

Vegetation Community Functioning on the Barrier Islands of the
Delmarva Peninsula: Investigation of Site Water Relations and
Environmental Change, and the Use of an Experimental Lidar to
Determine Leaf Area Index

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Master's Project

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Abstract

The proposed study will investigate the effects of site water conditions on barrier island vegetation, and further apply the findings to the characterization of the relationship between these water/vegetation conditions and environmental forcing factors such as sea level rise, climate change and geomorphologic change. Measurement of vegetation biophysical properties like Leaf Area Index (LAI) will be accomplished with a unique small-footprint airborne scanning *lidar* (Light Detections and Ranging) system. Field sampling will verify remotely sensed data, and describe site water relations. Resource (water), geomorphic, and vegetation assemblage gradients identified by field observation will be tested for correlation with patterns in LAI and other pertinent vegetation measures like height, basal area, and community structure. This novel combination of remotely sensed properties and field environmental data will be developed to investigate fundamental physiological interactions (such as water and LAI in transpiration) and characterize and monitor effects of environmental change on island vegetation.

Introduction

The significance of understanding the physical structure of forests in the context of ecological processes has long been recognized. Monsi et al. (1973) note “...morphological features... have a great influence upon the processes of action and reaction between plants and their environment through the modification and interception of fluxes of radiation, heat, carbon dioxide, etc.” Consequently, productivity is determined in substantial part by canopy structure (Monsi et al., 1973). It follows that these same morphological properties play an important role in site water relations through interception of precipitation and as a surface (leaf area) in transpiration (Gholz et al. 1990).

Barrier Islands are highly dynamic systems, and hence provide great opportunity for study of vegetation dynamics and structure and the controls exerted by various environmental factors. Published work on the ecology of *Pinus taeda* (loblolly pine)-dominated forests of the Mid-Atlantic barrier island system is scarce. Johnson and Young (1993) investigated declines in loblolly on Hog island of the Virginia Coast Reserve (VCR) and performed a dendroecological study of storm activity responses (Johnson and Young, 1992). Hayden et al. (1995) detailed geomorphic controls over island-wide vegetation distribution of the VCR (including the Virginia end of Assateague Island). There appears to be no published literature concerning the ecology of the extensive Assateague Island National Seashore (ASIS) forest.

Recent work by Lefsky et al. (1999) and others (Drake et al., 2003; Means et al., 1999) successfully utilizes *lidar* (Light Detections and Ranging) active remote sensing to estimate three-dimensional biophysical properties like biomass, leaf area index, canopy volume and stratification, and basal area of forests of various types. The lidar instrument to be used in the proposed study is the NASA EAARL (Experimental Advanced Airborne Lidar, see <http://lidar.net/>) developed by Wayne Wright at NASA's Wallop's Island

(Virginia) facility. The study will be conducted in cooperation with the USGS Center for Coastal and Watershed Studies (CCWS) (St. Petersburg, FL). USGS researchers are currently processing EAARL data collected in September 2002, and there has been two subsequent surveys – all performed over Assateague Island. In addition to using these data, the study will entail the scheduling and processing of future surveys of ASIS in Maryland and Parramore Island of the VCR.

The proposed study will attempt to characterize community structure and biophysical properties of forests stands within ASIS using EAARL data. Leaf Area Index (LAI) is a primary parameter of interest because of its wide applicability to forest processes. Ground surveys will investigate LAI and how and at what scale(s) it changes across resource gradients and will be used to validate the remotely sensed metrics. Scales at which changes occur will be determined, and predictive relationships between variables will be developed from the island-wide lidar data sets and ground environmental measures. The site water relations are of particular interest because of the influence of sea level rise on island fresh water table levels (Ehrenfeld, 1990). In summary, the study will examine LAI and its utility as a corollary and predictor of the site water environment.

Ecological Background

LAI is a determinant and result of several forest stand processes of interest in this study. Hebert and Jack (1998) note its applicability as an index of site productivity in loblolly stands “because it affects interception of radiation, assimilation of carbon, carbohydrate storage, transpiration of water and accumulation of nutrients.” It follows to reason that changes in LAI may significantly affect productivity and water availability (Gholz 1990). In their seminal paper, Grier and Running (1977) find that a LAI clearly varies across vegetation zones with a precipitation gradient in Oregon. Water stress can therefore limit LAI, and reduce – more significantly than any other site factor – tree growth in general (Spurr and Barnes, 1980). There is little known, however, concerning the relationship between LAI and site water for individual species (Vose et al., 1994).

