RESEARCH REPORTS

Overview of a Workshop to Expand the Use of Emerging Technology to Understand the Ecology of Grouse in a Changing Climate

Jennifer Forbey, Gail Patricelli, Donna Delparte, Alan Krakauer, Peter Olsoy, Marcella Fremgen, Jordan Nobler, Nancy Glenn, Lucas Spaete, Bryce Richardson, Lisa Shipley and Jessica Mitchell

We held a workshop related to the use of emerging technology to understand the ecology of grouse on 03 September 2015 from 08:00 to 17:30 at the Reykjavik Family Park and Zoo, Reykjavik, Iceland as part of the 13th International Grouse Symposium. Our overall objective was to translate technological advances in remote sensing, rapid biochemical assays, and robotics to resource managers for improved understanding, monitoring, and management of wildlife habitat and behavior in a changing climate. The workshop included seminars and hands-on demonstrations of equipment used to collect, analyze, interpret, and share data related to monitoring and predicting how grouse interact with their environment. Professors Jennifer S. Forbey (Boise State University), Gail Patricelli (University of California, Davis), and Donna Delparte (Idaho State University) chaired the workshop, which was funded by a grant from the U.S. National Science Foundation. Sessions in the workshop were led by a team of faculty, students, and researchers who developed and routinely use the technology to conduct research at the interface of basic research and wildlife management. Through *Grouse News*, we hope to distribute the information related to several types of emerging technology to the wider community and grouse researchers specifically. For each technology type, we offer a list of equipment used, an overview of the technology, and examples of how the technology is used in different systems. We encourage researchers and wildlife managers to contact the users of the technologies listed here if they have additional questions.

TECHNOLOGY #1: UNMANNED AIRCRAFT SYSTEMS (UAS) TO ASSESS HABITAT COMPOSITION

UAS contacts: Donna Delparte, delparte@isu.edu, Idaho State University; and Peter Olsoy, peter.olsoy@wsu.edu, Washington State University

Equipment Details

Instrument: Quad copter Unmanned Aircraft Systems (UAS, Figure 1)
Flight time: 20-35 min
Sensors: RGB Olympus PG, Tetracam ADC Micro, Rikola Hyperspectral sensor, InfraredCamerasInc thermal camera
Power: Electric, 2 to 4 LiPo batteries at 5 cell, 6000-10000 mAh
Autopilot System: 3D Robotics Pixhawk
Controller: FR Sky Taranis X9D
GPS navigation: 3D Robotics
GPS survey grade for image acquisition
Other equipment required: Laptop, battery charging station, 4+ ground targets AND/OR mounted survey grade GPS
Software: Mission Planner (data collection and flight planning), Pix4D, Agisoft Photoscan, Ensomosaic (data processing, data export).

Figure 1. Donna Delparte flying Quad copter Unmanned Aircraft Systems (upper left) in sagebrush steppe ecosystem with hyperspectral camera to differentiate species of sagebrush (Artemesia spp.) in Idaho, USA.

Introduction

The use of UASs for conservation management and wildlife research applications is growing in popularity. Here are typical steps in planning your UAS activities:

- Identify the research question or conservation management problem for a selected study area or region
- Select the appropriate sensor(s) to address the problem
- Select an appropriate UAS system – a multirotor platform or fixed wing UAS that is capable of carrying the required sensor and covering the study area
- Pre-plan your flight mission(s) in accordance with weather conditions, time of year and if repeat flights are required. Obtain necessary permits and approvals well in advance
- Fly your mission in compliance with safety regulations, national airspace requirements and with qualified personnel
- Perform in-field QA/QC to confirm data is being collected to standards and meets research objectives
- Data processing can be conducted post collection:
    - GPS differential correction can be performed real-time or post processed
    - Images collected during flight are typically stitched together using photogrammetry (structure from motion) processing software such as Pix4D
    - A digital surface model (DSM) can be generated
    - Multispectral/Hyperspectral data mosaics can be generated
- Analysis/Visualization: Further metrics can be calculated for model input and visualization

Application of UAS
UAS have been used for wildlife surveys, habitat assessments, animal tracking, and monitoring poaching activities.

Example 1: Quantification of vegetation structure and biomass
Source: Cunliffe AM, RE Brazier, K Anderson. 2016. Ultra-fine grain landscape-scale quantification of dryland vegetation structure with drone-acquired structure-from-motion photogrammetry. *Remote Sensing of Environment* **183**:129-143.
URL: http://dx.doi.org/10.1016/j.rse.2016.05.019
Summary: UAS was used to measure fine-scale vegetation structure and estimate biomass and carbon storage in a dryland ecosystem.

Example 2: Estimating prairie dog colony populations with Unmanned Aircraft Systems for black-footed ferret reintroduction
Source: Delparte D, T Stone, K Bly, M Tracy, R Behrendt, M Belt, E McCaffery (*in prep*).
URL: N/A
Summary: UAS surveys were flown over prairie dog colonies in north central Montana to determine population size and density in support of black-footed ferret reintroduction efforts. Object-oriented feature extraction analysis was utilized to automatically extract and count prairie dog burrows to compare with field observations. Each colony was further characterized based on vegetation composition and population density.

