Chapter 12.—Discussion on Remote Sensing for Aquatic Monitoring

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Introduction

The special session on Remote Sensing for Aquatic Resource Monitoring concluded with an expert panel discussion. Panel members were Jennifer Bountry (hydraulic engineer, Bureau of Reclamation), Mimi D'Iorio (GIS analyst and database manager, National Oceanic and Atmospheric Administration), Russ Faux (president, Watershed Sciences, Inc.), Steve Lanigan (team leader, Aquatic and Riparian Effectiveness Monitoring Program, U.S. Forest Service), and Amar Nayegandhi (computer scientist, Jacobs Technology, contracted to U.S. Geological Survey). The panel was moderated by Ralph Haugerud (geologist, U.S. Geological Survey) and there were significant contributions from the audience. The dialogue is summarized below in question and answer format. This summary is followed by discussion of what we learned in the course of the special session and identification of some next steps for the Pacific Northwest aquatic monitoring community.

A Note on LiDAR Technology

Presentations in the special session, the panel discussion, and papers in this volume addressed three types of airborne LiDAR (LIght Detection And Ranging) instrument: discrete-return IR LiDAR, high-energy, full-waveform green LiDAR, and EAARL. Essential aspects and differences between these various LiDAR are summarized here, as some readers may not be familiar with them.

Discrete-return infrared (IR) LiDAR instruments use a laser that operates at 1,064 nm wavelength (near infrared), pulses at rates of 10 to 150 kHz, and records the returned signal as one or more discrete returns. These returns are simplifications of a continuous waveform into constituent peaks that correspond (ideally) to reflections from discrete surfaces in the target area. On-ground laser beam diameter typically is on the order of 15 cm. Pulse densities (the basic measure of data quantity and the limiting factor for XY resolution) commonly are in the range of 1–12/m^2 (0.3–1 m spot spacing). Flying height commonly is 800 m or greater. There are many discrete-return IR LiDAR instruments in commercial operation. Surveys by such instruments can be contracted with relative ease. Airborne1, Sanborn, Terrapoint, Watershed Sciences, and many other firms provide discrete-return IR LiDAR surveys. The CLICK (Center for LiDAR Information Coordination and Knowledge) website (http://lidar.cr.usgs.gov) provides a useful entry to the world of IR LiDAR. Swoboda and et al. (2009, chapter 7, this volume), Faux and et al. (2009, chapter 6, this volume), and Hilldale and et al. (2009, chapter 4, this volume) discuss data obtained with discrete-return IR LiDAR. Infrared light does not penetrate water and therefore these instruments can not survey beneath the water surface.

A handful of high-energy, full waveform, green LiDAR instruments are in operation, used primarily for navigational charting in shallow water. These instruments use a laser that operates at 532 nm wavelength and pulses at 0.8–4 kHz. On-ground laser beam diameter is on the order of 2 m and typical pulse densities are 0.05–0.25/m^2 (2–4 m spot spacing). Flying height commonly is 200 m. Rather than simplifying the returned signal to one or more discrete returns, the entire waveform is recorded for later analysis. To provide enough light to return a signal from depths in excess of 20 m, the lasers consume more power and require more cooling than commercial IR systems. Consequently, the instruments are heavy, require a multi-engine aircraft for a platform, and are expensive to operate. Per-area survey costs are an order of magnitude greater than with commercial IR systems, whereas the resulting data densities (per area) are 1–2 orders of magnitude less. The great strength of these systems lies in their ability to provide good bathymetry at depths of 1–20 m in settings where hydroacoustic surveys are hazardous or prohibitively expensive. Guenther (2007) provides a useful discussion of high-energy, full waveform green LiDAR. Systems available for collecting data include:

CHARTS	http://shoals.sam.usace.army.mil/CHARTS/
HawkEye	http://www.airbornehydro.com/HawkEyeII/hawkeyeII.html
LADS	http://www.lhd.tenix.com/Main.asp?ID=30#

CHARTS (and before 2003, its predecessor SHOALS) is operated by the Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX), staffed by the Army Corps of Engineers, Naval Oceanographic Office, and NOAA National Geodetic Survey, with significant support by contracted employees of Fugro Pelagos, Inc. CHARTS surveys are available commercially from Fugro Pelagos. Tiffan and et al. (2009, chapter 5, this volume) discuss data obtained with the SHOALS system.

