LiDAR: providing structure

Since the days of MacArthur, three-dimensional (3-D) structural information on the environment has fundamentally transformed scientific understanding of ecological phenomena (MacArthur and MacArthur 1961). Early data on ecosystem structure were painstakingly laborious to collect. However, as reviewed and reported in recent volumes of *Frontiers* (eg Vierling *et al.* 2008; Asner *et al.* 2011), advances in light detection and ranging (LiDAR) remote-sensing technology provide quantitative and repeatable measurements of 3-D ecosystem structure that enable novel ecological insights at scales ranging from the plot, to the landscape, to the globe. Indeed, annual publication of studies using LiDAR to interpret ecological phenomena increased 17-fold during the past decade, with over 180 new studies appearing in 2010 (ISI Web of Science search conducted on 23 Mar 2011: [{lidar AND ecol*} OR {lidar AND fores*} OR {lidar AND plant*}]).

The storehouse of LiDAR data available for ecological analysis was slated for a tremendous boost later this decade, with the planned NASA launch of the DESDynI (Deformation, Ecosystem Structure, and Dynamics of Ice) global satellite mission. However, this plan was dashed in late February 2011, when the DESDynI mission was cancelled amidst the uncertain budget environment in the US (Platnick 2011). While this news is a major disappointment to the ecological community, we argue that a wealth of LiDAR data exists and continues to be collected, with which scientists can continue to develop new applications and test fundamental ecological hypotheses.

We are often asked by fellow ecologists how to find or procure LiDAR data at specific field sites within the US and abroad. In addition to a growing number of commercial LiDAR data providers available for hire, numerous government-sponsored LiDAR collection programs have already taken place. Statewide collections often involve a large and diverse cross-section of state and private stakeholders, and data are often freely available either upon request or via placement in the public domain. US federal airborne LiDAR data collection has begun in earnest, with priority collection occurring in riparian and coastal zones, and concepts for a LiDAR-based National Enhanced Elevation Dataset are being developed in the near term that will not only characterize ground elevation but also retain vegetation structural data for analysis (Stoker *et al.* 2008). Other ecologically relevant LiDAR resources include the NASA spaceborne ICESat Geoscience Laser Altimeter System (GLAS; http://glas.gsfc.nasa.gov) and airborne Laser Vegetation Imaging Sensor (https://lvis.gsfc.nasa.gov), academia-led initiatives such as the National Center for Airborne Laser Mapping (www.ncalm.cive.uh.edu) and Carnegie Airborne Observatory (http://cao.stanford.edu), and the forthcoming NEON Airborne Observation Platforms (www.neoninc.org/science/aop). Ground-based LiDAR instrumentation and collection support are available from programs such as UNAVCO (www.unavco.org). Coordination, standardization, archiving of, and access to these datasets are of utmost importance; substantial progress is being made in this area through efforts such as the Open Topography initiative (www.opentopography.org) and USGS Center for LiDAR Information Coordination and Knowledge (http://lidar.cr.usgs.gov).

Progress toward collection of geographically extensive datasets outside of the US is also occurring. Importantly, the second-generation NASA ICESat2 orbiting platform is still planned for launch in 2016 (http://icesat.gsfc.nasa.gov/icesat2), with specifications appropriate to complement global-scale characterization of vegetation structure using first-generation GLAS data (Lefsky 2010). Moreover, many countries are procuring LiDAR data for numerous applications, ranging from geohydrological planning, to biodiversity conservation, to climate-change mitigation.

While vigilance among the scientific community is critical to ensure that LiDAR-based ecosystem structural data will continue to be collected and made available from both airborne and space-based vantage points, we remain optimistic that the transformative information provided by LiDAR technologies will foster considerable ecological work in this era of financial restrictions. Long-term, global-scale observations – such as those to have been provided by the DESDynI mission – will continue to be important to systematically scale local and regional measurements dynamically through time. However, the diversity of current and planned LiDAR data resources, coupled with continued creative and interdisciplinary collaboration among scientists, bode well for fueling further discovery in linking ecological structure with ecological function for decades to come.

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Maintaining multifunctionality as landscapes provide ecosystem services

In the October issue (*Front Ecol Environ* 2010; **8[8]**: 409–13), Fissore *et al.* indicated that prairie restoration and afforestation on previous cropland in the Upper Midwest of the US would not reduce carbon dioxide (CO_2) emissions significantly without large reductions in the amount of harvested cropland. Fissore *et al.*'s findings highlight an important aspect of landscape redesign. Multifunctional landscapes should not be designed to maximize one ecosystem good or service but to optimize the production and provisioning of multiple goods and services. Just as current agricultural systems emphasize crop productivity at the expense of many ecosystem services (Robertson and Swinton 2005), focusing exclusively on carbon storage – rather than on a suite of ecosystem goods and services – is likely to have unintended negative side effects.

Fissore *et al.* found that 29% of CO_2 emissions from the Upper Midwest could be offset by converting 40% of the harvested cropland in that area to prairie or forest, but less than 5% of the CO_2 emissions could be offset if only 10% of the harvested cropland were converted to prairie or forest. We agree with the authors' conclusions that removing 40% of the cropland area in the Upper Midwest from production is not feasible. Converting 10% of the harvested acres of cropland into prairie or forest, on the other hand, may be achievable, particularly if policies are enacted to encourage removing environmentally sensitive land from production.