Example 3: Wildlife Tracking with UAS
Source: Dos Santos GAM, Z Barnes, E Lo, B Ritoper, L Nishizaki, X Tejeda, A Ke, H Lin, C Schurgers, A Lin, R Kastner. 2014. Small unmanned aerial vehicle system for wildlife radio collar tracking. Mobile Ad Hoc and Sensor Systems (MASS). In *2014 IEEE 11th International Conference*, pp. 761-766, IEEE.
URL: http://dx.doi.org/10.1109/MASS.2014.48
Summary: This is an example of a low cost system to facilitate VHF tracking from signals originating from a wildlife tracking collar.

Other Applications and Reviews:

Anderson K, KJ Gaston. 2013. Lightweight unmanned aerial vehicles will revolutionize spatial ecology. *Frontiers in Ecology and the Environment* **11**:138–146. http://dx.doi.org/10.1890/120150.

Christie KS, SL Gilbert, CL Brown, M Hatfield, L Hanson. 2016. Unmanned aircraft systems in wildlife research: current and future applications of a transformative technology. *Frontiers in Ecology and the Environment* **14**(5):241–251. http://dx.doi.org/10.1002/fee.1281

Dandois JP, EC Ellis. 2013. High spatial resolution three-dimensional mapping of vegetation spectral dynamics using computer vision. *Remote Sensing of Environment* **136**:259–276. http://dx.doi.org/10.1016/j.rse.2013.04.005

Hodgson JC, SM Baylis, R Mott, A Herrod, RH Clarke. 2016. Precision wildlife monitoring using unmanned aerial vehicles. *Scientific Reports* **6**:22574. http://dx.doi.org/10.1038/srep22574

Hruska, R, JJ Mitchell, MO Anderson, NF Glenn, N. 2012. Radiometric and geometric analysis of hyperspectral imagery acquired from an Unmanned Aerial Vehicle (UAV), *Remote Sensing*, **4**: 2736-2752. http://dx.doi.org/10.3390/rs4092736

Hugenholtz CH, K Whitehead, OW Brown, TE Barchyn, BJ Moormanh, A LeClair, K Riddell, T Hamilton. 2013. Geomorphological mapping with a small unmanned aircraft system (sUAS): feature detection and accuracy assessment of a photogrammetrically-derived digital terrain model. *Geomorphology* **194**:16–24. http://dx.doi.org/10.1016/j.geomorph.2013.03.023

Koh LP, SA Wich. 2012. Dawn of drone ecology: low-cost autonomous aerial vehicles for conservation. *Tropical Conservation Science* **5**(2):121–132. http://tropicalconservationscience.mongabay.com/content/v5/TCS-2012_jun_121-132_Koh_and_Wich.pdf

Mitchell, JJ, MO Anderson, RC Hruska, NF Glenn. 2016. Flight Considerations and Imaging Spectroscopy for Dryland Vegetation Management from a Fixed-wing UAS. *Environmental Management and Sustainable Development* **5**(2): 41-57. http://dx.doi.org/10.5296/emsd.v5i2.9343

Wing MG, J Burnett, J Sessions, J Brungardt, V Cordell, D Dobler, D Wilson. 2013. Eyes in the sky: Remote sensing technology development using small unmanned aircraft systems. *Journal of Forestry* **111**(5):341–347. http://dx.doi.org/10.5849/jof.12-117

Resources:
Conservation Drones: http://conservationdrones.org/
Check out their Ted Talk here:
http://www.ted.com/talks/lian_pin_koh_a_drone_s_eye_view_of_conservation?language=en
DIY Drones: http://diydrones.com//

TECHNOLOGY #2: TERRESTRIAL LASER SCANNING (TLS) TO ASSESS HABITAT STRUCTURE

TLS contacts: Nancy Glenn, nancyglenn@boisestate.edu, Boise State University, Lucas Spaete, lucasspaete@boisestate.edu, Boise State University and Peter Olsoy, peter.olsoy@wsu.edu, Washington State University

Equipment Details

Instrument: Riegl VZ-1000

- Near-infrared laser (operated at 1550nm wavelength)
- Can collect data at a distance of up to 1400m (range)
- Beam width: ~2mm at 10m range, increasing 30mm per 100m distance
- Field of View: 100° x 360°
- Measurement Rate: 29,000 – 122,000 measurements/sec
- At 100 m distance, Accuracy: 8mm, Precision: 5mm

Other equipment required: Laptop, tripod, digital camera, 3+ targets OR mounted RTK GPS

Software: RiSCAN Pro (data collection, post-processing, data export), BCAL Lidar Tools (height filtering and further post-processing of LAS files; https://bcal.boisestate.edu/tools/lidar)
More information: Riegl VZ-1000 Datasheet
(http://www.riegl.com/uploads/tx_pxpriegldownloads/DataSheet_VZ-1000_2015-03-24.pdf)

Introduction

Terrestrial laser scanning (TLS) is a ground-based, active imaging method that rapidly acquires dense 3D point clouds of object surfaces by laser range-finding (Figure 2). How it works:

- A laser pulse leaves the scanner, hits an object, and then returns to the sensor. This is done tens of thousands of times per second
- The location of the point in space is calculated by knowing the angle at which the laser left the scanner and precisely measuring the time-of-flight
- Results in a 3D point cloud with millions of points
- The point cloud can be analyzed directly or can be processed to create continuous rasters:
    - A digital elevation model (DEM) of the bare earth surface is created with the ground subset (i.e., ground elevation above sea level)

