitute approximately 35% of the globe (based on urban and agricultural land uses; Marris 2011), and are predicted to increase most notably in tropical and subtropical regions by 2100 under various International Panel on Climate Change (IPCC) climate scenarios (Williams and Jackson 2007). Current

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landscape change is distinguished from historical eras based on: (a) faster rates of change owing to anthropogenic drivers; (b) increased intensities of chemical inputs; and (c) expanding spatial patterns of landscape fragmentation. In the contemporary context, ecologists predict that novel landscapes will become the new normal (Williams and Jackson 2007).

Novel communities offer an opportunity to revise current pedagogical approaches to teaching future practitioners who will be working in landscapes undergoing rapid transformation. For educators in college and university faculty in the ecological and design fields, two primary questions emerge in teaching restoration: how can design education engage landscapes not previously encountered, and how can educators and students acquire the necessary knowledge and experiences to be successful practitioners in non-analog communities? These educators are beginning to adjust their pedagogical strategies to help students become knowledgeable about adaptable and persistent landscapes under conditions of uncertainty.

In this paper, I first provide background about and examples of novel landscapes. I then describe the key complexities associated with novel systems made evident through research in the ecological sciences in order to understand the pedagogical challenges facing educators. I propose five pedagogical strategies that can facilitate exposure to and experience with uncertainty and ecological dynamism that characterize novel systems. These changes include: making uncertainty central to the learning experience through creating future scenarios; using visualization and quantification technologies and playing digital game exercises; providing research opportunities for students through collaborations with municipalities and other experts, including natural and social scientists; and facilitating deliberations with ethicists, designers, and scientists about the political and ethical dimensions of interventions in hybrid and novel systems. I conclude with brief descriptions of three courses that integrate pedagogical strategies while investigating novel systems.

Novel Landscapes: Background and Definitions

Graham (1986) has been credited with articulating the concept of no-analog biotic assemblages, where individual species (not communities) migrated in response to changing climatic conditions. In the Quaternary Period, individual species migrated in different directions, at different rates, and for different distances. These shifts created biotic assemblages in the Pleistocene composed of previously co-located species that are observed separated from each other (Bloom 2002). Species respond to changes individualistically rather than as community units (Gleason 1926), and research still aims to understand the dynamics among fluctuating species composition and function.

No-analog communities of today are unlike the naturally occurring Pleistocene no-analog communities, due to the dominance of anthropogenic drivers of change (i.e., land use, chemical inputs, and human introductions of species) and the significantly faster rate of change systems undergo (Williams and Jackson 2007). Modern-day novel systems can be understood as human-dominated systems, where conversions of land cover into land uses, the application of chemical inputs for industrial and agricultural production, and the human introduction of non-native species alter not species composition and the underlying abiotic processes and ecosystem functioning. For the purposes of this paper, ecosystem functioning includes the internal processes (Christensen et al. 1996) as well as ecosystem goods, and ecosystem services (de Groot et al. 2002). Pools of materials (i.e., organic matter and carbon) and the rates of internal processes (including energy exchange between pools and the fluxes of materials) constitute ecosystem properties (Hooper et al. 2005). A subset of the ecosystem properties are the ecosystem goods that have direct market value (e.g., food, timber, and recreation) and the services that direct and indirectly benefit people (e.g., hydrologic cycle, regulating climate, and soil formation) (Daily 1997, Millennium Ecosystem Assessment 2005).

The role of human agency has been considered by some scholars to be an important contributor to the formation of novel landscapes (Hoffman and Jackson 2000, Mascaro et al. 2008, Thompson and Jackson 2013). Early definitions of novel landscapes included those that resulted from deliberate and inadvertent human action, and which depended on persistent human intervention for maintenance (Hobbs et al. 2006). Recent taxonomies distinguish between non-anthropogenic ("natural") and anthropogenic novel systems (Thompson and Jackson 2013). Anthropogenic novel systems include those that emerge unintentionally and in unforeseen ways (haphazard novelty) and those that are foreseen yet unintentional. Intentional novel systems emerge because they are a means through which management goals are met. Thompson and Jackson (2013) refer to management with novelty (as a tool within plans) and management of novelty (adjusting plans based on recognizing novel systems previously not acknowledged). Novel systems that are intentionally created raise interesting questions about the distinctions between restoration and engineering.

Cities have been considered novel in relation to their non-urban counterparts (Kowarik 2011). The physical processes of urbanization (i.e., regrading of terrain, the removal of vegetation, and proliferation of impervious surfaces) and social dynamics (i.e., introduction of exotic, non-native, and ornamental plant species, altered hydrologic regimes, and biogeochemical cycles through development) have made cities hotspots of non-native species diversity (Kowarik 2011).

More recently, definitions of novel systems have clarified the distinction from historic and hybrid systems:

> *A novel system is a system of abiotic, biotic and social components (and their interactions) that, by virtue of human influence, differs from those that prevailed historically, having a tendency to self-organize and manifest novel qualities without intensive human management. Novel ecosystems are distinguished from hybrid ecosystems by practical limitations (a combination of ecological, environmental and social thresholds) on recovery of historical qualities* (Hobbs et al. 2013: 58).

