APPENDIX II

PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION
Cover Page

FOR CONSIDERATION BY NSF ORGANIZATIONAL UNIT (Indicate the most specific unit known, i.e. program, division, etc.)	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? Yes ____ No X ; IF YES, LIST ACRONYM(S):
Ecosystem Studies	

PROGRAM ANNOUNCEMENT/SOLICITATION NO.:	CLOSING DATE (IF ANY):
LTER Program	November 3, 1986

NAME OF SUBMITTING ORGANIZATION TO WHICH AWARD SHOULD BE MADE (INCLUDE BRANCH/CAMPUS/OTHER COMPONENTS)

Department of Environmental Sciences, University of Virginia

ADDRESS OF ORGANIZATION (INCLUDE ZIP CODE)

Department of Environmental Sciences, University of Virginia, Clark Hall
Charlottesville, VA 22903

TITLE OF PROPOSED PROJECT

Long-term ecological research on landscape development and ecological processes in a tide-dominated barrier-lagoon complex: LTER

REQUESTED AMOUNT	PROPOSED DURATION	DESIRED STARTING DATE
$1,994,620	5 Years	November 1, 1987

PI/PD NAME AND SOCIAL SECURITY NO. (SSN)*	PI/PD PHONE NO.
Raymond D. Dueser / [redacted]	(804) 924-7761

PI/PD DEPARTMENT	PI/PD ORGANIZATION
Department of Environmental Sciences	University of Virginia

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ADDITIONAL PI/PD AND SSN*	ADDITIONAL PI/PD AND SSN*
Nuttle, W. / [redacted] Odum, W.E. / [redacted] Oertel, George F.	Shugart, H.H. / [redacted] Zieman, J.C. / [redacted]

FOR RENEWAL OR CONTINUING AWARD REQUEST, LIST PREVIOUS AWARD NO.:	SUBMITTING ORGANIZATION IS ____ IS NOT XX A SMALL BUSINESS CONCERN (see CFR Title 13, Part 121 for definitions).

*Submission of social security numbers is voluntary and will not affect the organization's eligibility for an award. However, they are an integral part of the NSF information system and assist in processing the proposal. SSN solicited under NSF Act of 1950, as amended.

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW:

- ☐ Animal Welfare
- ☐ Human Subjects
- ☐ National Environmental Policy Act
- ☐ Endangered Species
- ☐ Marine Mammal Protection
- ☐ Research Involving Recombinant DNA Molecules
- ☐ Historical Sites
- ☐ Pollution Control
- ☐ Proprietary and Privileged Information

	PRINCIPAL INVESTIGATOR/ PROJECT DIRECTOR	AUTHORIZED ORGANIZATIONAL REP.	OTHER ENDORSEMENT (optional)
NAME	Raymond D. Dueser	D. Wayne Jennings	William E. Odum
SIGNATURE			
TITLE	Associate Professor	Director, Sponsored Programs	Chairman, Environmental Sciences
DATE	October 30, 1986	October 30, 1986	October 30, 1986

NATIONAL SCIENCE FOUNDATION

PROJECT SUMMARY

FOR NSF USE ONLY			
DIRECTORATE/DIVISION	PROGRAM OR SECTION	PROPOSAL NO.	F.Y.

NAME OF INSTITUTION (INCLUDE BRANCH/CAMPUS AND SCHOOL OR DIVISION)

University of Virginia
Charlottesville, Va 22903

ADDRESS (INCLUDE DEPARTMENT)

Department of Environmental Sciences
Clark Hall
University of Virginia
Charlottesville, Va 22903

PRINCIPAL INVESTIGATOR(S)

Raymond D. Dueser et al.

TITLE OF PROJECT

Long-term Ecological Research on Landscape Development and Ecological Processes in a Tide-dominated Barrier-lagoon complex: LTER

TECHNICAL ABSTRACT (LIMIT TO 22 PICA OR 18 ELITE TYPEWRITTEN LINES)

We propose to conduct a long-term ecological research program on the barrier-estuarine system on the Atlantic coast of Virginia. This 1,000-km^2 system has developed during the period of Holocene sea level rise. This LTER project is thus designed to incorporate a wide domain of scales of time and space. We plan to study the interrelationships of secular climate change, sea-level change, island movement, and marsh growth and development with data from dated sediment cores. We plan to study the interrelationships of the current climatic environment, stochastic climatic disturbances and surficial landscape processes such as plant and animal succession with data from remotely-sensed imagery, field and laboratory experimentation, and direct field observation of population distributions and processes such as decomposition and element cycling. A system of three coupled models, including a biogeochemical process model, a succession model and a landscape model, will be used both to guide and to synthesize studies of processes occurring on different scales of time and space.