- A canopy height model (CHM) is calculated with the vegetation subset (i.e., range of vegetation heights from 0 cm and up)
- A digital surface model (DSM) may be calculated using all points (ground + vegetation)

- From the point cloud, vegetation metrics such as height and height variability can be calculated for model input (e.g., random forest or multiple linear regression)

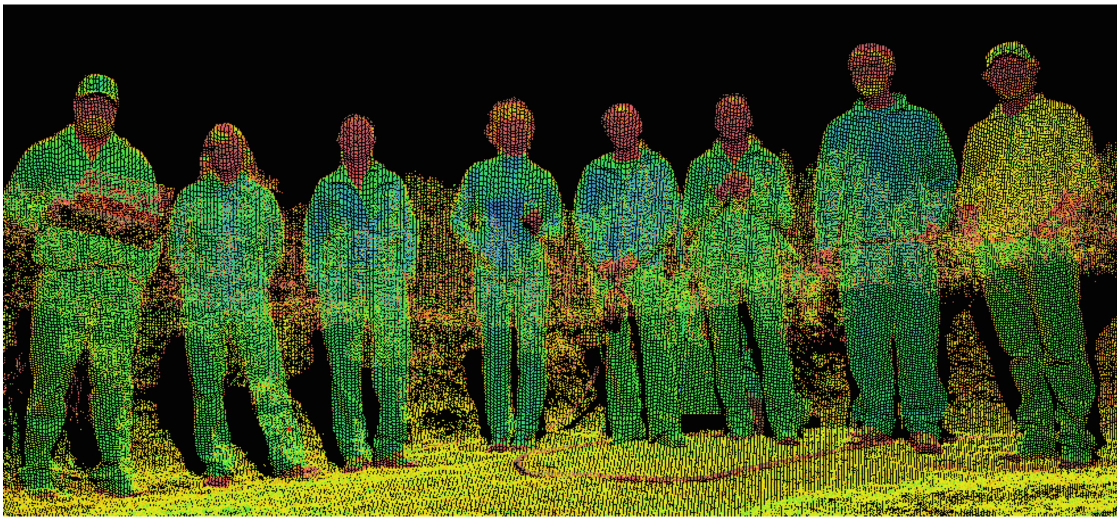


Figure 2. Example of 3D point cloud image generated from a terrestrial laser scanner (TLS) during the technology workshop. The scan depicts some members of the technology workshop team and background vegetation.

Application of TLS

TLS is expanding the options for mapping habitat features across the landscape by not only addressing existing mismatches in scales between ground and aerial, but also allowing for greater flexibility in modeling and predicting habitat changes to test a broad range of hypotheses. The TLS point cloud is very dense (~100–1000 pts/m^2), but usually only covers a small area (~0.01–1 km^2), which makes it ideal for projects that require greater detail at smaller geographic scales.

Example 1: Predicting concealment for prey

Source: Olsoy PJ, JS Forbey, JL Rachlow, JD Nobler, NF Glenn, LA Shipley. 2015. Fearscapes: mapping functional properties of cover for prey with terrestrial LiDAR. *BioScience* **65**:74–80.

URL: http://dx.doi.org/10.1093/biosci/biu189

Summary: A TLS was used to estimate horizontal concealment and visibility across a range of scales and from a range of vantage points representing predator sightlines. TLS was found to be highly correlated with field measures of habitat cover (R^2 = 0.85).

Example 2: Capturing 3D vegetation structure

Source: Olsoy PJ, JJ Mitchell, DF Levia, PE Clark, NF Glenn. 2016. Estimation of Big Sagebrush Leaf Area Index with Terrestrial Laser Scanning". *Ecological Indicators, **61***(Part 2), 815-821.

URL: http://dx.doi.org/10.1016/j.ecolind.2015.10.034

Summary: Leaf Area Index (LAI) was estimated from TLS scans using structural variables such as height, canopy cover, and volume for 42 Wyoming big sagebrush across three different collection sites in the Snake River Plain. Strong predictors of LAI included canopy cover (r^2 = 0.73) and shrub volume (r_2 = 0.76). The convex hull method of estimating shrub volume and compared favorably to point-intercept sampling (r^2 = 0.78), a field-based method used in rangelands.

Example 3: Monitoring nests for wildlife

Source: McFarlane DA, W Roberts, M Buchroithner, G Van Rentergem, J Lundberg, S Hautz. 2015. Terrestrial LiDAR-based automated counting of swiftlet nests in the caves of Gomantong, Sabah, Borneo. *International Journal of Speleology* **44**:191–195.

URL: http://dx.doi.org/10.5038/1827-806X.44.2.8

Summary: A TLS was used to scan a cave in Borneo to count and distinguish between swiftlet nests and bats. Nests were undercounted by only 1.5% compared to manual photo counts, while bat counts had an error of 15%.