Several scholars involved in developing the above definitions conceptualize novel systems as existing along a continuum (Hobbs et al. 2009, Hallett et al. 2013, Mascaro et al. 2013); others argue that novel systems need to be clearly delineated and distinguishable from hybrid and historical systems in order to be useful for developing restoration and management goals (Chapin et al. 2006, Seastedt et al. 2008). Classifying historic, hybrid, and novel ecosystems has been based on the drivers and pathways of development (Milton 2003, Hobbs et al. 2006, Hobbs et al. 2009), reversibility of ecosystem changes (Hobbs et al. 2009), degradation of ecosystem function (Jones 2013), and levels of observed transformations (Kowarik 2011; Table 1).

Relationships among species composition, species richness and ecosystem functioning are complex. Understanding how changes in species richness and composition influence ecosystem properties requires understanding species' functional traits (Hooper et al. 2005). Functional traits influence ecosystem properties or species' response to environmental conditions. Some research demonstrates that invasive plant species do not have negative impacts on pollinator services (Nielsen et al. 2008), while other work demonstrates that forests composed of non-native species are able to recruit native species in later successional stages (Lugo 2004). Understanding these nuances helps distinguish between landscapes composed of many novel elements (e.g., invasive species) and novel systems. There can be significant novel elements within a system that do not irreversibly alter ecosystem function (Hobbs et al. 2013). Ecosystems with many novel elements represent a hybrid stage, where restoration interventions can potentially reverse and alter the trajectory of unwanted environmental conditions.

Being able to distinguish historic from hybrid from novel ecosystems is important for restoration practice. The distinction is equally important for educating future restoration practitioners so that restoration goals and interventions are realistic, feasible, and successful; funds—especially public funds—are invested wisely, based on the best available science; and restoration projects have a higher probability of persisting under extraordinary rates of change.

The Dynamics Between Shifting Species Composition and Ecological Function

Research on the emergence of novel systems seeks to understand the complex dynamics associated with ecological change, particularly the impact of ecological functioning owing to shifts in species composition based on designation (native, non-native, alien) and the introduction of non-native species (Ruesink et al. 2005, Sax et al. 2007, Walther et al. 2009, Schlaepfer et al. 2011, Tockner et al. 2011). Relationships between species designation and ecosystem functioning are not clear-cut. Some research documents the detrimental impacts of non-native species on desired ecosystem function (Vila et al. 2010), while other research describes the introduction of new ecosystem functions through the use of non-native species (Ewel and Putz 2004, Ruesink et al. 2005) and the most current research discusses reintroducing native species into novel systems (Fischer et al. 2014). These several research strands demonstrate the complex relationship of interpretive approaches to novel systems that both respond and contribute to shifting perceptions about restoration practice, particularly related to species designations, the value of non-natives, and ecosystem function as a restoration goal.

Shifting Species Composition

Working in novel systems requires revisiting biases that fail to acknowledge beneficial contributions of non-native species for preserving and maintaining ecosystem function (Schlaepfer et al. 2011). In this paper, non-native refers to species that occur outside their historic range and invasive refers to those non-native species that produce biological, social, or economic harm. The adaptation of native species to current environmental conditions is well-documented (Lesica and Allendorf 1997, Joshi et al. 2001) and the use of native species in restoration projects is considered a best management practice for reducing costs associated with maintenance (United States National Park Service and the Soil Conservation Service 2000). Native plants can be drought-tolerant, and for places experiencing chronic drought conditions, promoting the use of native species becomes part of a larger water conservation strategy, especially among federal agencies, urban municipalities, and homeowners' associations (US Environmental Protection Agency 2004). Some western cities provide financial incentives for homeowners to remove water-intensive lawns and to plant native, drought-tolerant, xeric species, oftentimes referred to as water-wise landscapes (Austin Water Utility 2014, Lovett 2013). Increasingly, homeowner associations in master-planned developments require a percentage of native plant species for household landscaping, while making similar claims about water conservation (Lerman et al 2012).

Invasive species have been characterized generally as being aggressive colonizers (e.g., kudzu, *Pueraria montana*,

Table 1. Comparisons of historic, hybrid and novel systems based on three criteria: levels of transformation, degradation of function, and reversibility of change. Adapted from Hobbs et al. 2009, Kowarik 2011, and Jones 2013.

