Technology as a Driver of Future Change in the Forest Sector: Projected Roles for Disruptive and Emergent Technologies

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Abstract: This paper examines emergent and disruptive technologies as potential drivers of change in forest sector futures. Two questions are addressed: (1) Which emergent and disruptive technologies can be projected to substantively impact forestry futures? (2) What are the possible implications of emergent and disruptive technologies for decision makers, policymakers, and other stakeholders involved in forest sector futures? A 20-year timeframe is used for this explorative paper. A cross-disciplinary review of futures literature was implemented to identify and investigate leading emergent and disruptive technologies. A list of candidate technologies was developed from the literature review and eight technologies were selected: artificial intelligence, autonomous vehicles, electronic performance enhancement systems, genomics and synthetic biology, the Internet of Things, materials science, nanotechnology, and robotics. Each of the eight technologies was then defined and three representative forecasts were projected for each technology.

The goal is to provide decision makers, policymakers, and other stakeholders in the forest sector with an awareness of emergent and potentially disruptive technologies and how they might disrupt forest sector futures. The purpose of this paper is not to predict the future in detail, but to (1) promote awareness and informed thinking about the relationship between potentially disruptive technologies and forest sector futures and (2) stimulate a research agenda based on the study of these projected futures.

KEY WORDS: emergent technology, disruptive technology, artificial intelligence, autonomous vehicles, electronic performance enhancement systems, genomics and synthetic biology, Internet of Things, materials science, nanotechnology and robotics

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Introduction

The future is uncertain and it is not known how emergent and disruptive technologies will impact the future of the forest sector. What is known is that disruptive and emergent technologies are both volatile and unpredictable (Kaku 2011). Their potential impacts are largely unforeseen and frequently upset established norms of order by challenging traditionally accepted ideas, models and practices, and perceptions of what is possible in the future. Fortunately, foresight provides tools for anticipating many of these technologies and exploring their potential impacts.

There are several categories of technologies: disruptive, emergent, sustaining, and convergent. Disruptive technologies are new or enhanced technologies that rapidly and unexpectedly overturn established assumptions, models, and practices and radically redefine the competitive landscape in terms of unanticipated products or services. Disruptive technologies often supplant existing technologies and quickly render them obsolete (Armstrong 2017, Christensen 2016). Emergent technologies are new technologies that exhibit relatively fast growth, persistence, and the potential for substantial but uncertain impacts in the future (Rotolo et al. 2015). Emergent technologies are often unexpected. However, not all emergent technologies produce major disruption. Sustaining technologies are technologies that improve an existing product or service (Christensen and Raynor 2003). Finally, technological convergence is the synergistic combination of two or more different technologies in a single device or system (Roco and Bainbridge 2003). Technological convergence creates (1) artifacts or systems with new or improved features or applications and (2) a combined effect greater than the sum of individual technologies acting alone.

The emergence of new technologies encourages the development of innovative forest sector strategies. New technologies foster innovation by (1) expanding the range of opportunities and choices available to decision makers, policymakers, and stakeholders and (2) instigating the creative destruction of existing norms and modes of business. Because emergent and disruptive technologies are moving targets, they continuously surprise and challenge leaders and stakeholders through their sudden appearance and accelerated rates of adoption. They frequently develop in a nonlinear fashion that precludes prediction or detailed projections (Kurzweil 1999, 2005, 2006).

Surprise and disorientation often occur when legacy strategies fail to keep pace with emergent and disruptive technologies. This is especially true when the technologies are evolving at internet speed. It is within this rapid change framework that forest sector leaders and policymakers are constantly challenged to develop well-informed and continuously updated views of technology futures. This is not an easy task and leaders must be ready to experiment, invest, and disrupt their organizations (Christensen and Raynor 2003).

It is not the intention of this paper to predict which technologies will become the most disruptive or to determine the exact scope and consequences of their impacts. Rather, the goal is to provide decision makers, policymakers, and other stakeholders in the forest sector with an informed awareness of the importance of emergent technologies and their potential for future disruption.

Purpose

The purpose of this paper is threefold: (1) identify emergent and potentially disruptive technologies that are likely to exert significant impacts on forest sector futures, (2) examine a range of plausible consequences that can be attributed to these technologies, and (3) encourage informed thinking about alternative forest sector futures. The information developed through these questions will provide valuable information and insight for decision makers, policymakers, and others involved in influencing the future of the forest sector. It is also anticipated that the outcomes presented in this paper will produce new ways of thinking about forest sector strategies and generate further research into forestry futures.