Other Applications and Reviews:

Davies AB, GP Asner. 2014. Advances in animal ecology from 3D-LiDAR ecosystem mapping. *Trends in Ecology & Evolution* **29**:681–691. http://dx.doi.org/10.1016/j.tree.2014.10.005

Lichti DD. 2011. Special Issue Terrestrial Laser Scanning. *Remote Sensing* 3(1-10) http://www.mdpi.com/journal/remotesensing/special_issues/terrestrial-laser-scanning

Loarie SR, CJ Tambling, GP Asner. 2013. Lion hunting behaviour and vegetation structure in an African savanna. *Animal Behaviour* **85**: 899–906. http://dx.doi.org/10.1016/j.anbehav.2013.01.018

Lone K, LE Loe, T Gobakken, JDC Linnell, J Odden, J Remmen, A Mysterud. 2014. Living and dying in a multi-predator landscape of fear: roe deer are squeezed by contrasting pattern of predation risk imposed by lynx and humans. *Oikos* **123**:641–651. http://dx.doi.org/10.1111/j.1600-0706.2013.00938.x

Müller J, R Brandl, J Buchner, H Pretzsch, S Seifert, C Strätz, M Veith, B Fenton. 2013. From ground to above canopy—Bat activity in mature forests is driven by vegetation density and height. *Forest Ecology and Management* **306**:179–184. http://dx.doi.org/10.1016/j.foreco.2013.06.043

Olsoy PJ, NF Glenn, PE Clark, DR Derryberry. 2014. Aboveground total and green biomass of dryland shrub derived from terrestrial laser scanning. *ISPRS Journal of Photogrammetry and Remote Sensing* **88**:166–173. http://dx.doi.org/10.1016/j.isprsjprs.2013.12.006

Vierling KT, C Bässler, R Brandl, LA Vierling, I Weiß, J Müller. 2011. Spinning a laser web: predicting spider distributions using LiDAR. *Ecological Applications* **21**:577–588. http://dx.doi.org/10.1890/09-2155.1

Vierling KT, LA Viering, WA Gould, S Martinuzzi, RM Clawges. 2008. Lidar: shedding new light on habitat characterization and modeling. *Frontiers in Ecology and the Environment* **6**:90–98. http://dx.doi.org/10.1890/070001

TECHNOLOGY #3: SPECTRORADIOMETER FOR ASSESSING ORGANIC COMPOUNDS

Spectroradiometer contacts: Nancy Glenn, nancyglenn@boisestate.edu, Boise State University; Jennifer Forbey, jenniferforbey@boisestate.edu, Boise State University; and Jessica Mitchell, mitchellj@appstate.edu, Appalachian State University

Equipment Details

ASD FieldSpec® HandHeld 2

- Wavelength range: 325 nm – 1075 nm
- Accuracy: ±1 nm
- Resolution: <3 nm at 700 nm
- Field of view: 25° (fore optics are available)
- Weight: 1.2 kg
- Battery life: 2 (alkaline)-5 hours (lithium)
- Internal memory: up to 2,000 individual spectrum files

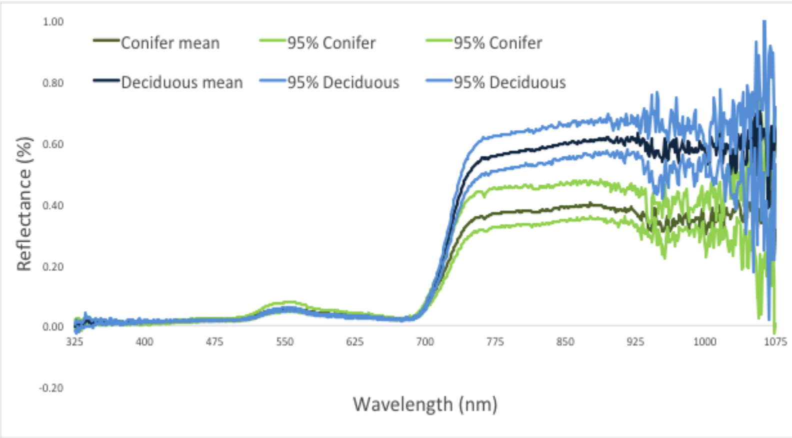
Software: RS^3 (instrument optimization and control), FieldSpec HH2 (data export and organization), ViewSpec Pro (data processing and analysis)

More information: ASD FieldSpec® HandHeld 2 Manual (http://support.asdi.com/Products/Products.aspx)

Introduction

The HandHeld 2 is a portable spectrometer that measures reflected light between the wavelengths of 325 nm – 1075 nm. This range includes much of the visible and near infrared (NIR) portions of the electromagnetic spectrum (Figure 3). Light reflected from the target passes through an internal diffraction grating and its intensity is measured along the entire wavelength range of the instrument. By adjusting the integration time (i.e., sensitivity) of the instrument, and calibrating reflection to a known standard, investigators can measure a target's reflectance. Reflectance is defined as the proportion of light reflected from an object to the light striking an object:

Figure 3. Example of spectral fingerprints (% reflectance over different wavelengths +/- 95% confidence intervals) for conifers (green) versus deciduous (black with blue CI) plants scanned by participants in the field with the HandHeld 2 during the Technology Workshop in Iceland.



$$Reflectance\ (R) = \frac{Reflected\ Light\ (R_s)}{Incident\ Light\ (I)}$$

This reflectance is a characteristic of the object being measured and is independent of light conditions. Entire or partial reflectance spectra can be compared to known standards to estimate specific compounds (e.g. plant protein, Mitchell et al. 2012) or correlated with measurements of interest (e.g. animal intake, Moore et al. 2010).