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EAARL (Experimental Advanced Airborne Research LiDAR) is a very successful attempt to build a green full-waveform LiDAR with a different set of compromises. Using a smaller laser pulsed at 5 kHz and with a 15 cm on-ground beam diameter, EAARL consumes about 1/20th the power of CHARTS or LADS and can be operated from a single-engine aircraft. Consequently, it is significantly cheaper to operate than other bathymetric LiDARs. Further, the short pulse width and narrow receiver field-of-view of the EAARL allows simultaneous mapping of bare-earth topography and shallow submerged topography in coastal and riverine environments. Nayegandhi (2009, chapter 1, this volume) further describes the EAARL system. The EAARL system is operated by the USGS (formerly by NASA) and is not available commercially. Material on the Web about EAARL includes:

http://lidar.cr.usgs.gov/downloadfile2.php?file=Wright_EAARL_Overview.pdf
http://coastal.er.usgs.gov/remote-sensing/advancedmethods/eaarl.html

McKean and others (2009, chapter 2, this volume) and Kinzel (2009, chapter 3, this volume) discuss data obtained with EAARL.

Two other LiDAR technologies are worth briefly noting. In the last few years, small scanning LiDAR units designed to be mounted on a tripod have become available and are used for surveying areas with dimensions of 101–103 m with accuracies of a centimeter. The original application of LiDAR was as fixed, upward-looking instruments for measuring the height and density of atmospheric particulates.

Questions (and comments) and Answers

1. What is the best technology for surveying streams?

Airborne discrete-return infrared (IR) LiDAR—the technology used by the Puget Sound LiDAR Consortium and the Oregon LiDAR Consortium—can provide excellent descriptions of the subaerial environment. Over the last decade, airborne IR LiDAR has become the technology of choice for obtaining digital elevation models (DEMs) at XY resolution <5 m, supplanting photogrammetry, IFSAR, and ground surveys (Maune, 2007). For surveys with extents less than approximately $10\ \text{km}^2$ and requiring very high resolutions (XY resolution <0.3 m or Z resolution <5 cm), ground-based or photogrammetric technologies are still preferred. Airborne IR LiDAR is particularly effective at mapping topography in forested regions whereas photogrammetry and IFSAR tend to map only the canopy surface.

For the wet part of the world, possible survey techniques include hydroacoustic surveys in streams large enough for boat operations, full-waveform green LiDAR, IR LiDAR at low flow to survey the emergent part of the channel, and field crews with sticks, GPS, and(or) total-station instruments.

What is the best technology?

All these technologies have their place. Key issues include the spatial scale (extent and resolution) involved, access, weather, whether the technology is capable in the particular setting, and cost. Present technology limits green LiDAR to an XY resolution of 1 m (EAARL) to 2 m (SHOALS, CHARTS) with Z resolution on the order of a decimeter. IR LiDAR typically produces higher resolutions, as good as 0.3 m XY and a few centimeters in Z. Hydroacoustic surveys can provide excellent high-resolution data but at a limited extent, typically 2,030 km of river length. Moreover, many streams large enough to survey from a boat are not considered navigable and thus there may be legal and physical access issues exemplified by cross-stream fences. Airborne LiDAR, whether IR or green, requires the ground be clearly visible from the aircraft; where rain and (or) low cloud cover are the norm, the cost of standby time while waiting for adequate weather may favor a ground-based survey. For mountain streams, pool depths might be most accurately and cheaply obtained by a field crew, especially as CORS (Continuously Operating Reference System, e.g., Stone, 2006) GPS becomes more widely available. Deep or turbid streams can not be surveyed by green LiDAR (see below). In some settings, stream depth may be usefully inferred from hyperspectral imagery. For some streams, the combination of a hydroacoustic survey at high flow (during winter, or high tide) and IR LiDAR at low flow may be very effective.