	Historic Systems ➔	Hybrid Systems ➔	Novel Systems
Level of transformation	*Low* Remnants of natural ecosystems Example: Old tropical moist forests contains indigenous species, many endemic to Puerto Rico (Lugo 2004).	*Medium* Remnants of human-made ecosystems, resulting from early habitat transformations Example: Invasion by non-native grass (*Andropogon gaynus*) in Australian savanna alters fuel characteristics due to higher biomass of non-native grass (Brooks et al. 2004) and causes nutrient losses (Rossiter-Rachor et al. 2008).	*High* Emerging assemblages after habitat destruction Example: Urban sites with highly modified soils, climate, and hydrology populated show increased proportion of introduced species preadapted to novel site conditions (Kowarik 1995, Pysek 1998, Picket et al. 2001). Example: Places in the Everglades, Florida that have been transformed by rock plowing and subsequently populated by non-native plant species (Ewel 2013).
		Medium to high Transformed remnants or newly established landscapes after habitat destruction Example: Gardens Many introduced non-natives and ornamentals species done to sustain desired ecosystem function and introduce new functions (e.g., aesthetics or recreation) (Primack and Miller-Rushing 2009).	
Degradation of ecosystem function (based on historical reference)	Primary processes fully functional.	Biotic threshold is crossed. Primary processes partially functional.	Abiotic threshold is crossed. Primary processes nonfunctional. Emergence of new system functions.
Pathways of development and reversibility of ecosystem changes	Ecosystems remain within their historical range of variability.	Modified from historical state by changing biota and/or biotic characteristics. Reversing ecosystem changes requires removal of invasive species and/or amelioration of altered environmental conditions.	Modifications to abiotic conditions or biotic composition are irreversible when restoration of ecosystem structure and/or function can be achieved without returning to historic system characteristics.

in the southeastern US) (Sakai et al. 2001), and their proliferation is seen as contributing to the emergence of biologically homogenous environments (Bullock et al. 2011). Research suggests that an abundance of invasive species might increase as habitats are modified, potentially reducing the biodiversity of native species in these disturbed areas (Didham et al. 2007). Little empirical evidence exists, however, that supports aggressive colonization as a trait across taxa (Sakai et al. 2001) and questions remain about the impact of invasive and non-native species on ecosystem functioning (Pejchar and Mooney 2009, Schlaepfer et al. 2011). Additionally, biases associated with negative perceptions of invasive species among researchers have been documented (Slobodkin 2001, Gurevitch and Padilla 2004, Stromborg et al. 2009), and some scholars speculate on the underreporting of studies that fail to associate negative effects with non-native species (Schlaepfer et al. 2011).

In a controversial commentary published in *Nature*, a group of ecologists referred to the adherence to native species in restoration practice and research as 'biological bias' (Davis et al. 2011). This bias is attributed to the influence of nostalgia, ignores evidence of rapid and intense environmental landscape change, and dismisses the positive effects of many invaders. Research has documented forests in Puerto Rico, dominated by non-native species that have greater species richness while also creating opportunities for the establishment of native species (Lugo 1992). Novel forests in Hawaii had, on average, as many foreign or non-native species as native forests and out-performed or performed at equivalent levels to native Hawaiian forests by measures of nutrient cycling and above ground biomass (Mascaro et al. 2008, Marris 2011).

Replication of Historical Communities

Many ecological design studios often focus on replicating historical communities in order to achieve site-specific biodiversity goals; occasionally these are tied to specific ecosystem functions (i.e., hydrologic cycles). Ecological design studios represent an ecological design subset of landscape architecture, where designs minimize environmentally destructive impacts through the integration of living systems (Madge 1997, Van der Ryn and Cowan 1996). In the design studio context, research involves locating historic records to guide plant selection, where use of native plants and the removal of non-natives and invasive species are often emphasized.

Researchers working in novel landscapes question replicating the composition of historical communities as an endpoint for restoration projects (Choi 2007, Millar et al. 2007, Davis et al. 2011, Schlaepfer et al. 2011). Reference communities, defined as those whose species composition is less impacted by processes driving environmental change (including urbanization, habitat fragmentation, and pollution) often serve as a benchmark against which the ecological fidelity of a plan is measured (Egan and Howell 2001). Yet, problems arise about how to determine the appropriate point in time for selecting the reference community (Higgs 2003). Additional questions arise about ability of re-constructed historical communities to persist successfully in landscapes where significant environmental changes exceeds the tolerance limits of individual species (Davis et al. 2011, Marris 2011).

The related concept of historical range of variability (HRV) recognizes the spatial and temporal dynamics associated with landscape change, and questions the practice of recreating historic assemblages. HRV assets that there no perfect reference exists, that ecological variation (micro and macro) is a key attribute of human-modified landscapes, and that stochastic events contribute to patterns of diversity, structure, and function (White and Walker 1997, Higgs 2003). HRV recognizes the full range of conditions across spatial and temporal scales and the diversity of specific ecosystem elements. Forest managers have used HRV to identify areas for biodiversity conservation (Aplet and Keeton 1999) and to restore areas where current conditions are significantly different from historical variations (Reynolds and Hessburg 2005).

Understanding a site's history yields insights into how ecological processes have changed over time (Pulliam and Johnson 2002, Higgs 2003). It can shed light on how current conditions deviate or not from an historic envelope of conditions (Keane et al. 2009). Both historic community assemblages and HRV can be used as guides; as heuristic tools to better understand species dynamics and the impacts of shifting species composition on ecosystem function (Millar et al. 2007).

Ecological Function

Ecosystem function is a broad terms that refers to the internal ecosystem processes, including primary production, decomposition, and nutrient cycling (Hooper et al. 2005). Four more specific meanings of function include the interactions between two things (e.g., organisms and processes); the overall ways in which an ecosystem operates based on the contributions of specific components; the ecological function of species (Jax 2005); and, in the context of ecosystem services, the capacity of a site to provide goods and services that directly and indirectly benefit humans (deGroot et al. 2002). Restoration goals related to ecosystem function as a whole, or to the provisioning of goods and services benefiting humans, contrast with restoration goals that retain species diversity, often measured as native species richness (Hobbs et al. 2011).