NSF Form 4 (7-83)

Table Of Contents

LIST OF FIGURES AND TABLES

FIGURES

TABLES

I. PROGRAM DESCRIPTION

I.A. Objectives

Events and processes important to the functioning of ecosystems occur over several orders of magnitude of scale in space and time. Two of the central problems in ecosystem ecology are (1) to identify and measure events and processes that operate on more than one scale and (2) to identify general procedures for aggregating or disaggregating data for processes occurring on different scales (Rosswall and Woodmansee, in press). Risser (1986) has identified the "scale problem" as a central difficulty in mounting interdisciplinary environmental research programs:

> Scientists have realized that our understanding of large-scale geospheric-biospheric interactions is significantly limited by the difficulty of dealing with the disparities in spatial and temporal scales used for studies in terrestrial, freshwater, marine and atmospheric environments. For example, because of heterogeneity in landscape, information collected at a small scale (e.g., square meters) cannot readily be extrapolated to characterize vegetation over large areas (e.g., square kilometers) that is required as input to atmospheric models.

Long-term (Callahan 1984) and large-scale (Forman and Godron 1981) research strategies hold great promise for identifying events and processes that occur on multiple scales. Both strategies, applied simultaneously, will be required for identifying general aggregation/disaggregation procedures.

The proposed LTER project is designed to investigate ecological processes representing a wide domain of scales of time and space (Fig 1.). Emphasis will be directed toward coupling ecosystem dynamics to larger-scale events and processes. We propose to address these issues with long-term environmental data to be collected on the Virginia Coast Reserve (VCR), a 14,170-ha barrier island-estuarine system on the Atlantic coast of Virginia. Ecological patterns are evident on the VCR at scales ranging from a few meters (e.g., vegetation changes along the gradient from high marsh to low marsh) to several kilometers (e.g., the north-south gradient in the ratio of marsh surface to open lagoon). Similarly, important processes occur on temporal scales ranging from minutes (e.g., microbially-mediated nitrogen transformation on tidally-exposed sediments) to decades (e.g., marsh succession forced by eustatic rise in sea level). The interrelationships among these events and processes at such apparently disparate scales is the focus of the proposed research. The VCR is thus an excellent location for investigating the local, regional and global implications of landscape/marine and landscape/atmosphere interactions.

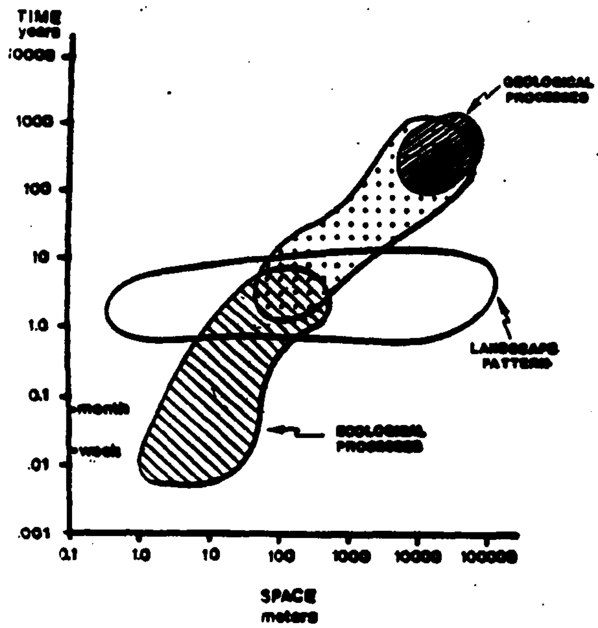


Fig. 1: Temporal and spatial scales important to ecological research on the Virginia Coast Reserve LTER study site.