Comparative costs are not easily estimated. At present, large-area IR LiDAR surveys cost about $1/acre and costs vary with size of surveyed area, local relief, pulse density requirements, and weather and access conditions. Small and irregular areas (e.g., stream corridors) cost significantly more. SHOALS/CHARTS are an order of magnitude more expensive. EAARL is less expensive to operate than SHOALS/CHARTS (but in deep-water settings, EAARL is less capable). However, because EAARL is not a commercial system, costs are not comparable. West of the Cascade crest, the rarity of coincident good weather, suitable ground conditions (snow absent, streams not flooding), and leaf-off conditions (to increase the fraction of LiDAR pulses that yield ground returns) is likely to significantly increase the cost, or reduce the success, of all airborne LiDAR surveys. Ground surveys almost always will be more expensive than airborne surveys for the amount of data obtained. But ground surveys typically produce much less data per unit stream length. To a first approximation, the per-area cost of hydroacoustic surveys varies inversely with water depth, as swath width is greater in deeper water.

These technologies are complementary and the best solution is often a combination of techniques depending on the physical characteristics of the stream. For example, IR LiDAR can provide wide area characterization of the floodplain morphology, riparian vegetation, and upland influences (i.e., landslides, roads, etc.) allowing ground based surveys to concentrate efforts within the wetted channel or in intensive study reaches. A small footprint, bathymetric LiDAR (EAARL or successor) may eventually offer the best solution for stream surveys, but it is not there yet.

2. How important is bathymetry? Can we get by without it?

Bathymetry of streams is expensive to acquire. For the same cost, one can survey the topography of much larger riparian and upland areas. The bathymetry of steep, high-energy mountain streams may change rapidly and surveys may have a limited useful lifetime, further increasing their relative cost.

> *Can we get adequate answers without the expense of bathymetric surveys?*

In general, there is no simple answer to this question. A good topographic DEM, probably acquired by infrared discrete-pulse LiDAR, will be sufficient for modeling floodplain inundation. For detailed modeling of bank protection, levee removal, or design of diversion dams, good bathymetry is essential. Our experience with hydraulic modeling is “Garbage in, garbage out.” We must pay the cost of collecting bathymetry to get useful results.

3. Can we survey subaquatic vegetation with waveform LiDAR?

Currently (2008), there is a great deal of research into the potential for describing the forest canopy with airborne discrete-return IR LiDAR and airborne and satellite full-waveform IR LiDAR (e.g., Lefsky and others, 2002; Andersen and others, 2005; Hyypp et al., 2008). With time, IR LiDAR is likely to prove to be the best technique for measuring many aspects of forest vegetation (with the exception of species composition) over areas of 1 to 10,000 km^2.

> *Is green waveform LiDAR similarly powerful in describing subaquatic vegetation (SAV)?*

Describing SAV with green waveform LiDAR is a difficult problem. The SAV signal is convolved with attenuation and scattering within the water column and surface and bottom reflections to produce the return waveform. Deconvolving the SAV signal is challenging. Sea grass can be distinguished from bare sandy bottom (Nayegandhi, personal commun., 2008; see also Tuell and et al., 2005) largely because of the gross difference in albedo. There is more work to be done.

4. Did EAARL find bottom everywhere along the Boise River?

There are limitations to the settings in which green LiDAR systems can measure bathymetry.

> *Was EAARL everywhere effective in the recent survey of the Boise River?*

No. Where the water is too turbid, or bottom reflectivity is too low, green LiDAR systems will not map the bottom. Water clarity is the biggest factor. In general, EAARL can map at depths up to 1.5x the Secchi depth. Bathymetric LiDARs use green lasers: if the bottom is dark in green light, it will be hard to map. If bottom is visible to the naked eye, it can be mapped with EAARL. If not, EAARL may or may not be capable of mapping the bottom.

Note that other bathymetric survey techniques rarely provide depths for all of a stream. Although incomplete, an EAARL survey may still be more complete than any feasible alternative.

5. Is there EAARL capacity to survey all PNW streams?

McKean and others (2009, chapter 2, this volume) indicate that EAARL can survey moderate-size stream channels at about 30 km/h. There are hundreds of thousands of kilometers of significant streams in the Pacific Northwest.

> *Is EAARL available for enough time to survey all Pacific Northwest streams?*

Probably not. EAARL is a research system, built by Wayne Wright at NASA to map coral reefs and other coastal environments. Since EAARL was built, Wright and EAARL have moved to the USGS Coastal and Marine Geology program. There is some freedom for EAARL to work on western streams, but the primary obligation of the instrument is to the Coastal and Marine Geology program. In particular, during hurricane season on the East Coast—a large part of summer and early fall, prime time for western stream surveys—EAARL must be on the East Coast.