There is increasing evidence that maintaining a diversity of species functional groups is critical for highly disturbed and rapidly changing environments (Elmqvist et al. 2003). The complex dynamics between shifting species composition and ecosystem function is influenced by species losses and additions (Mascaro et al. 2008), which is driven by and depends upon particular disturbance regimes. Rather than maintain species diversity (richness), restoration projects might focus on making landscapes able to accommodate changing environmental conditions by selecting plant species that have wide tolerance ranges, or plasticity (Hunter 2011). Broadening the mix of species to include functionally redundant species, selected from a wider range of environments, increases the likelihood of containing a particularly resilient species for the local context (Suding and Leger 2012). Additionally, the diversification of ecosystem functions for human benefits means that restoration efforts target landscape dynamics that maintain core ecosystem services (e.g., increasing water infiltration to reduce flood risk). The focus on ecological function, however, does not always preclude native species diversity. Introducing an ecological function that has been eliminated (i.e., fire regimes) is a management approach used by restorationists to maintain native species (Agee 1996). The shifts in how non-native species can contribute to ecological function and restoration goals highlight the complex dynamics among species composition, the plasticity of species, ecosystem function, and restoration practice.

Novel Landscapes: Challenges for Educating Future Ecological Restoration Practitioners

Educators of future restoration practitioners are faced with adjusting their pedagogical strategies to align with the realities of a rapidly changing world under increased awareness of uncertainty. Climate change disrupts trophic networks and community-level interactions (Gilman et al. 2010), making the reliance upon past conditions for guidance about future restoration decisions tenuous (Millar et al. 2007, Hunter 2011). Structuring a design studio or science class around the concept of uncertainty is an important step towards educating and training future practitioners to act in the face of unknown futures. Conceptualizing landscapes in novel or transition states is no easy task. How might educators help students become knowledgeable about adaptable and persistent landscapes under conditions of uncertainty? What kinds of pedagogical strategies facilitate exposure to and experience with uncertainty and ecological dynamism that characterize novel systems? In this section, I propose pedagogical approaches, and provide example of current efforts to address novel systems and research in course offerings in distinct and informative ways.

Pedagogical Strategies

1. *Highlighting uncertainty.* Structuring a design studio or science class around the concept of uncertainty is an important step toward educating and training future practitioners to act in the face of unknown futures. Uncertainty can be confusing and demoralizing, resulting in paralysis and an inability to move forward (Peterson et al. 2003). Among environmental designers and planners, uncertainty has been associated with the unintended consequences of constructing designs and implementing plans that alter a site (Johnson et al. 2002). However, uncertainty is increasingly recognized as central to the repair and management of landscapes (Pastorok et al. 1997, Simenstad et al. 2006, Millar et al. 2007), especially among proponents of adaptive management (Brewer and Gross 2003, Allen et al. 2011). For restoration students, recognizing that climate change is creating uncertainties in species distributions, interactions, and assemblages across ecoregions challenges the assumption that replicating pre-settlement conditions will lead to persistent landscapes (Huntley and Webb 1988). Rather than restoring past conditions, the challenge now is to realign systems to present and anticipated future conditions so that landscapes can respond adaptively to change (Millar and Woolfenden 1999). Shifting from conceptualizing restoration as the replication of historical communities to emphasizing the macro-dynamics that are responding to climate fluctuations and influencing species distributions, extirpations, and colonization (Millar and Brubaker 2006) represents a significant shift that reorients students from a reliance on the past toward a larger-scaled, dynamic vision of landscape change.

   A more explicit focus on larger-scaled processes does not, however, require a complete abandonment of historical ecology (Millar et al. 2007). Faculty can incorporate information from historical ecology about shifting species distribution as a way of demonstrating the spatial and temporal dynamics of communities. Introducing students to research about the exposure species have had to rapidly changing conditions and fluctuating climates over the past 2 to 20 million years (Zachos et al. 2001) challenges students to think about interventions—and their understanding of landscape dynamics—in a much longer time frame. For design students, this extended temporal scale can be difficult to grasp, and even appear unhelpful given the reality of practice, where designs are typically presented more statically. Faculty can manage this difficulty by reframing the goal of ecological interventions being the design of landscapes that accommodate change and adapt to transforming environmental conditions (Millar et al. 2007, Hunter 2011). For landscapes transitioning from slowly from historic to hybrid states, students can think of interventions that create and sustain gradual processes of adaptation. Alternatively, for rapidly transforming landscapes where control over future change is limited (e.g., coastal communities facing significant levels of sea level rise), students need to think of interventions that can leverage adaptation processes immediately. These interventions could include approaches for facilitating transitions and population adjustments (Millar et al. 2007) based on a well-developed understanding of historical range shifts and associated disturbances. Students will need specific information in order to translate ideas about the past into decisions about the future. Design students, in particular, will need to be exposed research that assesses, for example, the adaptation of urban trees and assemblages under various climatic conditions (Aitken et al. 2008, Woodall et al. 2010). Students who are interested in conservation will need to be exposed to work that predicts how the distribution of protected areas will change with future climate spaces (Wiens et al. 2011).