Although converting just 10% of the current cropland to native vegetation will have only a small impact on offsetting CO_2 emissions, a multitude of other ecosystem goods and services could be provided by such land-use changes, including improved water quality and increased biodiversity. Converting 5% of an annual row crop dominated landscape to switchgrass riparian buffers reduced sediment loss into adjacent streams by 78%, total nitrogen loss by 51%, and total phosphorus loss by 55% (Lee *et al.* 1999). Converting 10% of watersheds from annual row crop production to prairie vegetation reduced sediment losses from the watersheds by 95% and increased native plant species richness by more than 400% (Liebman *et al.* 2011). Animal diversity, including both insects and vertebrate wildlife, has been found to be positively correlated with increasing grassland plant diversity (Fargione *et al.* 2009). Native vegetation, such as that associated with prairies and forests, can also produce multiple ecosystem goods, such as biomass for biofuel production or electricity generation (Fargione *et al.* 2009).

If native vegetation is reincorporated into agricultural landscapes strategically, disproportionate benefits in ecosystem services relative to the area of land-use change can be realized as a result of the non-linearity in response of many ecosystem processes to land-use change (Liebman *et al.* 2011). As awareness about the importance of obtaining both ecosystem goods and services from agricultural landscapes increases, a focus on landscape multifunctionality – rather than single ecosystem service maximization – becomes increasingly necessary.

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A reply to Jarchow and Liebman

In their comment on our article (*Front Ecol Environ* 2010; **8[8]**: 409–13), Jarchow and Liebman (hereafter J&L) address the need to manage the land and its resources in a more holistic way, emphasizing the provision of multiple ecosystem goods and services. We welcome their expanded perspective and share their view of the importance of maintaining landscape multifunctionality. As J&L point out, several co-benefits (eg erosion control, increased biodiversity), in addition to carbon (C) sequestration potential, can be achieved by adopting best management practices and therefore should be included and emphasized in environmental plans and policies. However, our decision to focus solely on terrestrial C sequestration potential associated with land-use change originated from concern about the growing number of proposed or adopted plans and policies that rely heavily – and erroneously – on terrestrial ecosystems to offset unrealistically high proportions of current carbon dioxide emissions from fossil-fuel combustion. In our case, ignoring the value of co-benefits was necessary to not divert the readers' attention from this pressing issue.

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Inadequate enforcement of the Endangered Species Act

Several military bases in the southern US manage large areas of naturally regenerated pine forest that support numerous federally listed threatened and endangered species. One endangered species of particular concern is the red-cockaded woodpecker (RCW; *Picoides borealis*). Because the pine forests in which these birds reside are federally owned lands (Figure 1), RCW management falls under those provisions of the Endangered Species Act (ESA) that require federal agencies to protect listed species and also to restore their numbers and their habitat. In this case, the agency responsible for assuring compliance with the ESA is the US Fish and Wildlife Service (FWS). Below we offer three examples of RCW management efforts on military lands – two (at Fort Bragg, North Carolina, and Eglin Air Force Base, Florida) in which the Department of Defense (DoD) should be commended for its environmental stewardship, and one (at Fort Benning, Georgia) in which we think that both the FWS and the DoD have made serious mistakes. We are concerned that this last example could be used as a precedent for future policy decisions.

According to the official 2003 recovery plan for the RCW (www.fws.gov/rcwrecovery/recovery_plan.html), one criterion for recovery is that 11 of 13 primary core populations on federal lands have reached a stable population estimated to contain at least 350 potentially breeding pairs. Of these 11 core populations, one – located within Florida's Apalachicola National Forest – has had 350 breeding pairs for several decades. Two of the remaining core populations, one at Fort Bragg and another at Eglin Air Force Base, have reached their recovery goals.

However, the Fort Benning RCW population – the sixth largest range-wide – occurs where an immense new program of construction and training, called the Maneuver Center of Excellence (MCOE), is underway. According to the Army's Biological Assessment, the MCOE program is expected to "take" (a legal term for destroy), directly and indirectly, more than 3200 hectares of current woodpecker habitat.

In May 2009, the FWS published a Biological Opinion stating that the scope and intensity of the MCOE program would "jeopardize" (a legal term for put at risk) the base's RCW population, in violation of the ESA. The Opinion concluded that, by jeopardizing the RCW population at Fort Benning, the MCOE would also jeopardize the recovery of the species as a whole.

The Biological Opinion was a strong statement by the FWS about the threat posed by the MCOE to an endangered species and its habitat, but the settlement negotiated between the FWS and the US Army did not substantially reduce the likelihood or severity of this threat. Destruction of a few RCW territories was avoided, and some previously inaccessible areas were opened to monitoring and management. Nevertheless, severe impacts to RCWs (including habitat destruction) were still to be permitted to 97 of about 300 potential breeding groups. Although the FWS stated that its settlement was sufficient to preclude jeopardizing the species, we think this conclusion has little scientific justification. Indeed,

US Army/Fort Bragg Public Affairs

Figure 1. *Red-cockaded woodpecker sign posted at Fort Bragg, North Carolina.*

the FWS admitted that the negotiated changes would hardly affect the delays in population recovery attributed to MCOE. In August 2009, the Army issued a record of decision, also admitting that recovery of the woodpecker would be delayed, but nevertheless indicated its intent to implement the proposed action.

At Fort Benning, the Army is engaged in a major violation of the ESA, and the FWS has failed in its oversight and supervisory role. The initial problem was caused by the US Congress, which mandated that a major military training program be moved from Fort Knox, Kentucky, to Fort Benning, presumably as a cost-saving measure but without any regard for its environmental impact. At present, it is too soon to tell what the full effect will be. The positive conservation record of the DoD at some installations is marred by this violation of the ESA, and the FWS should not have been intimidated regarding enforcement. The loser here is not just the RCW but also the southern pine forest ecosystem and the rare plants and animals that depend on it.

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