There are plans to build a second EAARL system to be mounted on a USGS aircraft. This should increase availability, but it is still unlikely that there would be sufficient capacity to monitor all streams of interest to the PNAMP community. Funding is a different question.

6. When will we see a commercial equivalent to the EAARL system?

Although NOAA and the USGS have supported EAARL, and the USGS may build a second EAARL, this may not provide the capacity that is needed to survey western streams. Furthermore, Federal research agencies find it difficult to staff, on a sustained basis, survey operations that depend on highly skilled operations personnel. The required capacity could be provided by the commercial sector.

When will we see a commercial equivalent to the EAARL system?

Watershed Sciences is very interested in lightweight, small-footprint green full-waveform LiDAR. They are interested in mounting a federally owned EAARL on Watershed Sciences aircraft and have approached commercial instrument manufacturers (Optech, Leica) about building a similar system. The primary concerns are the cost of the instrument and whether there will be sufficient demand to support its operation.

What if the possible market in estuarine mapping does not pan out because EAARL produces poor results on the dark bottoms of Pacific NW estuaries?

Is there a Federal incentive to operate such an instrument, or a guaranteed Federal market?

We should remind ourselves that the primary purpose of EAARL is technology development. EAARL does not exist to supplant the commercial sector, but at present is the only system available with its unique capacity to survey moderate-depth streams at moderate cost.

7. Can we promote landscape-wide LiDAR surveys?

Limited budgets and a strong focus on in-stream and riparian issues have led fisheries interests to fund LiDAR surveys of narrow corridors along streams. Yet stream health is affected by the entire drainage basin, stream-corridor LiDAR surveys are more expensive per unit area than landscape-wide surveys, other groups will use LiDAR data from upslope areas, and the benefit-cost ratio to the community as a whole is very likely greater for landscape-wide LiDAR surveys.

How can we promote landscape-wide surveys?

There is not a simple answer to this question. The U.S. Forest Service's Aquatic and Riparian Effectiveness Monitoring Program (AREMP; see Eldred, 2009, chapter 10, this volume) would benefit from landscape-wide surveys to provide a more accurate stream network, to provide a more accurate and more uniform road network, and to provide a better vegetation layer (but see Moeur et al., 2009, chapter 11, this volume, for a LANDSAT-based solution). But AREMP alone can not fund large-area LiDAR.

The Puget Sound LiDAR Consortium has been contracting large-area surveys since 1999. It has been most successful at covering the landscape when it has had significant Federal funding that is not strongly tied to a particular area. When all funding has been from partners with strong responsibilities to their own jurisdictions or immediate areas of interest, the result has been patchwork partial coverage. Despite this, the consortium may still be the best way to provide relatively coherent coverage with common specifications, deliverables, and quality control. The younger Oregon LiDAR Consortium, with significant State funding and a commitment to covering much of the State, may be more successful at landscape-wide coverage.

8. What about sensors other than airborne LiDAR?

Remote sensing comes in flavors other than airborne LiDAR: CASI (Garono and et al., 2009, chapter 8, this volume), Landsat (D'Iorio and Volk, 2009, chapter 9, this volume; Moeur and et al., 2009, chapter 11, this volume), FLIR (D'Iorio and Volk, 2009, chapter 9, this volume) IKONOS, ASTER, and many more.

What do these other sensors offer to the aquatic monitoring community?

Landsat has the particular advantage of near-global coverage at very little cost to the end user. Disadvantages are its limited spatial resolution (about 30 m) and modest spectral resolution. Landsat data may be particularly appropriate for defining a limited spatial target for analysis with a higher resolution, more expensive airborne sensor.

The CASI sensor offers greater spatial and spectral resolution and shows significant utility in mapping landcover types to better understand habitat dynamics (Garono et al., 2009, chapter 8, this volume).

9. How do we encourage data sharing?

Audience members expressed frustration, echoed by the panel, over the frequent inability of agencies to share data in a timely fashion, thus increasing the cost of monitoring and limiting the quantity and richness of science that can be done.

How do we fix this?

Discussion identified several impediments to data sharing: absence of a high-level mandate to share; licensing restraints on commercial data; fear of lost glory for failing to interpret the story first; fear of loss of credit to the entity that funded data acquisition; lack of confidence that data from another agency are of adequate quality; ignorance about what data are available.