   Considering climate change as an "ecosystem architect" (Millar and Brubaker 2006) means using the uncertainty about the future as a concept through which dynamics at the site scale are related to dynamics operating at eco-regional scales. Faculty can facilitate discussions about changing species ranges and the impacts of site level interventions on regional processes of establishing species, avoiding or driving extinction, and creating refugia. Teaching about multiscalar interactions, macro-level processes, and dynamics between species composition and ecological function may extend beyond the expertise of many faculty. Guest experts—including atmospheric scientists, climate modelers, landscape ecologists, paleoclimatologists, and ecosystem scientists—can be brought in to discuss the implications of increased atmospheric carbon on temperature, soils, and persistence of vegetation. Faculty will need to cultivate interdisciplinary relationships with these experts and integrate research findings into the learning process, including student learning objectives and assignments that integrate research findings.

2. *Taming uncertainties through scenario planning.* Uncertainty about the future also demands that faculty and students think about adaptable and functional landscapes in multiple trajectories of the future. Scenario planning provides a framework for developing approaches to landscapes under high levels of uncertainty and low levels of control (Ahern 1999, Berkhoust et al. 2001, Peterson et al. 2003). The resulting scenarios are structured accounts of possible futures that can be tools for communicating and planning future options, accompanied by narratives and empirical analysis. Originally used by corporations for strategic planning purposes (Berkhout et al. 2002), future scenarios are widely developed in climate science (Berkhout et al. 2002, Shackley and Deanwood 2003), conservation biology (Peterson et al. 2003), restoration ecology (Harms et al. 1993, Fuller et al. 2008), and landscape planning (Ahern 1999, Shearer 2005), but are not yet to be widely used as a teaching tool for design and science students. Scenarios are "coherent, internally consistent and plausible description(s) of a possible future state of the world" (Parry and Carter 1998 in Berkhout et al. 2002) that can be organized into three classes based on the following questions: what *will* happen (business as usual scenarios); what *could* happen (forecasting); and what *should* happen (normative or backcasting). A forecasting approach creates scenarios that are contextual and maps trends and identifies uncertainties out of which alternative futures are constructed (Vergragt and Quist 2011). Participants are encouraged to think unconventionally as they attempt to account for unforeseen and unintended consequences of future trajectories. The International Panel for Climate Change (IPCC) scenarios are now the most well-known examples of forecasting, and are credited with impacting public opinion and policies. Normative approaches are based on developing a single vision of the future, and then looking backwards in an iterative and reflexive manner to devise strategies for achieving the future vision (Vergragt and Quist 2011).

   There are many approaches to scenario planning, but the one approach that has developed in conjunction with adaptive management practice consists of six interacting stages: identification of the central issue and research question; assessment of system components related to the issue; identification of alternative ways in which the system under investigation could evolve; construction of scenarios; testing of scenarios; and development of policy responses (Peterson et al. 2003). Restoration students involved in constructing scenarios could develop narratives that relate present conditions and key dynamics identified through analysis of historical ecology to plausible future outcomes. The development of four or five narratives would track a key indicator variable derived from the research question. The scenarios consider how critical uncertainties may impact the future, and to identify hidden dangers and opportunities (Biggs et al. 2010). Scenario planning is viewed as an effective strategy for bridging disciplines involved in landscape issues (Ahern 1999) and might contribute to minimizing the dichotomy between ecology and design through joint creative analytic problem solving (Hunter 2011). Students become more practiced in being anticipatory thinkers, able to link processes across time and at various spatial scales. A key difficulty with scenario planning efforts is maintaining awareness of assumptions among participants (Peterson et al. 2003). Class discussions and exercises would be needed to check, reveal, and revise assumptions during the planning process. However, bringing scenario planning into courses investigating novel systems and future actions would provide students a structured way of learning to anticipate. It could cultivate the capacity for anticipatory thinking—both of which are considered important skills for educating future practitioners dealing with climate change adaptation (Tschakert and Dietrich 2010).

3. *Problem-solving under uncertainties through quantification, visualization, and gaming.* Working within novel systems involves dynamics among shifting species compositions, ecosystem functions, and landscape performance. Digital quantification and visualization technologies can be powerful tools for supporting learning. There are many tools that visualize and quantify landscape performance. The i-Tree tool (http://www.itreetools.org/index.php) is one example of an open-source, peer-reviewed set of assessment tools provided by the USDA Forest Service that calculates benefits associated with urban forests at multiple spatial scales. The quantification of services and the monetization of benefits derived from urban forests are based on the ecosystem services framework (Millennium Ecosystem Assessment Report 2005). Benefits associated with street trees are monetized based on the regulating, provisioning, and cultural services from which humans directly and indirectly benefit. While there is discussion about the dangers associated with monetizing ecosystem benefits (Gomez-Baggethun and Perez 2011), the i-Tree outputs do provide educators and students with accessible, understandable, and standardized measures, which can then become part of broader exercises, including future

scenario planning. Current research at the University of Texas has modified some of the i-Tree tools for regional application to be used in scenario planning efforts in order provide real-time measures of ecosystem services and land uses that can be immediately assessed relative to established project goals (R. Paterson and T. Hilde, The University of Texas, School of Architecture, Community and Regional Planning Program pers. comm.). Successful integration of these kinds of assessment tools into the classroom does require that faculty and students skilled in GIS programs and data management.