Our general objectives are (1) to reconstruct (in outline) the Holocene geological history of the VCR, to describe antecedent landform conditions, (2) to identify and measure the rates of response of this barrier-lagoon system to climatic events, sediment deposition and erosion over the past 75 years, to describe the development of the present landscape, and (3) to identify and measure the rates of ecosystem processes (e.g., primary production, groundwater movement), to describe the functioning of the modern landscape. Accomplishment of these objectives will resolve the first of the central problems outlined above, identification and measurement of events and processes that occur on more than one scale. The required data will come from dated sediment cores, remotely-sensed imagery, and direct field observations and experiments, all concentrated on a series of box transects between the islands and the mainland.

Identification of general procedures for aggregation/disaggregation will be tackled with mathematical modelling. Individual models will be constructed to function at a specific time/space scale, a traditional approach that uses the expertise of participating specialists in the best fashion. A novel approach to model integration will then be used. The key questions to be addressed are (1) how do long-term changes in the landscape influence ecological succession along transects across the barrier-lagoon complex ("disaggregation" from large to intermediate scales) and (2) how do fine-scale ecosystem processes control the development of these same transects ("aggregation" from scales to intermediate scales)? The first question can be approached in a rather straightforward manner for the VCR: large-scale changes control the position of the beach face which is the primary boundary condition for any transect. The second question will be approached using statistical methods to summarize the *synthetic* data derived from the process *models* in a form suitable for the transect-level model. That is, time-series outputs of complex models can generally be related to forcing functions in a much simpler way than through the original model structure. For example, one might develop a simple statistical time-series model that would serve as an excellent predictor of marsh productivity simulated by a complex process-level model. Such simple relationships capture the essence of the dynamic behavior of the fine scale and serve as appropriate aggregations for the transects. This recently-developed model application already has proven highly effective (Young, Hornberger and Spear 1978).