Pines of the southeast undergo multiple foliage flushes during a growing season, the number of which is determined by environmental variables - “especially moisture” (Spurr and Barnes 1980). This indeterminate growth makes it difficult to estimate a temporal pattern in loblolly pine LAI (Sampson et al., 2003), thus requiring very specific site information and regular surveys to make accurate characterizations of change. Hebert and Jack (1998) were unable to directly relate a moisture gradient and LAI in loblolly plantations but they note the range in precipitation may have been too small for them to observe significant LAI change within the experimental design.

Though relatively protected from direct overwash impact, the loblolly forests of Assateague can be affected by changing availability of freshwater resources and related surface interactions like those described in Hayden et al. (1995). Here, the researchers describe the interplay of three dynamic surfaces: land, sea and fresh water table. Vertical changes in one or more of these will affect the distance to ground water for vegetation

communities and/or groundwater storage capacity, possibly resulting in assemblage shifts. In this way, geomorphological description can act as a proxy for site water availability (Hayden et al., 1995).

Progressive freshwater table rise could drown the rooting zone of various species on the islands and thus reduce water absorption (Spurr and Barnes 1980). It is unclear if direct salinization of rooting zone water will be an issue in the forest stands of Assateague. Johnson and Young (1993) observed reduced stomatal conductance in coastal loblolly with temporary salt inundation but found the trees recovered quickly. They theorize, however, that frequent inundation would limit growth through reduced gas exchange. A transpiration model (MCHOG) developed for barrier island *Myrica cerifera* that shows the species' sensitivity to sea level and climate changes could be adapted to forest habitats (Shao et al., 1995).

In light of the previous findings, it is apparent that one must make well-informed decisions as to the scope and the scale of changes to be studied in order to develop accurate models and useful analyses. It is expected that EAARL will provide for precise and relatively accurate estimates of the forest parameters of interest (LAI, basal area, community type). Spatial resource gradients should be observable, but as the term of study is only two seasons, temporal change may be difficult to assess directly and may require modeling and chronosequence proxies found in spatial gradients. However, patterns of water availability and LAI may be resolvable back to the first EAARL survey in Fall 2002 using precipitation data. In fact, the extreme deviation between 2002 (near-record drought year) and 2003 (record wet year) precipitation could serve to strengthen the correlations with remotely sensed LAI during those years.

Need for Study

The forests of Assateague Island in Maryland and to a lesser extent those of Parramore Island in Virginia lack baseline information describing ecological processes and functioning. The identification and description of a universal and relatively easily measured parameter may enhance the ability to monitor ecological functioning in these dynamic coastal systems; a particularly important capability in light of the threats associated with global climate change and concomitant sea level rise. Hayden et al. (1995) report that the VCR is undergoing a relative (land subsidence plus real sea-level rise) sea-level change of $+3.0\text{mm yr}^{-1}$. Freshwater reserves atop salt water would rise accordingly, changing site water tables and, theoretically, vegetation communities. Ehrenfeld (1990) writes the effects on “species diversity, community structure, and ecosystem function are likely to be profound.” Water availability plays a major role in vegetation dynamics and productivity, but the governing interactions, including LAI in transpiration and photosynthesis, are not well-understood (Gholz 1991).

It is widely accepted that climatic change can alter vegetation patterns, and Shao et al. (1995) show that barrier island shrub transpiration could be significantly altered by a change in temperature. Altered storm patterns and frequencies could affect island geomorphology and water relations such that maritime forests may experience die-back

such as occurred on Hog Island of the VCR in the 1920's, and recently on North Parramore (Hayden et al. 1995). Salinization of ground and soil water due to sea level rise resulted in observable patterns of slash pine (*P. ellioti*) mortality on Sugarloaf key, Florida (Ross et al., 1994).

In order to predict possible effects to the extent and distribution of vegetation communities, there must be accurate descriptions of site water conditions and sufficiently specific knowledge of site water relations. Currently, fundamental hydrological relationships are not well understood for Assateague. Bolyard et al. (1979) applied a model developed in the Outer Banks of North Carolina to Assateague Island. The paper details the complex nature of freshwater reserves on the island and presents the variables relevant to the hydrological model. Without a detailed resistivity survey of ASIS, the authors note, they can not infer a robust system description. Recently, detailed surveys have been initiated on ASIS that should provide hydrological descriptions likely to be helpful in the characterization of site water conditions.