Monitoring programs could refuse to purchase data without unlimited redistribution rights. Grants that fund data acquisition could require speedy release of data. The geospatial community could develop more complete, and stronger, standards for data quality. The monitoring community could continue to reinforce the benefits of sharing.

Better metadata would help. Necessary improvements include widely understood formats for spatially explicit metadata, routine designation of go-to individuals (not groups) for all datasets, and routine inclusion in all metadata of direct links to data.

Audience members reported experience with agencies that claim incomplete QA/QC to avoid release of data, followed by the suggestion that such data be released with a PRELIMINARY stamp. It was then observed that digital GIS data commonly do not have a place for such a stamp. The Puget Sound LiDAR Consortium is concerned that distribution of data constitutes implicit acceptance, thus the PSLC does not distribute preliminary data. But the PSLC's acquisition contracts define a short (3045 day) window in which QA/QC must be completed.

It was suggested that social scientists be included in monitoring projects with the explicit task of encouraging natural-resource scientists to share data. This was followed by an anecdote about a project that had 20% of the budget allocated to social science, yet when the social scientist talked the biologists were out in the hall having side conversations.

10. There is more to monitoring than data acquisition

Beyond data acquisition, monitoring also requires data analysis. Considerable concern was expressed about funding of data acquisition without corresponding funding of data analysis. In some cases, data acquisition contractors can perform analysis and it may be useful to include analysis in the acquisition contract.

Concern also was voiced for the need of the monitoring community—and often individual agencies—to create and conserve a pool of expertise. Too often, hard-won analytical expertise is lost as temporary employees move on.

Some concern was voiced that a disproportionate amount of available funding is directed to sensor development instead of data analysis. This did not appear to be a majority view.

11. How do we pool monitoring funds from multiple agencies?

Economies of scale, shared interests, and multiple-use data suggest that would be good to pool monitoring funds from multiple agencies for acquisition of remotely sensed data.

How do we do this?

The following suggestions were made: To collaborate in data acquisition, managers need to be convinced that collaboration will (a) save money, (b) reduce risk, and (or) (c) help make better decisions. Some agencies divide funding for natural-resource studies into inventory and monitoring components; however, both activities commonly need the same data and the division makes it more difficult to fund data acquisition. We need the secretaries of Agriculture, Commerce, Defense, Energy, and Interior to give us a mandate to collaborate. PNAMP has a role to play in solving these coordination problems.

Shared data acquisition will be easier with strong data standards. Existing standards for bathymetric mapping are oriented towards nautical charting and, in shallow-water areas, do not match well with the needs of natural-resource scientists or the capabilities of current technology. NOAA and USGS could collaborate to provide better standards for mapping of shallow-water areas. For IR LiDAR, “A proposed specification for lidar surveys in the Pacific Northwest” by Haugerud et al. (2009) should be useful.

What have we learned?

LiDAR, which is primarily geometric (position, shape) information, is qualitatively different from other remote sensing technologies that provide reflectance (Landsat, CASI) or emittance (FLIR) data, and from which geometric information is derived by photogrammetry. LiDAR data are not pictures, though we commonly make pictures from them. A growing body of experience demonstrates that such shape information is very powerful (e.g., Haugerud and et al., 2003b; McKean and et al., 2009, chapter 2, this volume).

IR LiDAR works well for describing the terrestrial environment, including riparian and upland areas. EAARL is useful for describing in-stream parts of many western aquatic systems, as well as the riparian and upland areas, although it has less resolution and is likely to be more costly than IR LiDAR.

Airborne IR LiDAR and EAARL (and its successors) are likely to revolutionize ecological studies (Vierling and et al., 2008; McKean et al., 2009, chapter 2, this volume). They provide increased ecological scope; make it feasible to acquire continuous data; establish a more accurate geometric framework for sensor fusion, correlation with ground data, and spatial analysis; and for some phenomena provide previously unattainable spatial resolution and accuracy.