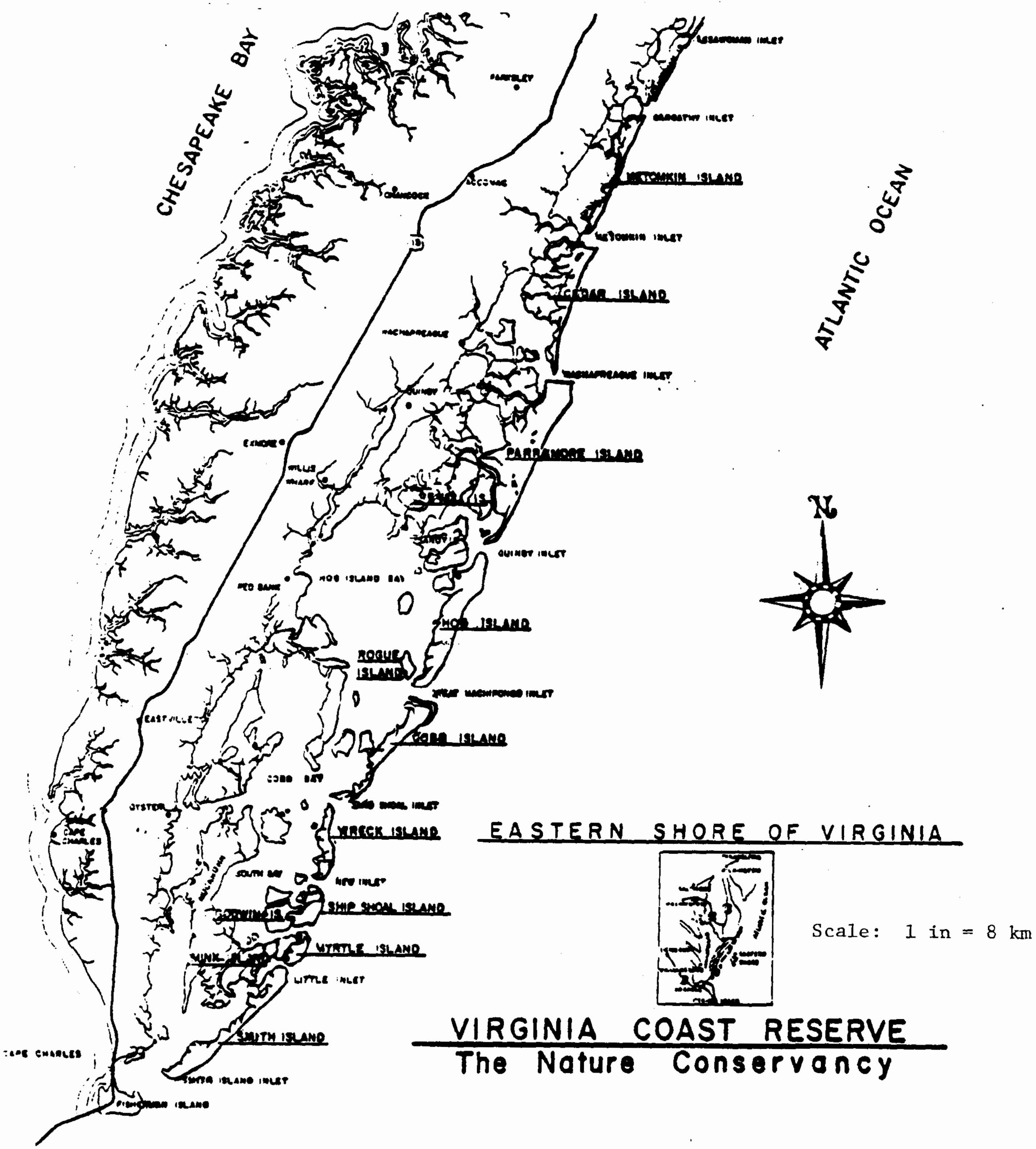
I.B. Site Description

The proposed study site extends 100 km along the seaward margin of the Delmarva Peninsula, from Assawoman Inlet southward to the mouth of Chesapeake Bay (centered on 37° 30' N and 75° 40' W). This barrier-lagoon complex includes barrier islands and intervening inlets, back-barrier islands, and extensive bays, tidal flats and salt marshes (Fig. 2). Although the islands have been inhabited sporadically since the landing of Captain John Smith in 1608 (Graham 1976). they remain isolated.uninhabited and relatively little changed from the natural state (Dueser et al. 1976). The Nature Conservancy (TNC) in 1970 designated approximately 14.170 ha of islands and marshes as the Virginia Coast Reserve. dedicated to conservation. education and research (Cutler and Jenkins 1976). The VCR is now a Man and the Biosphere (MAB) Reserve. Most of the marsh and island acreage outside the VCR is under state or federal control. The area is bounded by Chincoteague National Wildlife Refuge on the north and Fisherman's Island National Wildlife Refuge on the south.

This barrier-lagoon complex formed during late Holocene rise in sea level (Shideler et al. 1984). The actual time of development of the barrier chain was probably similar to that of other barriers along the mid-Atlantic coast. 5,000 to 6,000 years B.P. Newman and Munsart (1968) reported that the Wachapreague Lagoon. has been in existence for at least 5.500 years. This barrier-lagoon complex has been undergoing continuous. relatively rapid change throughout much of the late Holocene transgression. The islands have migrated across the continental slope at a rate adjusted to local sea level stand. The islands may have migrated as much as 4 km landward during the past 4.500 years (Finkelstein 1981). The modern islands continue to experience shoreline recession. with local erosion rates as high as 13 m/yr (Dolan and Hayden 1983). The islands range in area from 29 ha (Little Cobb) to 2.197 ha (Parramore. Dueser and Brown 1980).

The back-barrier lagoon is a complex of shallow open bays. tidal inlets and creeks. tidal flats. salt marshes and marsh islands. Shallow sediment cores indicate progressive lagoonal infilling following the development of the barrier island system. Shideler et al. (1984) attribute this infilling to a combination of overwash from the retrograding barrier system. the development of flood-tidal deltas. and *in situ* marsh

Fig. 2: The proposed Virginia Coast Reserve long-term ecological research site includes the islands, bays and marshes along the seaward margin of the Delmarva Peninsula.



development. Infilling may have been promoted by a reduction in the rate of Holocene rise in sea level and an increase in back-barrier sedimentation rates relative to local subsidence rates. Shideler et al. (1984) describe a probable developmental sequence from shallow open bays, to tidal flats, and eventually to salt marshes in areas where the substrate aggraded to upper intertidal levels that would permit the growth of halophytes.

Different units of the lagoonal landscape have developed at different rates. Marsh development is most extensive in the immediate back-barrier fringe areas, reflecting relatively rapid substrate aggradation by overwash processes. Pre-Holocene paleotopography also seems to have influenced modern marsh development, with salt marshes developing preferentially on paleotopographic highs (e.g., Mockhorn Island) but not on paleotopographic lows (e.g., Smith Island Bay). Both back-barrier sedimentation rates and late Pleistocene paleotopograph have controlled modern marsh development.