Potential applications and limitations of small-footprint, waveform-returning lidar need to be documented. Lidar monitoring of vegetation communities may provide a valuable tool in measuring environmental effects and in the identification of areas vulnerable to change. The EAARL technology appears to hold particular promise because of its ability to characterize above ground vegetation as well as bare earth topography – the latter necessary in determining hydrological patterns. This study will involve novel techniques of data processing, analysis, and application that could inform future research and EAARL activity, and support the development of standardized methodologies to monitor LAI and/or other vegetation parameters for use in modeling and interpreting forest stand processes.

Research Objectives

The central question of the proposed study is:

What are the observable patterns in vegetation structural/canopy properties across environmental gradients on Mid-Atlantic barrier islands, and can these data predict the site environment, E.g., water relations? The following are necessary subordinate topics to be addressed within the context of this central question:

- 1) Is the EAARL laser instrument capable of reliably determining LAI, other vegetation metrics, and community distribution?
- 2) Can trends in vegetation properties and community structure be discerned from EAARL data – E.g., what is the appropriate scale? – and further, can they be validated, monitored, and correlated with environmental conditions?
- 3) Can EAARL lidar provide a more precise and less costly dataset than that generated by traditional ground-based surveys for analysis of island-wide ecological functions?

4) Can EAARL data run accurate models of matter and energy fluxes – E.g., evapotranspiration – the framework of which could be widely applicable?

Expected Products

1. A Master's Thesis through the University of Virginia Department of Environmental Sciences; Advisor, Hank Shugart, PhD
2. Publication(s) of work specific to thesis as covered in this proposal, and possibly, related issues
3. Baseline ecological process information and relationships
4. Data processing, synthesis, and interpretation techniques
5. Framework and recommendations for monitoring protocols and for development of mathematical ecological models

EAARL Specifications

From <http://lidar.net>:

The EAARL system is the first airborne lidar to simultaneously map submerged, subaerial, and vegetation covered topography. It uses a 5kHz 532nm 1.2-NS laser, a wide dynamic range high speed optical receiver, and a pair of multi-channel 4-Giga Sample/second waveform digitizers. The system digitizes 192 million samples each second and, using adaptive realtime processing, edits each waveform to accommodate and retain only the complex back-scatter of interest greatly reducing the amount of data which must be stored. The system effectively auto-adapts to the terrain, vegetation covered earth, or bathymetry being mapped.

EAARL departs from other small-footprint lidar instruments in its waveform capability and 532 nm (water penetrating) laser as the existing models are discrete-return and tuned to between 900-1064 nm (Near-Infrared). EAARL's footprint is 20cm, the spacing between each pulse is 2 meters, and its swath width is approximately 240 meters. Surveys performed thus far have covered areas multiple times to increase point density. A high resolution spectral digital camera will be installed to coincide with the next survey of ASIS in the late summer/early fall of 2004.

Estimation of Biophysical Attributes with LIDAR

Much of the foundation for the proposed work lay in studies of large footprint waveform-returning, scanning lidar. Researchers have successfully predicted field-verified stand

variables from lidar -derived information. Lefsky et al (1999) reliably inferred LAI and biomass from lidar data and others have found strong correlations between ground-collected basal area, mean stem diameter (Drake et al, 2003), canopy height and leaf biomass (Means et al., 1999) and the respective lidar metrics.

Recently, similar work has been accomplished with small-footprint discrete-return lidar. Lim et al. (2003), utilizing the first/last and intensity returns of a 20cm footprint lidar (ALTM 1225) found agreement with their ground measures of, for example, LAI (hemispherical photo-derived), and biomass. The same instrument was successfully applied to the prediction of foliage distribution and light transmittance (Todd et al., 2003). Naesset (2002), in a stand assessment (using an ALTM 1210) found agreements between the remote and ground data sets of R^2 0.84 to 0.92 (i.e., lidar data could explain 84-92% of the variation in the field data) where predictions of stem number were the least reliable.