Without a robust geometric framework and good geolocation of remotely sensed data, fusion of data from different sensors and correlation of remotely sensed data with ground observations is likely to produce significant errors. Analysis of a subset of the Hood Canal CASI data (Garono et al., 2009, chapter 8, this volume) by Haugerud et al. (2003a) illustrates the problem. In an attempt to understand physiographic controls on eelgrass distribution, Haugerud et al. (2003a) intersected CASI-defined landcover with elevation and local slope. Although there were significant correlations, the strongest conclusion from the analysis was that many elevations inferred for the CASI pixels were incorrect. CASI data were from the intertidal zone (minimum elevation circa -4 ft MLLW, maximum elevation circa +8 ft MLLW), yet a significant number of CASI pixels had apparent elevations outside this range. This largely reflects errors in the reference DEM, although there was some contribution from mislocation of the CASI data (with estimated RMS location errors of 5–24 m). One of the strengths of LiDAR data is that above all they are accurately located—except for the intensity values, LiDAR data are locations (x,y,z). As such they provide a robust framework for spatial correlation and analysis of other information.

Computing with and managing the large volumes of data produced by LiDAR surveys are problematic for many users. Crosby et al. (2006), Swoboda et al. (2009, chapter 7, this volume), and McKean et al. (2009, chapter 2, this volume) suggest that the solution lies in centralized data storage and computation, with associated economies of scale and concentration of expertise. Results would be accessed via a custom web interface and file download or as a web mapping service. Such centralized storage and computation may become a locus for a growing community of expertise in analyzing these data.

Presentations at the session provided some suggestions on data density and accuracy necessary for aquatic resource monitoring. McKean et al. (2009, chapter 2, this volume) state that 0.25 pulse/m^2 (2 m spot spacing) EAARL data were not dense enough to accurately describe steep banks. Hilldale et al. (2009, chapter 4, this volume) note that poor XY resolution because of large spot size for SHOALS (and CHARTS) is a problem, and that existing mapping standards (IHO, NMAS) may not be adequate to meet the needs of the aquatic monitoring community. Hilldale et al. (2009, chapter 4, this volume) also note that stated errors for LiDAR are commonly Z errors on flat ground; XY errors on the steep slopes common in Pacific Northwest riparian zones contribute to aggregate Z errors that commonly exceed stated values.

What do we do next?

Presentations in the special session and the panel discussion illuminated some likely next steps for the Pacific Northwest aquatic monitoring community.

We need a better understanding of the capacities and associated costs of various bathymetric survey technologies, as well as a better understanding of our data needs, so that we can select the most appropriate and most cost-effective survey technology. To this end, we could use more reports on bathymetric surveys and consequent analyses that document survey methods, survey costs, the data obtained, and the results of data analysis. These reports will be most useful if they include sensitivity analyses that explore how the results depend on the quality and quantity of the survey data.

We need to share data more effectively. To do this, we need tools to facilitate sharing. These include better metadata, including a standard protocol for spatially explicit metadata; strong data standards that are appropriate for community needs; and a better data inventory. We also need to grow a culture that promotes data sharing. Grants that fund data acquisition should require timely release of data. Where we are allowed to copyright our data, we can assert copyright and license the use of our data under terms that make it freely available (see http://creativecommons.org/). We should support our professional societies as they develop policies that promote open access to data.

We need to devote more resources to validating models developed for aquatic monitoring. The use of existing datasets to model watershed health is a necessary part of the large and complex task that is aquatic monitoring. However, our ability to construct a model is no guarantee that the model is useful. Modeling needs to be verified by independent observations! Validation with the observations used to construct the model is likely to be uninformative. Models developed on the basis of observed correlations, rather than on a basis of explicit, quantitative knowledge of the relevant biological, hydrological, and geological processes, are especially likely to need validation.

We need to acquire landscape-wide LiDAR data. We know that the benefits of such data for aquatic monitoring will be great, but the costs are likely beyond the resources of this community alone. However, large-area, high-resolution LiDAR surveys also provide useful information on timber resources, forest health, wildfire fuel loads, forest carbon sequestration, landslide occurrence and susceptibility, seismic hazards, flood hazards, water resource availability, habitat for terrestrial and avian species, highway design, irrigation design, and more, and the relevant communities should be amenable to calls for collaboration. The Puget Sound LiDAR Consortium and the Oregon LiDAR Consortium are cooperatively funding large-area surveys and effectively sharing data. The USGS hosts a nascent national LiDAR initiative. The Pacific Northwest Aquatic Monitoring Partnership should encourage the aquatic monitoring community to participate in these efforts. We clearly need more research on obtaining habitat metrics from airborne LiDAR data, but our need to monitor change dictates that we acquire the best data possible now, without full knowledge of all the ways that these data will be analyzed in the future.

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