Application of spectroradiometer technology

Near infrared spectrometry has been applied to disciplines including ecological, geological, agricultural, and hydrologic investigations. Portable, field-based units have been used to ground truth data collected by airborne or space-borne sensors (e.g., differentiate taxonomic groups, Figure 4), assess soil and crop characteristics in agricultural settings, determine properties of snow and ice, and measure photosynthetic productivity of vegetation.

Example 1: Quantifying nutritional content
Source: Olsoy PJ, TC Griggs, AC Ulappa, K Gehlken, LA Shipley, GE Shewmaker, JS Forbey. 2016. Nutritional analysis of sagebrush by near-infrared reflectance spectroscopy. *Journal of Arid Environments* **134**:125-131.
URL: doi:10.1016/j.jaridenv.2016.07.003
Summary: The capacity of near-infrared reflectance spectroscopy (NIRS) to measure and monitor the dietary quality of sagebrush was evaluated using a scanning monochromator (NIRSystems Model 5000, FOSS North America). Calibration equations were developed for crude protein (CP), dry matter digestibility (DMD), 1,8-cineole (cineole), and total polyphenolics. The coefficients of determination (r^2) were 0.93 for CP, 0.83 for DMD, 0.64 for cineole, and 0.64 for total polyphenolics.

Example 2: Mapping plant palatability
Source: BD Moore, IR Lawler, IR Wallis, CM Beale, WJ Foley. 2010. Palatability mapping: a koala's eye view of spatial variation in habitat quality. *Ecology* **91**:3165–3176.
URL: http://onlinelibrary.wiley.com/doi/10.1890/09-1714.1/full
Summary: NIR spectral characteristics were correlated with an animals' willingness to consume specific plants in feeding trials. These characteristics were then mapped over a landscape and used to predict the landscape's palatability and habitat use.

Example 3: Identifying bacteria-carrying mosquitoes
Source: Sikulu-Lord MT, MF Maia, MP Milali, M Henry, G Mkandawile, EA Kho, RA Wirtz, LE Hugo, FE Dowell, GJ Devine, 2016. Rapid and non-destructive detection and identification of two strains of *Wolbachia* in *Aedes aegypti* by near infrared spectroscopy. *PLOS Neglected Tropical Diseases* **10**(6).
URL: http://dx.doi.org/10.1371/journal.pntd.0004759
Summary: Reflection spectra from laboratory-reared mosquitoes were used to identify spectral signatures characteristic of infection with *Wolbachia* bacteria. Single scans (3 seconds) of live mosquitoes were consequently able to identify infected individuals with up to 96% accuracy.

Other Applications and Reviews
Bian, M, K Skidmore, M Schlerf, T Wang, Y Liu, R Zeng, T Fei. 2013. Predicting foliar biochemistry of tea (*Camellia sinensis*) using reflectance spectra measured at powder, leaf and canopy levels. *ISPRS Journal of Photogrammetry and Remote Sensing* **78**:148–156. http://dx.doi.org/10.1016/j.isprsjprs.2013.02.002

Foley, WJ, A McIlwee, I Lawler, L Aragones, AP Woolnough, N Berding. 1998. Ecological applications of near infrared reflectance spectroscopy a tool for rapid, cost-effective prediction of the composition of plant and animal tissues and aspects of animal performance. *Oecologia* **116**:293–305. doi:10.1007/s004420050591

Jensen, KB, IW Mott, JG Robins, BL Waldron, M Nelson. 2012. Genetic improvement and diversity in Snake River wheatgrass (*Elymus wawawaiensis*) (Poaceae: *Triticeae*). *Rangeland Ecology & Management* **65**:76–84. http://dx.doi.org/10.2111/REM-D-10-00159.1

Liu, L, Y Zhang, J Wang, C Zhao. 2005. Detecting solar-induced chlorophyll fluorescence from field radiance spectra based on the Fraunhofer line principle. *Geoscience and Remote Sensing, IEEE Transactions on* **43**:827–832. 10.1109/TGRS.2005.843320

Lundberg, KM, PC Hoffman, LM Bauman, P Berzaghi. 2004. Prediction of forage energy content by near infrared reflectance spectroscopy and summative equations. *The Professional Animal Scientist* **20**:262–269. http://dx.doi.org/10.15232/S1080-7446(15)31309-7

Mitchell, JJ, NF Glenn, TT Sankey, DR Derryberry, M Anderson, RC Hruska. 2012. Spectroscopic detection of nitrogen concentrations in sagebrush. *Remote Sensing Letters* **3**:285–294. https://bcal.boisestate.edu/docs/Mitchell_et_al_2011.pdf

Wilson, ND, MS Ivanova, R A Watt, AC Moffat. 2002. The quantification of citral in lemongrass and lemon oils by near-infrared spectroscopy. *Journal of Pharmacy and Pharmacology* **54**:1257–1263. http://dx.doi.org/10.1211/002235702320402107

Van Kempen T, D Jackson. 1996. NIRS may provide rapid evaluation of amino acids. *Feedstuffs (USA)*. **12**: 12-15.

TECHNOLOGY #4: E-NOSE FOR DETECTING VOLATILES

E-Nose contacts: Bryce Richardson, brichardson.fs@gmail.com, USDA Forest Service; Marcella Fremgen, marcella.fremgen@westernalum.org, Bird Conservancy of the Rockies; and Jennifer Forbey, jenniferforbey@boisestate.edu, Boise State University

Equipment: Cyranose 320 with PCNose+ Version 10.11 software
Website: http://www.sensigent.com/products/cyranose.html

Introduction

The Cyranose 320 is an electronic nose that is used to compare chemical vapors. The "electronic nose" (or, e-nose) is trained to recognize chemical vapor classes, which are used as standards to analyze unknown samples. The Cyranose 320 compares the unknown samples to the "smell library" in its memory and provides a qualitative assessment of the chemical vapors associated with the sample.