Novel systems can also be explored using digital games. Digital games that involve making decisions about the environment have been referred to as virtual ecologies that operate in a problem space (Chang 2009). Developed in 2007 and played for 32 weeks by almost 1900 participants, World Without Oil (WWO) (http://worldwithoutoil.org/) was a collaborative simulation of a global oil shortage that required participants to develop approaches for living in a world where oil demand exceeded availability by 5%. Participants engaged in collaborative problem-solving through crowd-sourcing and peer-to-peer learning. A world without oil is a potential novel virtual system—a world we have not yet encountered, but one that many fear—that drew from the collective imagination of many players who experimented with decisions without material consequences (Chang 2009). Although the game is no longer played, there are ten lesson plans available that were developed based on the experiences and strategies developed by participants.

Climate change games and simulation were initially developed during the 2009 United Nations negotiations in Copenhagen (Reckien and Eisenack 2013). Role-playing games (for example, C-Learn, developed by Climate Interactive and the MIT Sloan School of Management; http://www.climateinteractive.org/tools/c-learn/) and management games for future scenarios (for example, Logicity, sponsored by British Gas, Logicom, and the National Energy Foundation; http://thepolarhub.org/resource/logicity) are the most common (Reckien and Eisenack 2013). Simulation and gaming also has a history in natural resource management, where simulated resources include water, land, crops, vegetation and wildlife and simulated users include landowners, farmers, ecologists, analysts, public officials, and private sector mangers (Barreteau and LePage 2007). The resource issues being simulated tend to be characterized as conflict-ridden owing to complex interactions between biophysical and social dynamics. The relationships presuppose that participants work constructively within antagonistic perspectives.

Similar to future scenario planning exercises, games and simulations highlight decision-making processes and social learning; they also effectively provide a bridge between many fields, including science and design. While there are no simulations that have been explicitly developed to assess novel ecologies, many of the games related to climate scenarios are learning tools about futures we have not yet experienced. They provide a safe space to actively learn about complex systems where uncertainty is high, to test assumptions, and to explore how systems are connected and respond to interventions (Barreteau and LePage 2007, Reckien and Eisenack 2013).

4. *Transforming uncertainties into scientifically driven and field-based research opportunities.* Other pedagogical approaches to address novel systems, issues of uncertainty, and multi-functional landscapes involve providing students with field-based research opportunities that address real-world issues (Fry 2001, Tress et al. 2001, Felson et al. 2013, Kondolf et al. 2013, Zeunert 2013). Fundamental questions about the persistence of landscape performance and the unknown longterm interactions between species under various environmental and climatic conditions can be translated into field-based research projects that appeal to design and ecology students. Research has well-established traditions in ecology (Ford 2000) and design programs (Selman 1998, Armstrong 1999, LaGro1999, Nassauer 2002); however, perceptions and approaches to research vary between the sciences and design fields. In landscape architecture education, research occurs before, during, and after design, and has been broadly classified as indirect (library research, consulting precedent studies) and direct (site inventory and analysis) (Milburn and Brown 2003). Among landscape architecture educators, research includes a range of activities, from casual observation to hypothesis-driven inquiry (Zube 1980). There is, however, an increasing emphasis on science-driven research that supports teaching an evidence-based approach to design (Deming and Swaffield 2011, Steiner et al. 2013).
In ecology classes with field labs, research includes experimental and quasi-experimental approaches with an emphasis on replicability and generalizability (Ford 2000). Currently, there are few opportunities for design students to participate in experimental research projects, and there are not many research oriented interdisciplinary courses that bring together design and ecology students. Below are three examples of courses that use research projects as a pedagogical strategy for studying novel systems (Table 2).
   a. *Experimental research design of urban tree mortality and recruitment.* Creating interdisciplinary classes in experimental research on novel landscapes is a powerful and pragmatic approach to

Table 2. Three courses that integrate research opportunities to investigate novel systems. Based on Felson et al. (2013), Hunter (2011) and Dooling (unpublished).