Rates of lagoonal sedimentation are known from only a few locations in the VCR. Shideler et al. (1984) accept a radiocarbon date of 1,430 ± 80 B.P. for a -0.4 m core sample as the inception of salt marsh development. This date may indicate attainment of a quasi-equilibrium state associated with present sea level and the beginning of salt marsh development along the mainland shoreline. Marsh development appears to have proceeded relatively rapidly. Maps published prior to 1912 show less marsh surface than at present throughout most of the area (Shepard and Wanless 1971). Consequently, the present extensive lagoonal complex appears to be a highly ephemeral feature.

Dueser et al. (1976) compiled a VCR ecosystem description, including synopses of climatology, soils, vegetation and biogeography. The vegetation of the islands and marshes is conspicuously patchy, with distinct zonation and sharp transitions between patches. High and low salt marshes, unvegetated sand flats, grasslands, shrub savannas and maritime forests occur in close proximity, with little transitional ecotone. This heterogeneity results from the combined effects of variation in the substrates, topography and disturbance. Because the terrestrial and marsh communities are perched on a relatively thin wedge of sediment, topographic effects on groundwater depth and salinity are pronounced. Groundwater varies from fresh (under high dunes) to saline or hypersaline (in areas subject to frequent saltwater flooding).

The climate of the VCR is dominated by extratropical frontal storms (i.e., northeasters) and by tropical storms and hurricanes (Dolan et al., in press). On the average 38 extratropical storms occur each year that are of sufficient magnitude to rework beach sands and to elevate tides above astronomical extremes. Much of the morphological structure of the islands, and consequently the vegetative cover, is forced by the hydraulic reworking of sands during storms. In addition, these storms are largely responsible for the landward migration of the islands across the lagoonal marshes. In effect, there is an ongoing perpetual experiment in ecosystem disturbance and plant succession.

Vegetation heterogeneity is further accentuated by climatic variation along the island chain. Precipitation records from island weather stations along the mid-Atlantic coast indicate a range of variation from 85 cm/yr (as in Kansas) to 140 cm/yr (as at the Okefenokee Swamp). This variation arises primarily from variation in summer rainfall, with thunderstorm frequency varying with local land/sea temperatures (the heat-island effect). In addition, 45% of late summer and autumn rainfall comes from tropical storms, although the central section of the VCR is in a tropical storm frequency minimum (Simpson and Riehl 1981). The VCR has a mild, marine-dominated thermal climate, and falls within plant hardiness zone 8b. Average minimum annual temperature varies from 15° to 20° F. Average temperatures during the coldest month (January) exceed 40 ° F.

The adjacent Delmarva Peninsula supports a rural population dependent primarily on agriculture and fisheries for subsistence. Land use is 29.1% agricultural land. 29% woodland. 32.2% tidal marsh. 1.5% coastal beach and 8.2% miscellaneous. Anthropogenic effects are thus largely restricted to agricultural chemicals washing into the VCR watersheds. Furthermore. the long. narrow mainland lacks large watersheds and major rivers. Sediment loads are modest and floodwater discharges small and short-lived (Virginia State Water Quality Control Board data). The landscape dynamics of the VCR thus are not dominated by fluvial or terrestrial influences.

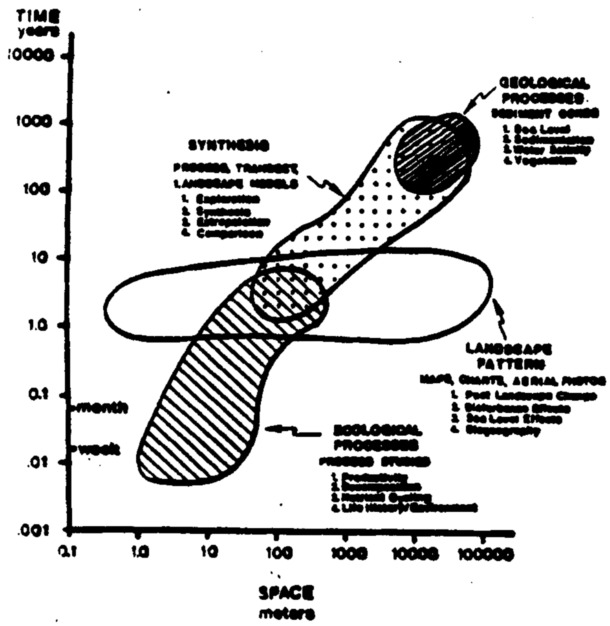
The University of Virginia. Old Dominion University. the Virginia Institute of Marine Science. NASA (Wallops Island) and The Nature Conservancy have conducted extensive environmental monitoring and systematic research programs focused on the VCR for the last 25 years. Archives of data from their research form a solid base for the proposed LTER. Of special note is the voluminous archive of NASA Wallops mapping quality aerial photography of the VCR. Much of this imagery has been digitized and is readily available for historical landscape analysis.