Electronic noses can be trained to identify a wide variety of compounds, but first the instrument must be exposed to the compounds before identifying unknowns by following these steps:

1. Develop a "smell library" using at least ten samples for each substance
2. Samples in the "smell library" must be cross-validated to ensure that the e-nose recognizes and correctly classifies substances
3. Unknown samples can then be compared to the smell library to see how similar the sample is to known substances (to identify substances)

Chemical measurements are produced when the 32-sensor NoseChip recognizes differences in resistance (voltage decreases) produced by interactions with the headspace gases. Each sensor is unique, and therefore responds differently for vapors, creating a chemical fingerprint, or "smell print" for vapors. The patterns produced by sensors are analyzed using principal components analysis (PCA) for pattern recognition.

Application of E-nose technology

The Cyranose 320 has primarily been developed for and used in medical and environmental monitoring applications. Some examples include breath-based diagnosis of diseases, pathogen identification, pneumonia diagnosis, air quality monitoring, and food quality testing. See links on the Cyranose 320 website for more detailed information about these uses:

http://www.sensigent.com/products/cyranose.html.

Example 1: Disease diagnosis
Source: Fend R, R Geddes, S Lesellier, HM Vordermeier, LAL Corner, E Gormley, E Costello, RG Hewinson, DJ Marlin, AC Woodman, MA Chambers. 2005. Use of an electronic nose to diagnose *Mycobacterium bovis* infection in badgers and cattle. *Journal of Clinical Microbiology* **43**(4): 1745-1751.
URL: http://jcm.asm.org/content/43/4/1745.short
Summary: The e-nose was used to evaluate whether both cattle and badgers tested positive for infections with *Mycobacterium bovis* (tuberculosis), thereby providing wildlife managers with a rapid, cost-effective, and relatively non-invasive test. The e-nose had 100% accuracy for detections in both species, negating the need for destructive sampling. The e-nose could be used to diagnose other wildlife health issues, especially for species of concern where destructive sampling is a common detection method.

Example 2: Evaluating food quality
Source: Pathange LP, P Mallikarjunan, RP Marini, S O'Keefe, D Vaugan. 2006. Non-destructive evaluation of apple maturity using an electronic nose system. *Journal of Food Engineering* **77**: 1018-1023.
URL: http://www.sciencedirect.com/science/article/pii/S0260877405005868.
Summary: The e-nose was used to classify fruits as immature, mature, or over-mature using volatile organic compounds. The classification was validated using destructive sampling (puncture strength, starch index). The classification accuracy was 83%. The e-nose could be used to evaluate wildlife forage.

Example 3: Evaluating diet selection
Source: Unpublished work, Marcella Fremgen (Bird Conservancy of the Rockies) and Jennifer Forbey (Boise State University).
URL: N/A
Summary: The e-nose was trained to identify sagebrush species present at different field sites in Idaho. After cross-validation, the e-nose was tested to be sure it recognized new samples of each plant species. Finally, fecal pellets were tested to see if the e-nose could recognize which sagebrush species were consumed by sage-grouse at that site. This method can be compared to monoterpene profiles produced from gas chromatography for both plants and fecal pellets, which can be used to identify diet, but is costly and time-consuming. The classification accuracy for identifying each sagebrush species (n=2) was 100% at each site (n=2). Classification of fecal pellets from each site was less accurate (with about 50% success at each site for 10 samples per site) for determining which plants were consumed at a foraging patch, compared to analysis using gas chromatography. This study could be extended to diet selection studies for other species, and costs could be compared between monoterpenes analysis using gas chromatography and e-nose.

Other Applications
Cheng ZJ, G Warwick, DH Yates, PS Thomas. 2009. An electronic nose in the discrimination of breath from smokers and non-smokers: a model for toxin exposure. *Journal of Breath Research* **3**: 1-5. http://dx.doi.org/10.1088/1752-7155/3/3/036003

Zheng X, Y Lan, J Zhu, J Westbrook, WC Hoffmann, RE Lacey. 2009. Rapid identification of Rice Samples Using an Electronic Nose. *Journal of Bionic Engineering* **6**: 290-297. http://doi:10.1016/S1672-6529(08)60122-5

TECHNOLOGY #5: ADVANCED TELEMETRY SYSTEM

Telemetry contacts: Alan Krakauer, ahkrakauer@ucdavis.edu, University of California, Davis; and Gail Patricelli, gpatricelli@ucdavis.edu, University of California, Davis

Equipment:
- Encounternet Master Node
- Encounternet Base Stations (Solar & Conventional)
- Encounternet Solar Tag

Website: http://encounternet.net/

Introduction: While animal telemetry has long been a critical tool for wildlife biologists, traditional VHF transmitters have some limitations for collecting large volumes of high-resolution data. A variety of new transmitter designs, including those that couple GPS logging with other types of sensors, provide powerful opportunities to study how secretive animals such as grouse move through and interact with their environment.