Importance

Disruptive and emergent technologies are important because they redefine what is possible, probable, plausible, and preferable in the future of forestry. Importantly, they accomplish this while retaining human choice in the determination of alternative futures. The premise of this paper is the basic assumption that decision makers and policymakers can benefit from an improved knowledge of projected futures and the options presented by emergent and disruptive technologies.

Approach

A cross-disciplinary literature review was conducted to identify and investigate emergent and disruptive technologies. Eight leading technologies were selected based on their prevalence in the literature and their potential to redefine or disrupt forest sector futures.

A 20-year timeframe was established to evaluate future impact potentials. This framework was used for two reasons: (1) a 20-year projection was determined to be sufficiently advanced in time to preclude many of the biases exerted by current assumptions and existing trends and (2) two decades was sufficiently near in time that the current literature base provided a credible basis for identifying emergent and disruptive technologies and projecting their possible impacts. A time horizon greater than 20 years was determined to be too far-reaching due to the increased probability of radical technical change and other unforeseeable developments (Makridakis 1990). Millett (2006) has noted that while extended timeframes stimulate creativity and improve strategy development, overly prolonged timeframes may produce a loss of relevance for decision making in the present.

Books, periodicals, and journal articles that address emergent and potentially disruptive technologies were reviewed. Futures literature was emphasized in the review. The literature survey identified 15 candidate technologies that were evaluated for their prevalence in the literature and their potential for future emergent and disruptive impacts in the forest sector within the specified 20-year framework. The candidate technologies were artificial intelligence, autonomous vehicles, big data, computers, electronic performance enhancement systems, energy generation and storage, genomics and synthetic biology, the internet, the Internet of Things, materials science, nanotechnology, networks and connectivity, robotics, 3D printing, and virtual reality (VR) and augmented reality (AR). Although numerous other technologies were reviewed during the development of this paper, they did not appear to represent the same potential for major disruption in the forest sector within the 20-year framework. More extensive studies are needed to explore those alternatives.

Eight technologies were then selected for further study. The selected technologies were artificial intelligence, autonomous vehicles, electronic performance enhancement systems, genomics and synthetic biology, the Internet of Things, materials science, nanotechnology, and robotics. They were listed in alphabetical order and were not ranked by probability of occurrence, preferability, or impact potential. Their selection for inclusion in this paper was based primarily on their prevalence in the literature examined and their assessed potential as emergent and disruptive technologies within the 20-year forecasting timeframe. Each technology was defined and three representative forecasts were projected for each technology.

Current Trends and Impacts

There is an explosion of technological invention, innovation, and dissemination (Amidon 1997, 2003). Thus, the rate at which emergent and disruptive technologies occur is increasing and the rate of their development, diffusion, and adoption is accelerating. The traditional interactions among invention, innovation, and application are rapidly collapsing (Kelly 2010).

This rapid technology development and implementation cycle precludes the ability to predict the future of disruptive technologies and the ways in which they will be applied in any detail (Martino 1978). It also renders it increasingly difficult to project the links between extravagant claims and realistic potential. In this milieu there are numerous, and often unforeseen, cultural, economic, structural, and institutional barriers to the adoption of technology and varying lag times between their introduction and adoption (Rogers 1983).

Potentially Disruptive Technologies

This paper identifies eight technologies that exhibit the potential to substantively disrupt the forest sector. The eight technologies are defined, and their potential future impacts are identified. The projected timing of their introduction and their future diffusion rates are not addressed.

Artificial Intelligence

Definition

Artificial intelligence includes computer software systems that mimic or characterize cognitive functions that are commonly associated with human decision making, learning, problem solving, or general reasoning (Russell and Norvig 2016). Artificial intelligence is a general-purpose technology that drives an increasing number of smart, or intelligent, technologies using neural networks, expert systems, and smart agents (Denning and Metcalfe 1997).

Potential Future Impacts

- Expert avatar foresters and administrators-on-a-chip; artificial personas that convivially interface with stakeholders
- Machine learning for tapping big data to develop and analyze complex forest sector planning and projections including real-time climate projections, fire modeling, and forest condition
- Design and conduct of forest research by machine intelligence; real-time automatic language translation for global forest sector stakeholders

Autonomous Vehicles

Definition

Autonomous vehicles are computer-enhanced mobile systems that operate with limited or no human intervention in a wide range of environments and conditions using computer intelligence, sensors and actuators, and automated navigation systems (Gonzalez-Aguilera and Rodriguez-Gonzalvez 2017, Singer 2009). Autonomous vehicles employ artificial intelligence to independently operate in a wide variety of environments (air, water, on or beneath ground surfaces) at a variety of scales (macro, meso, micro, and nano levels) (López et al. 2017).