Protection afforded by TNC ownership assures site access and integrity for the duration of the study (Appendix 2). TNC farm properties on the mainland assure deep-water access and access-control to study sites every few kilometers along the Peninsula. TNC property in Oyster. Virginia provides a dedicated. centrally-located LTER base of operations and laboratory. A staffed housing facility on Hog Island provides a seaside base of operations. Flow-through saltwater laboratories and a northern shore base of operations are available through the VIMS Eastern Shore Laboratory in Wachapreague. Virginia. Conference facilities and a research library are available through the NASA Wallops Island facility.

I.C. General Approach

The general objectives outlined in Section I.A. will require research on multiple scales of time and space (Fig. 3):

Fig. 3: Temporal and spatial domains of the observations, experiments and modelling proposed for the VCR/LTER site.



1. Centenary-to-millenial scale changes in the landmass, as recorded in Holocene sediment cores (5,000 years B.P., with resolution of 500 years).

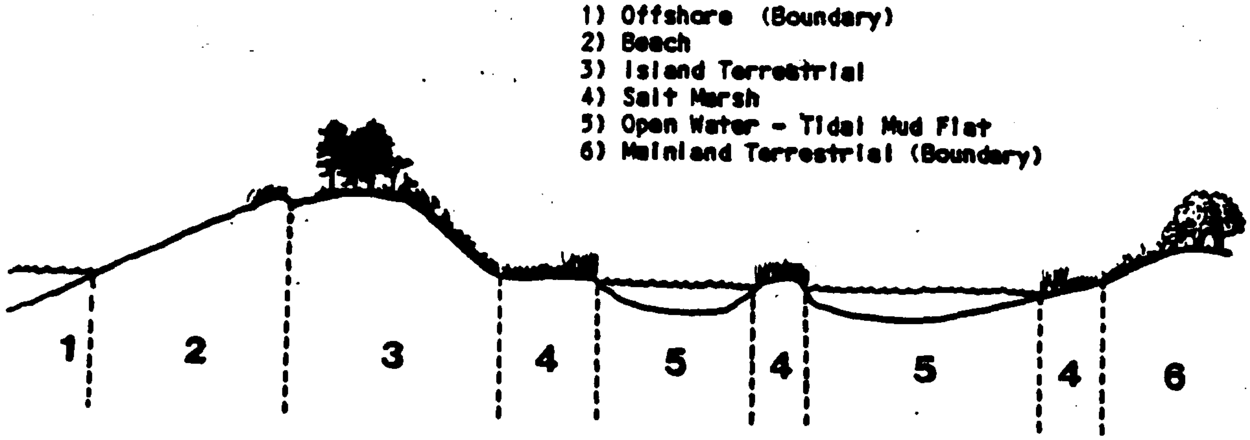
2. Decadal-to-centenary scale changes in landforms and vegetation, as recorded by mapping and remote sensing. Approximately 50 sets of remotely-sensed images since 1933 record landscape changes and disturbance effects in great detail.

3. Annual-to-decadal scale changes in the landscape, ecological processes (i.e., productivity, decomposition and element cycling) and the biota, as measured by direct observation and experimentation in the field.

4. Monthly-to-annual scale variation in the measured rates of processes such as primary production will be extrapolated to larger scales through the use of process models.

These objectives also require environmental monitoring on multiple spatial scales, ranging from 0.1 m^2 studies of grass density to VCR-wide biogeographic surveys. The islands of the VCR contain a variety of terrestrial environments (e.g., dune fields, grasslands, shrublands and forests) interwoven with semi-terrestrial environments (e.g., mud flats and tidal marshes) and aquatic environments (e.g., tidal creeks, bays and inlets). We recognize six basic landscape units within the VCR (Fig. 4).