	Pedagogical approach to research	Project goals	Research questions	Interdisciplinarity	Scales and project duration	Outcome
Designed Experiments Felson et al. 2013 and 2014 Yale University course http://uedlab.yale.edu/teaching	Field-based ecological research about tree response to environmental stressors and management practices are integrated into design studio.	Assess tree performance in order to protect and improve ecosystem services. Focus on constructed native forests. Externally funded project that is part of municipal green infrastructure project (NYC Afforestation Project).	How do urban environmental stressors affect the health and survival of planted trees? How does tree health and survival respond to management and planting practices? Will planted trees recruit to form the urban forest of the future or will this constructed forest instead be overwhelmed by invasive species?	Studio course that involves ecologists and design students. Ecologists designed experiments in collaboration with park managers. Designers created an aesthetic and park design based on experimental plots.	Urban park scale Ongoing assessment	Park design that includes 56 experimental tree plots Analysis of tree response and performance
Ecology Theory-Driven Design Hunter 2011 University of Michigan course http://natureforcities.snre.umich.edu/streetside-gardens/easement-garden-designs/	Translational research connects scientific theory, concepts and principles to designing and planning the built environment.	Develop planting designs that are resilient to climate impacts on urban ecosystem services based on plant adaptation criteria. Focus on adaptation of species to changing environmental conditions.	What planting design can be developed based on aesthetic, cultural, and ecological criteria? How do planting designs compare temperature plasticity, functional redundancy, response diversity, and structural diversity?	Studio course for landscape architecture students that considers that aesthetics, cultural, and ecological criteria for planting designs	Urban easement	Plant database composed of plants coded for plasticity and adaptation Two illustrated planting design demonstrations based on database
Topics in Sustainable Development Dooling (unpublished) The University of Texas course http://sarahedooling.com/my-students/	Field-based research and spatial analysis are integrated into course on urban forests, climate effects, green infrastructure, and governance.	Identify urban forest tree species based on ecological and municipal managerial issues for the short- and long-term future. Explicit recognition of shifts in species distribution due to climate effects.	What tree species are considered both ecologically viable and managerially feasible for Austin's urban forest in the short- and long-term future?	Seminar course included landscape architecture, public policy, and environmental engineering students. Informed by approval of City of Austin Urban Forest Master Plan.	City of Austin—private and public properties.	Student written report of findings

educating future practitioners. Recent examples are Felson's classes involved in designed experiments, which is externally funded afforestation research that is part of a larger municipal green infrastructure effort (Felson et al. 2005, Felson et al. 2013; Table 2). Interdisciplinary teams of ecology and design students, working with municipal staff and other experts, are collecting field data in order to assess the impacts of environmental stressors and planting practices on urban tree mortality and the ability of planted species to recruit and resist being replaced by invasive species. Ecology students and experts created the experimental research design and design students created a park space that accommodated the experimental plots. Although Felson's research questions are not directly related to novel systems, they are based on longterm assessment of a constructed urban forest system's performance that is part of a larger green infrastructure network.

b. *Translational research design of ecologically informed planting designs.* Another strategy of incorporating research into teaching design students about novel systems is Hunter's (2011; Table 2) ecological theory-driven approach to planting decisions. Hunter described her research as translational, connecting scientific theories, concepts, and principles to designing a built space (Hunter and Hunter 2008). The research goal was to develop planting designs that protected various ecosystem services in the face of climate impacts based on an analysis of plant adaptation characteristics. Two illustrated planting designs were developed and compared based on temperature plasticity, functional redundancy, response, and structural diversity. The analytic research effort consisted of constructing a plant database where species were coded for plasticity (how well species perform across a range of environmental conditions) and adaptation. Comparative analyses raised interesting issues. First, longterm monitoring is important as environmental conditions will continue to change, and the ability of plants to persist is not a given. Post-occupancy evaluations, a common research method in the design fields, could be conducted by successive classes once the designs are constructed. Second, global circulation models of climate projections have limited applicability when operating at finer geographic scales. Hunter instead used plant overwinter hardiness data and maps as a starting point for selecting adaptive plants. The struggles with imprecise climate change projections, uncertainty, and developing an informed planting strategy within the context of novel systems seemed difficult to navigate. However, Hunter's systematic approach to coding plant characteristics, her comparative analysis approach, and her recognition of long-term monitoring and post-occupancy evaluation offer pedagogical strategies for future efforts.

c. *Case study analysis of ecological viability and managerial feasibility of tree species in urban forests.* The third example of teaching about novel systems through research comes from my own class that asked: what constitutes an ecologically viable and managerially feasible collection of species in a city that is predicted to be hotter and drier? The chronic drought throughout the state of Texas and the approval of the City of Austin's Urban Forest Master Plan provided the context for developing the research effort. The class was composed of landscape architecture, public policy, and environmental engineering students that were organized into research working groups. Each group conducted their own analysis, which included interviewing managers, ecologists, and designers, change detection of tree canopy cover using ARC-GIS, and media analysis of local and regional coverage of drought and urban forests. The class employed a case study design that integrated multiple methods. Climate modelers, municipal urban foresters, ecosystem services quantification experts, and fire managers were brought in discuss the implications of their research for urban forests in the short and long-term future. The final class report, coauthored by the students and shared with City of Austin staff, recommended tree species for planting and modification of urban forest management goals. The research goals of future classes include collaborating with city partners to establish experimental plots to assess tree mortality as a function of environmental stressors and planting strategies (borrowing from Felson et al. 2013), developing a tree species database replicating Hunter's method (2011), and updating cover files for continued change detection of canopy cover.

These examples, although a small representation of pedagogical strategies for integrating research as a pedagogical strategy, offer three distinct approaches. Felson's class collected ecological data in the field, while my class collected social data in the field. Felson and Hunter have produced physical designs for smaller spatial scales, while my class has produced change detection maps at the city scale. The research effort in Felson's and my courses are intended to be longterm efforts, and are tied to existing municipal plans. Linking course-based research to existing municipal plans provides a real-world client and this relationship can be leveraged to secure external funding (which Felson did, and I hope to do). Hunter's course is the one disciplinary course (for design students). Interdisciplinarity has long been acknowledged as beneficial for educating and training students in fields where multi-disciplinary professional teams are common (Thering and Chanse 2011) and where the emphasis is on landscape, which serves as a uniting theme, and multifunctionality (Tress et al. 2001), which is one characteristic of novel systems.