One advanced telemetry system, the *Encounternet* system, was first developed for automated remote study of animal social networks. Lightweight **encounternet tags** can detect and log the proximity of other tags and exchange copies of their previous encounter logs. Encounternet engineers have broadened the capabilities of the tags into modular platforms that can potentially support a range of sensor types. The system also includes autonomous logging **base stations** (solar or battery powered) and a **master node** that serves as a Yagi antenna interface between the tags and base stations and a laptop running **Pymaster**, the Encounternet software. Advanced biotelemetry systems such as Encounternet represent unparalleled tools for studies of animal behavior and ecology. They can provide fine-grained information on activity and space use necessary to leverage the detailed maps of food quality and risk generated by other exciting conservation techniques, such as those discussed at this workshop.

Application of Encounternet Technology:
Encounternet animal tracking systems were first developed for proximity logging applications, such as measuring social networks, lek attendance by females, or nest-box visits by cavity-nesting birds.

Example 1: Greater Sage-grouse behavior monitoring
Source: Unpublished work, Alan Krakauer, Gail Patricelli, Amy Dirksen and Orr Spiegel (UC Davis).
URL: http://patricellilab.faculty.ucdavis.edu/; http://www.alankrakauer.org
Summary: Our studies of Greater Sage-grouse *Centrocercus urophasianus* employ Encounternet tags that log **GPS** and **3-axis accelerometer** data. The GPS tag provides data on landscape use and spatial movements away from the lek. The accelerometer data provides information on animal posture and body movement, thereby allowing us to determine what an animal was doing when using a particular area. The combination of these data sources allows us to link maps of bird activity with measurements of forage and habitat quality detailed in the other workshop stations. We can examine how off-lek activities relate to on-lek behaviors observed by video and audio monitoring and experiments with the robotic females. In sum, we gain a much more robust understanding of foraging ecology in a difficult-to-observe organism, and have an exciting opportunity to study, at the level of individuals, the feedbacks between on-lek courtship effort and off-lek behavior. Data-rich telemetry systems such as Encounternet sensor tags typically operates on higher frequency radio signals than traditional VHF radiotelemetry, resulting in a reduced range, especially for animals close to the ground such as grouse. We place base stations and master nodes on leks, where males are reliably found. Interacting with tags during non-lekking seasons could be challenging unless the birds are predictable in their movements.

Example 2: Mate selection
Source: Mennill DJ, SM Doucet, KA Ward, DF Maynard, B Otis, JM Burt. 2012. A novel digital telemetry system for tracking wild animals: a field test for studying mate choice in a lekking tropical bird. *Methods in Ecology and Evolution*. **3**(4): 663-72.
URL: http://onlinelibrary.wiley.com/doi/10.1111/j.2041-210X.2012.00206.x/abstract
Summary: Examines the utility of an advanced telemetry system for automated monitoring of a tropical lekking species. The system (small autonomous receivers and lightweight Encounternet tags) was able to detect simulated visits of transmitter-equipped females to male display territories where automated receivers had been placed. Moreover, distance vs. signal strength relationships were derived in order to estimate tag-receiver distances, and was capable of differentiating simulated visits to display perches versus nearby branches only 5m away. This demonstrates the potential to provide flexible, automated, and prolonged monitoring which could lead to greatly increase the spatial and temporal scope of social or ecological interactions.

Example 3: Social interactions
Source: Snijders L., et al. 2014. Social networking in territorial great tits: slow explorers have the least central social network positions. *Animal Behavior* **98**: 95-102.
URL: doi:10.1016/j.anbehav.2014.09.029
Summary: Describes the utility of an advanced telemetry network for simultaneously monitoring the movement and interactions of a population of small songbird. The system (another Encounternet system) featured close to 100 autonomous receivers deployed throughout the breeding grounds; the pattern of detection for each transmitter could be used to determine the location of many birds over long periods of time with high temporal resolution. This study leveraged these locations to identify events in which two

males interacted with each other in close proximity. This dataset of interactions was then used to construct the males' social network

Other Applications and Reviews

Brown DD, S LaPoint, R Kays, W Heidrich, F Kümmeth, M Wikelski. 2012. Accelerometer-Informed GPS Telemetry: Reducing the Trade-Off Between Resolution and Longevity. *Wildlife Society Bulletin* **36**: 139-146. http://onlinelibrary.wiley.com/doi/10.1002/wsb.111/abstract

Brown DD, R Kays, M Wikelski, R Wilson, AP Klimley. 2013. Observing the unwatchable through acceleration logging of animal behavior. *Animal Biotelemetry* **1**: 20-36. http://link.springer.com/article/10.1186%2F2050-3385-1-20

Kays R, PA Jansen, EM Knecht, R Vohwinkel, M Wikelski. 2011. The effect of feeding time on dispersal of *Virola* seeds by toucans determined from GPS tracking and accelerometers. *Acta Oecologica* **37**: 625-631. http://www.sciencedirect.com/science/article/pii/S1146609X1100107X

Kays R, MC Crofoot, W Jetz, M Wikelski. 2015. Terrestrial animal tracking as an eye on life and planet. *Science* **348**: aaa2478. http://www.sciencemag.org/content/348/6240/aaa2478.full

Nathan R, O Spiegel, S Fortmann-Roe, R Harel, M Wikelski, WM Getz. 2012. Using tri-axial acceleration data to identify behavioral modes of free-ranging animals: general concepts and tools illustrated for griffon vultures **215**: 986-996. http://jeb.biologists.org/content/215/6/986