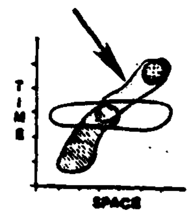
Fig. 4: Hypothetical sea-to-land transect through the landscape units of the VCR.



This conceptual model underlies much of the modelling philosophy and sampling protocol detailed below. Biological, geological and hydrological processes all play a conspicuous role in determining the structure and function of these landscape units and in creating steep environmental gradients. These units are related to one another by succession (in some cases) and by geological processes such as sedimentation (in other cases). The diversity of environments available for study, and their close juxtaposition, creates opportunities for comparative studies of ecosystem processes across a ranges of conditions.

A variety of sampling protocols will be required to capture the significant sources of variation operating in the VCR (e.g., extensive biogeographical surveys, point sampling, time-averaged sampling). Detailed protocols are discussed below. Our overall strategy, however, is designed to capitalize on the structure implicit in Fig. 4. A series of "box transects" will be established between the islands and the mainland. Each will be several hundred meters wide and several kilometers long, and will be positioned to intersect topographic highs. These transects will be the focus of intensive (e.g., process) studies, recurrent population censusing and instrumented monitoring. We plan to concentrate on a single transect in the short-term, from Hog Island to TNC headquarters at Brownsville, near the center of the VCR (Fig. 5). This transect will include representative samples of each of the major landscape units from barrier shoreface to mainland forest. Transects from Cedar Island to Wachapreague and from Cobb Island to Oyster will be instrumented at a later date. These three locations offer close proximity shoreside facilities. Transect data will be recorded on the box transect mapping system (BTMS). This mapping system will overlay the universal transverse mercator system (UTM) presently in use by the TNC.

II. MODELING AND SYNTHESIS



Computer simulation models of biogeochemical cycling, ecological succession and landscape dynamics will play four vital roles at the VCR/LTER site:

1) **Exploration** -- to guide prioritization and physical/temporal scaling of data collection efforts;

2) **Synthesis** -- to achieve synthesis and integration of process-level information and observations collected on different physical and/or temporal scales;

3) **Extrapolation** -- to develop predictions (that can be tested either directly or with strong inference); and

4) **Comparison** -- to achieve comparisons of ecosystem behaviors across the wide range of LTER ecosystem types.

We will develop a set of three interfacing ecosystem models (Table 1).Each model will operate on a different scale of space and time (fine scale, transect scale and landscape scale). The coupling of the fine-scale models to the transect model will be

Fig. 5: Hog Island Bay intensive study site. This box transect will be established and instrumented during year 1.