Small footprint lidars can be limited in their ability to penetrate canopies at high scan angles (Means et al., 1999). Canopy height estimates are low in some coniferous forests, as there is lower probability of scanning a tree top with a smaller footprint (Gaveau and Hill, 2003). This may be overcome to a degree by adjusting sampling density, and it is reasonable to assume that the problem is less significant with the more rounded canopies of loblolly pine. Lim et al. (2003) note that lidar could be more accurate than field measures in determining canopy height because of the frequent inability to see the top of the individual canopy from the ground when using traditional instruments.

This study can use similar ground techniques for validations, but there is also potential to relate the measures on an individual tree basis. Accurate ground positions and tree heights could be obtained using a Total Station surveying instrument or perhaps GPS. Additionally, optical markers for the spectral camera could be placed strategically in the study site, and their positions georectified. Coincident spectral information could also enhance the predictability of species-specific biological attributes from EAARL data (Gillespie et al., 2004).

In theory, though the EAARL wavelength (Green: 532nm) is considerably less reflective in vegetation than that typical of terrestrial lidars (NIR: 900-1064nm), the information retrieved is unlikely to be degraded unless, perhaps, scene species vary widely in their “green-ness”. Currently, processing is underway (Amar Neyaghandi, USGS CCWS) on the waveforms of the September 2002 survey, and depictions of return energy per unit volume appear to be resolvable – a major initial step to canopy description.

Field Research Plan

As seen in the previous section, precedents exist in the application of lidar to stand mensuration. In addition to verifying the unique EAARL for such goals, this study intends to investigate the utility of EAARL metrics in analysis of ecological problems. The work will involve an in-depth field analysis of site conditions and vegetation parameters. The latter will also be derived directly from EAARL data from which correlations to site environment will be developed.

Amar Neyaghandi of the USGS is currently developing the terrestrial habitat processing techniques for EAARL data. I intend to work closely with him on calibration of techniques and validation of the basic forest data during the course of the study. USGS CCWS has also requested my assistance in developing a vegetation community map from survey data; a product that will enhance the ecological descriptions developed by the study. I will consult with Dave Richardson (University of Virginia) regarding existing data sets from Parramore to determine their applicability to the current study and how they may inform project development.

Field surveys will begin in early June 2004 and extend through July 2004. A return trip will be made at the time of the next EAARL survey in the late summer/early fall 2004. A second season of work in 2005 will be conducted, likely to occur within a similar time-frame. Initial surveys will involve the determination of resource (water) and geomorphological conditions and gradients, and description of vegetation assemblages with an eye towards intra/inter-species and cross-gradient variation in LAI and other biophysical parameters. Representative areas will be located and mapped and plots/transects established. Six existing USGS plots will be read if needed (per Amar Neyaghandi's processing work) and assessed for possible inclusion in the study.

Currently, it is expected that approximately fifty 0.08-0.10 hectare plots will be established (HH Shugart, personal communication, May, 2004) – though preliminary analyses of selected measures' (E.g., LAI) sample variances may dictate adjustment of this number (Sokal and Rohlf, 1995). From the initial vegetation sample statistics derived from this plot set, an ordination analysis will be performed to determine an appropriate number of plots to be chosen from each 'population' (forest stands within a particular environmental niche like water availability) for in-depth environmental analysis (water, soils, etc.) (HH Shugart, personal communication, May, 2004).

The vegetation measures will include:

- **Leaf Area Index**
derived with a PCA (Plant Canopy Analyzer – LAI-2000; LiCor Inc.).
LAI is the main vegetation parameter of interest here for analysis of environmental interaction (see discussion below)
- **Tree height and DBH (Diameter at Breast Height), and species**
basic indicators of site quality
- **Litterfall estimates**
timing and intensity can be tested for correlation with water patterns
- **Understory cover, species**

- indicate community types and light/resource conditions
- **Transpiration estimates**
by species as determined in literature, and through models to determine relative contributions to site water balance
- **Tree cores of individuals representative of gradient position**
radial growth is affected by water conditions with up to 80% of the variation in conifers due to water stress (Spurr and Barnes, 1980).