5. *Political and ethical implications of novel landscapes.* Ecological change is never socially neutral (Harvey 1996). The spatial heterogeneity of landscape patches, especially in urban and urbanizing areas, lead to a corresponding unevenness in how landscapes perform and the distribution of ecosystem services (Heynen et al. 2006, Egoh et al. 2008). Given the large degree of uncertainty associated with the magnitude of climate change impacts on landscape composition and function, novel systems are inherently difficult to engage, not just ecologically, but ethically and politically. If one goal is to intervene responsibly in rapidly changing landscapes, then understanding the political and ethical implications of ecological dynamics in the context of uncertainty is critical for educating future practitioners. The larger political and ethical contexts are important for assessing and understanding how researching, designing, and regulating novel systems might replicate or ameliorate existing inequities, generate new risks or vulnerabilities, or mitigate current risks and vulnerabilities. The emergence of novel systems provokes questions about what will happen, and who will be impacted, if one landscape function (e.g., carbon sequestration) is prioritized over another (e.g., water conservation). It is important to ask questions about what political and participatory processes might be effective for deciding about and designing future function of public landscapes. Light's civic environmentalism framework offers one way of valuing public participation in restoration projects (Light 2003).

   There is a large body of literature on the ethical implications of restoring nature (Elliot 1997, Higgs 1997, Katz 1991, Gobster and Hull 2000, Thompson and Jackson 2013), and educators could draw from these works to inform comparative assessments of alternative future scenarios based on different ethical frameworks (i.e., utilitarian, pragmatism, intrinsic, etc.). Including readings that analyze the political-economic connections between who manages landscapes and how they are managed, and the ramifications for health, poverty, and housing (Robbins and Sharp 2003, Perkins et al. 2004, Park and Pellow 2011) can broaden the discussion by linking social policies to landscape performance. In my class, we discussed the policy and ecological drivers of significant differences in canopy cover patterns on public lands in East (less cover) versus West (more cover) Austin, and the implications this pattern has for expanding urban forests. Such conversations are not typical in ecology classes, and are not frequent in design studios. Given the persistence of urban renewal legacies, however, environmental justice implications for politically marginalized people must be examined.

   It is also increasingly important to understand the economic ramifications of newly designed landscapes, novel and otherwise, especially for residents in low-income areas that are ripe for reinvestment. 'Just green enough' describes an emerging attitude among environmental justice groups that associate greening-up of their neighborhood as leading directly to increased rents, displacement, an influx of wealthier households, and more expensive goods and services (Curran and Hamilton 2012, Wolch et al. 2014). Ecological gentrification is one way of describing the larger-scaled economic impacts of environmental planning and ecological restoration efforts on people with the fewest resources to respond to rapidly transforming places (Dooling 2009).

   Ecology and design students will benefit from discussions and deliberations over what is considered just, fair, and ethical. As facilitators of these discussions, educators will benefit from incorporating readings (some suggested above) and insights from colleagues—including environmental ethicists, environmental justice advocates—in the context of creating future scenarios, playing games, or working through data analyses. Discussions about what and how to value novel landscapes will become increasingly salient as students develop their own framework of responsible professional practice in rapidly changing environments under high levels of uncertainty.

Conclusions

Ensuring the relevance of education in training future practitioners—both designers and ecologists—for restoration work in rapidly transforming environments that renders the replication of historical communities problematic, if not inadvisable, will require significant yet feasible pedagogical changes. These changes include making uncertainty central to the learning experience through developing future scenarios, quantification and visualization technologies, and gaming exercises; providing research opportunities for students through collaborations with municipalities and other experts, including natural and social scientists; and facilitating deliberations with ethicists, designers, and scientists about the political and ethical dimensions of intervening in hybrid and novel systems. Educators will have to reach out and move beyond conventional areas of expertise to translate uncertainty about the future into rigorous and feasible researchable questions.

Embracing the idea and ecological reality of novel landscapes is ultimately about educators and students taking seriously the power and scope of an interdisciplinary approach to creating desired futures under conditions of uncertainty and unprecedented rates of ecological change (Thompson and Jackson 2013). Novel landscapes, as a focus in design studios and ecology courses, can be a bridging concept through which projects, scenario planning, visualization technologies, and games can synthesize research traditions, ethics, histories of inequities, and landscape function. The pedagogical recommendations and examples outlined here may contribute to more robust and interdisciplinary scholarship about design and management of novel systems. They can facilitate a more politically astute and ethically sensitive understanding of landscape interventions for vulnerable places and populations. Educators and future practitioners can be better prepared to work effectively under conditions of uncertainty. If novel landscapes are expected to become the new normal, then the ideas presented here could initiate discussions for ensuring the relevance, rigor, and creativity of education in a rapidly transforming world where the past is becoming a more tenuous link to the future and the future is dependent upon well-educated researchers and designers.

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