Potential Future Impacts

- Autonomous aerial, aquatic, and terrestrial vehicles for inventorying, monitoring, harvesting, and treating forest resources
- Autonomous aerial, water, and ground transport service for employees and visitors, transportation of law enforcement and emergency firefighting personnel and equipment, and rescue and evacuation
- Autonomous micro- and nano-sized drones that support multifaceted forest sector functions

Electronic Performance Enhancement Systems

Definition

Electronic performance enhancement systems (EPES) are a class of rapidly evolving computer software systems designed to enhance human ability to learn and perform work (Gery 1991, Rosenberg 2001). According to Winslow and Bramer (1994) and Bastiaens and others (1997), EPES promote real-time learning at points of performance and allow new workers to perform as world-class experts. They are networked and continuously updated systems that employ embedded smart or intelligent components that act together wherever and whenever needed to inform, guide, or assist in real-time learning and performance experiences (Dickelman 2000, Gery 1991).

Potential Future Impacts

- Multidisciplinary forest, administrative, and legal expert systems that provide the latest, leading-edge technical advice and assistance
- Performance enhancement systems that enable volunteers to perform as forest or administrative experts (across all disciplines and work assignments)
- Expert knowledge representation and reasoning systems that assist researchers

Genomics and Synthetic Biology

Definition

Genomics is the modification of the genes or genetic material (genomes) of organisms using one or more biotechnologies. Its purpose is to create new traits or capabilities in organisms (Lesk 2012). Synthetic biology involves the interaction of biology and engineering to design and construct, or redesign, new biological parts, devices, or systems; its purpose is to create new biosystems or new biosystem properties (or both) (Church and Regis 2012).

Potential Future Impacts

- Forest energy farms capable of generating power using genetically engineered foliage for solar energy biocollectors; genetically engineered forests that employ artificial photosynthesis to capture and store the energy of sunlight in chemical form for use in fuel cells
- Biological systems reprogrammed genetically for different properties (e.g., existing tree species genetically engineered for rapid growth, premium wood stock, drought and insect resistance, or climate change accommodation; trees designed for optimized carbon sequestration, fuel generation, or pharmaceutical production (Kaku 2011)
- Revival of extinct flora and fauna and creation of entirely new species

Internet of Things

Definition

The Internet of Things includes networked objects and environments that contain embedded electronics, computer software, sensors, actuators, and data communication technologies (Greengard 2015, Rose 2014). The Internet of Things is built into objects and environments to form connected, and increasingly self-adapting, systems that learn and modify their behaviors. They are projected to operate across a variety of scales (from macro-level to nano-level devices submolecular in size), operate in increasing densities, and function with increasing degrees of autonomy. The technology corporation Cisco has estimated that Internet of Things devices reached 20 billion in 2015 and will double to 50 billion connected devices by 2020 (Bates 2015). Constellation Research estimates that the Internet of Things will consist of over 80 billion sensors by 2020 (Bates 2015).

Potential Future Impacts

- Real-time inventorying of forest resources using organisms genetically engineered with smart bio-barcodes (operating at nano levels and equipped with networked active transmitters); continuous networked micro- or nano-level sensor monitoring of all protected organisms, sites, restricted areas, and sensitive zones
- Smart delivery of targeted microdrip fertilizer and pesticide applications
- Continuous (24 hours a day, 7 days a week) intelligent forest fire detection and suppression systems, building automation and energy management, predictive maintenance, and visitor scheduling and routing

Materials Science

Definition

Materials science addresses the design and production of new materials that exhibit unique physical properties and structures (Ball 1997). Materials science enables the creation of products with new or greatly improved properties (e.g., nano cellulose-based foam fire suppressants, load-bearing construction glass, ultralight and ultrastrong building materials, frictionless bearings, self-cleaning coatings, and programmable matter).