The environmental measures will include:

- **Soil description**
variation could indicate water and nutritional controls
- **Water: depth to mottling/water table and soil moisture**
frequent measures could provide a fair assessment of gradients. Zencich et al. (2002) found depth to water table to be a major control over vegetation in a sandy coastal area of Australia
- **Geomorphic characterization**
gathered from lidar bare earth data to point to natural gradient(s), E.g., geomorphic controls over depth to groundwater (Hayden et al., 1995)
- **Meteorological data**
Meteorological records for ASIS and VCR from the time of the initial EAARL survey will be acquired, and representative areas geared with rain gauges.

The PCA was determined to be the most appropriate means of measuring LAI after a review of the literature. Though it is reported that the PCA “systematically” underestimates LAI in coniferous forests (Scurlock et al., 2001), it appears to be the most promising method for this study. A correction method that requires the estimation of total projected needle area: shoot silhouette area ratio through shoot sampling and photographic analysis (Gower and Norman, 1991) will be investigated for possible use. The PCA, in providing instantaneous results, may be most appropriate in “estimat[ing] seasonal patterns in LAI when LAI varies continuously over the course of the year” (Sampson et al., 2003). Destructive (whole-tree) harvesting methods to derive a site-specific dbh to LAI regression (Vose et al., 1994) can result in better accuracy, but are very labor-intensive and the National Park Service (NPS) prohibits resource destruction.

Ground-truthing and plot survey coincident to EAARL surveys will include the georectification of individual trees and precise measurements of height with a Total Station surveying instrument or geodetic grade GPS (property of the NPS). Georectification will be enhanced by the inclusion of the high-resolution digital spectral camera. Also, representative samples of LAI measures will be taken at this time – September is the time of peak LAI for loblolly (Sampson et al., 2003). These data could be instrumental to the characterization of light interactions in the canopy as determined by EAARL.

At present, it is assumed that sampling protocols established during the first field season will be repeated in the second. Accordant with the experimental nature of EAARL, however, it may be necessary to add, remove, or alter sampling procedures in order to

derive information on relationships of interest and/or calibrate analyses. It also remains to be seen in what capacity the spectral camera may be used in the analyses – though this is peripheral to the main line of inquiry.

Summary

The proposed study is designed to assess environmental change and the effects to plant community structure and distribution through, mainly, altered water relations. There is a general consensus among scientists that global climate change is occurring and that rates of sea-level rise are accelerating. Barrier islands can play a pivotal role in analyzing the effects of these phenomena in coastal habitats – yet there is relatively little known about the ecological functioning of the forests of the Mid-Atlantic barrier islands. Leaf Area Index is known to be sensitive to site conditions like water and nutrients, yet precise determinations of the metric can be quite labor-intensive. EAARL lidar data may provide for an accurate derivation of LAI or supply proxies for the analysis of structural change over resource gradients. If so, then EAARL may prove an efficient means of generating data to support the development of relationships and perhaps mathematical models to analyze the effects of environmental change on the interplay between variables such as LAI and site water. In addition, EAARL may provide land managers with a viable new method of monitoring vegetation community structure for assemblage shifts associated with changing environmental conditions.

Proposed Budget June, 2004 – December, 2005

		<u>UVA</u>	<u>NASA</u>
Personnel:	GRA \$9096/year	\$14402	
	Tuition:	\$4864	
Travel:	Auto/Air travel	\$1100	
Supplies:	Field supplies	\$1500	
Lidar Data Acquisition	EAARL (NASA)	*	\$10,000
Total Direct Costs		\$22184	
MTDC			
	Modified Direct costs; less Tuition	\$17320	
Overhead			
	15% NPS negotiated rate x MTDC	\$2188	
INSTITUTIONAL TOTALS		\$24373	\$10,000
GRAND TOTAL FROM NPS		\$34373	

BUDGET EXPLANATION

Graduate student – A half-time Graduate Research Assistantship is requested for Michael O’Connell at a rate of \$9100/year (\$758/month)

Fringe Benefits – 7% summer months

Equipment – N/A

Data Acquisition - *Special Item to be paid directly to NASA, \$10,000

Travel – Funds are requested to cover trips to and from the University of Virginia to ASIS and the Eastern Shore of Virginia for research related activities and air travel to USGS CCWS in St. Petersburg, FL.

Materials and supplies – to perform field measurements

Tuition - Funds are requested to cover ½ tuition and fees of the student involved in the project, based upon \$6318 for 4-8 hours.

Indirect Costs – Indirect costs are requested according to the negotiated amount approved with the Park Service (15%).

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