Wilmers CC, B Nickel, CM Bryce, JA Smith, RE Wheat, V Yovovich. 2015. The golden age of bio-logging: how animal-borne sensors are advancing the frontiers of ecology. *Ecology* **96**: 1741-1753. http://onlinelibrary.wiley.com/doi/10.1890/14-1401.1/abstract

Resources:

Additional Analysis Software

AcceleRater: A free online tool for behavioral classification from accelerometer data.
http://accapp.move-ecol-minerva.huji.ac.il/

Animal Tracker and MoveBank, http://www.orn.mpg.de/animal_tracker

Tracklab GPS Analysis, http://www.biotrack.co.uk/tracklab-gps-analysis.php#s4

Alternative Hardware Vendors

E-obs, http://www.e-obs.de/products.html

TechnoSmart, http://www.technosmart.eu/index.php

UvABiTS, http://www.uva-bits.nl/system/

TECHNOLOGY #6: BIOMIMETIC ROBOT

Robotics contacts: Gail Patricelli, gpatricelli@ucdavis.edu, University of California, Davis; and Alan Krakauer, ahkrakauer@ucdavis.edu, University of California, Davis

Equipment Details: Custom made robotic female sage-grouse
Website: http://patricellilab.faculty.ucdavis.edu/research/

Introduction: Biomimetic robots can be a powerful tool for eliciting behaviors, studying behavioral interactions, and approaching free-living animals for data collection. We have used robotic female sage-grouse (fembots) in **playback experiments** for all of these purposes (Figure 4). Playback experiments involve playing simulated or recorded behaviors back to other animals to elicit a response. The classical playback experiment involves playing a recorded song to a territorial male bird to learn the function (i.e. "meaning") of the song or measure the responsiveness of the target male. We use the robot as a 3D interactive playback of female behavioral signals and cues, allowing us to learn the function of female behaviors during courtship and measure male responsiveness to these signals in a controlled fashion. The robot also allows us to collect courtship display data on all males on the lek, including peripheral or juvenile males that are difficult to observe courting females (because real females avoid them). This allows us to study how male behavior—the quality of male displays and the responsiveness to female signals—relates to male fitness (measured as mating success), and thus how selection acts on male behaviors.

The robotic females have been especially powerful in combination with other technologies. For example, we have been using the Encounternet radio-tracking system to measure male foraging success and collect samples for analysis of diet quality using near infrared (NIR) spectrometry; we can then relate these measures to male display effort measured during controlled courtships with the fembots and to observations of male mating success. This allows us to examine links between ecology, off-lek foraging behaviors, foraging success, display behaviors and fitness. In future work, we will examine how male behaviors relate to the topography and vegetation cover on and around the lek using data collected with Unmanned Aerial Systems, LiDAR and Terrestrial Laser Scanning.

Figure 4. A robotic female sage-grouse (fembot) and remote controller (left). A male greater sage-grouse courting the fembot (right).

Applications of Biomimetic Robotics:

<u>**Example 1:** Breeding behavior</u>
Source: Patricelli GL, AH Krakauer. 2010. Tactical allocation of display effort reduces trade-offs among multiple sexual signals in greater sage-grouse: an experiment with a robotic female. *Behavioral Ecology* **21**: 97-106.
URL: doi: 10.1093/beheco/arp155
Summary: Examines tradeoffs in male sage-grouse courtship between display quantity (strut rate) and acoustic quality, and how males may tactically adjust their displays to avoid such tradeoffs. Used controlled approaches of the robotic female sage-grouse to experimentally induce changes in male display rate, and measure consequent changes in quality. Found that unsuccessful (non-mating) males face a tradeoff between quantity and quality, whereas successful males appear to tactically allocate their limited display energy by responding to female behaviors.

<u>**Example 2:** Breeding selection</u>
Source: Koch R, AH Krakauer, GL Patricelli. 2015. Investigating female mate choice for mechanical sounds in the male Greater Sage-Grouse. *The Auk* **132**: 349-358.
URL: http://dx.doi.org/10.1642/AUK-14-63.1
Summary: Examines variation among male sage-grouse in a non-vocal sound, the "swish", produced during courtship displays when males rub their wing feathers across highly-modified feathers on their chests. Used controlled approaches of the robotic female sage-grouse to experimentally induce courtship in males. Found significant variation among males in these sounds, but no relationship between the acoustic features of the sound and male mating success.

Other Applications and Reviews:
Patricelli GL. 2010. Robotics in the Study of Animal Behavior. In: Breed MD and J Moore, (eds.) *Encyclopedia of Animal Behavior*, volume 3, pp. 91-99. Academic Press.
Krause J, AF Winfield, JL Deneubourg. (2011). Interactive robots in experimental biology. Trends in Ecology & Evolution **26**(7): 369-375. doi:10.1016/j.tree.2011.03.015

Resources:
Futaba remote controller systems:
http://www.futaba-rc.com/systems/futk8100-8j/index.html
Tank kit for chassis:
www.robotmarketplace.com/products/package10.html

Taxidermy body form for robot:
http://www.mckenziesp.com/GBF17-P4878.aspx
Camera for robot:
http://www.veho-muvi.com/muvi_product/muvi-pro-micro/

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