Potential Future Impacts

- Polymorphic infrastructure materials such as variable opacity smart glass that is stronger than steel, rust-proof, self-cleaning, and energy generating (e.g., no more graffiti or corrosion)
- Macroexpanding, environmentally friendly, nano cellulose fire-retardant aerogels that can be seeded by aircraft and computer controlled to degrade as soil nutrients
- Programmable matter that produces metamaterial-based invisibility cloaks for use by field researchers and visitors

Nanotechnology

Definition

Nanotechnology is based on the manipulation of matter at the molecular, submolecular, and atomic level (i.e., approximately 1 to 100 nanometers in at least one dimension) (Drexler 1986). Nanotechnology uses molecular disassemblers and assemblers to create new devices and materials involved in carbon nanotubes, nano medicine, nano solar cells, new building materials with extreme properties, and nano-scale machines (including nanocomputers and nanorobotics capable of self-repair and, in some instances, self-reproduction) (Drexler 2013, Drexler et al. 1991, Mulhall 2002).

Potential Future Impacts

- Nanoremediation of contaminated sites (e.g., remediation of contaminated soil and water on localized farm or industrial sites, large-scale pollution spills, and expansive super-sites) through nano conversion and nano filtration of toxic materials into valuable commodities
- Engineered nanoparticles that act as nano carriers to deliver ultra-low volumes of chemicals, herbicides, or genes to targeted plants or animals
- Real-time monitoring and analysis of entire biomes from submolecular levels to global systems using self-reproducing, self-repairing, nano-level biosensor networks and pocket-scale supercomputers (Petersen 1994)

Robotics

Definition

Robots are machines with computer systems that commonly employ mechanical body structures with sensors, appendages that can be manipulated (actuators), locomotive or moving subsystems (or both), electronic controls, and one or more power sources and software instruction systems (Bekey 2005, Singer 2009). They may be autonomous (e.g., using artificial intelligence or swarming systems), remotely controlled, or a combination. Robots are commonly used for a wide range of applications such as agriculture, domestic services, food service, health care, manufacturing, medical care (including surgery), and law enforcement applications (Kurzweil 2005, Miller 2010). Future robots will operate at an increasing range of scales (e.g., nanorobots operating at submolecular levels and megaconstruction robots operating at massive scales) and in a variety of environments (e.g., airborne, marine, terrestrial, and subterrestrial [Singer 2009]).

Potential Future Impacts

- Self-reconfiguring mobile modular robots conducting a wide range of physical labor in the forest sector (e.g., timber inventory, treatment, pruning, thinning, and removal) with minimal environmental intrusion
- On-demand robo-fire fighters and robo-emergency responders; animatronic robots for visitor assistance; robo-law enforcement agents; and robots for construction and infrastructure maintenance
- Nano- and micro-level robots operating sub-surface for soil aeration or amendment; aquatic robots for water quality sampling and treatment; and airborne robots for surveillance, inventorying, or cloud seeding

What is the value of this exercise? The value lies in promoting an awareness of the future, the opportunities that it presents, and the need to prepare for future unknowns (Johansen 2007). Each of the technologies presented in this paper represents the potential to produce sudden and largely unforeseen changes in forestry. It is an exercise that invites anticipatory governance, the capacity to manage emerging technologies in advance (Guston 2014).

Implications for Forestry and the Forest Sector

Over the next 20 years people will witness changes in the forest sector on an unprecedented scale. Emergent and disruptive technologies will continue to be among the major drivers of those changes and will continue to surprise, disorient, and misdirect (Johansen 2012, Schwartz 2003). However, while surprise may be inevitable, the element of surprise does not undermine the value of preparation (Lombardo 2006).

The literature of technology forecasting documents the value of how forward-looking, anticipatory stances can enhance decision making, policy formulation, and stakeholder understanding of future alternatives (Amstéus 2011, Lustig 2015). It confirms how well-conducted futures studies, using established methodologies, can (1) promote the development of robust and resilient options for the future and (2) identify scenarios that permit the exploration of potential primary, secondary, and tertiary impacts (Bell 1997, Hines and Bishop 2006, Ringland 1998). A major goal of this paper is to identify a range of emergent and disruptive technologies that might serve as valuable candidates for future forest-related horizon scanning efforts.

Conclusions

This paper addresses emergent and disruptive technologies that have the potential to change the game for forest leadership, forest policymakers, and forest sector stakeholders. It is probable that these technologies will create entirely new ranges of forest products, services, and capabilities in the future. It is equally probable that they will also create a spectrum of legal, social, and regulatory challenges that have not existed before. The challenge for forest sector decision makers , policy formulators, and stakeholders today is to develop an awareness of (1) future technological possibilities, (2) how future game-changing technologies have the potential for disruption, and (3) how to turn future disruptive technologies into opportunities. The challenge is awesome!

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