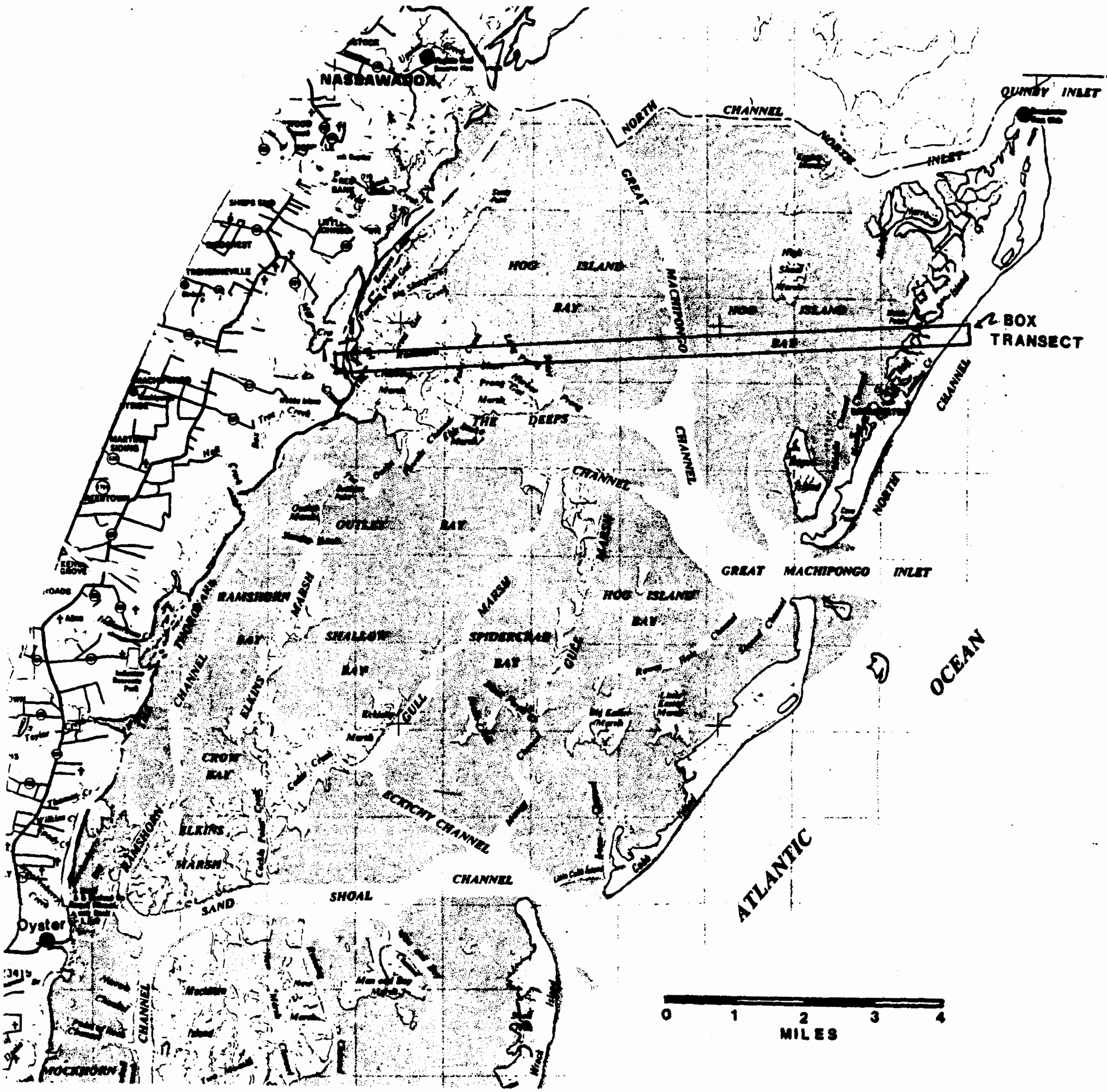


Table 1: General descriptions of models to be developed in conjunction with the Virginia Coast Reserve LTER site.

Process Models

Description: Models emphasizing processes that have analogs in any ecosystem (e.g., decomposition).
Form: Differential and difference equations.
Time Scale: Typically annual-to-decadal.
Space Scale: Size of sample unit used to obtain parameters. Can be scaled to large size by multiplying by areal extent, under an ergodic assumption.
Validation: Time and space scale allow model testing in projects with LTER study durations.
Initial Applications. Spartina marshes. Nutrient cycling models will be applied to all major lamdscape units.

Transect Models

Description: Models of succession, vegetation (modeled at the individual plant level to interface with proccess models), hydrological and geomorphological dynamics.
Form: Simulation models. Hydrology derived from solutions to partial differential equations describing hydrogeological behavior of barrier islands; vegetation from nested, individual-plant stochastic simulator; geomorphology from landscape model.
Time Scale: Decadal-to-centenary (millenial in some applications).
Space Scale: 2-dimensional transects approximately 10 km long and extending 5 m above and below ground level. Can be replicated to obtain 3-dimensional patterns in landscapes in which transect to transect interactions are small.
Validation: Some direct observations can be used to test the models when these data are collected at an LTER. Air photographic records and paleoecological data provide long-term tests based on inference.
Initial Applications. Continued development and testing of prototype model developed for terrestrial landscapes units.

Landscape Models

Description: Models of change in landscape pattern under the influence of storm events and eustatic sea level rise.
Form: Markov models of change for each of thousands of small cells in the landscape mosaic. Probabilities in the models are conditioned by dynamic variables (e.g., sediment transport).
Time Scale: Decadal-to-centenary.
Space Scale: 10 by 10 km or larger.
Validation: Data from aerial photography, development of model for one locale and testing at another locale.
Initial Applications. Simulation of dynamic change of the location of active foredunes of barrier islands.

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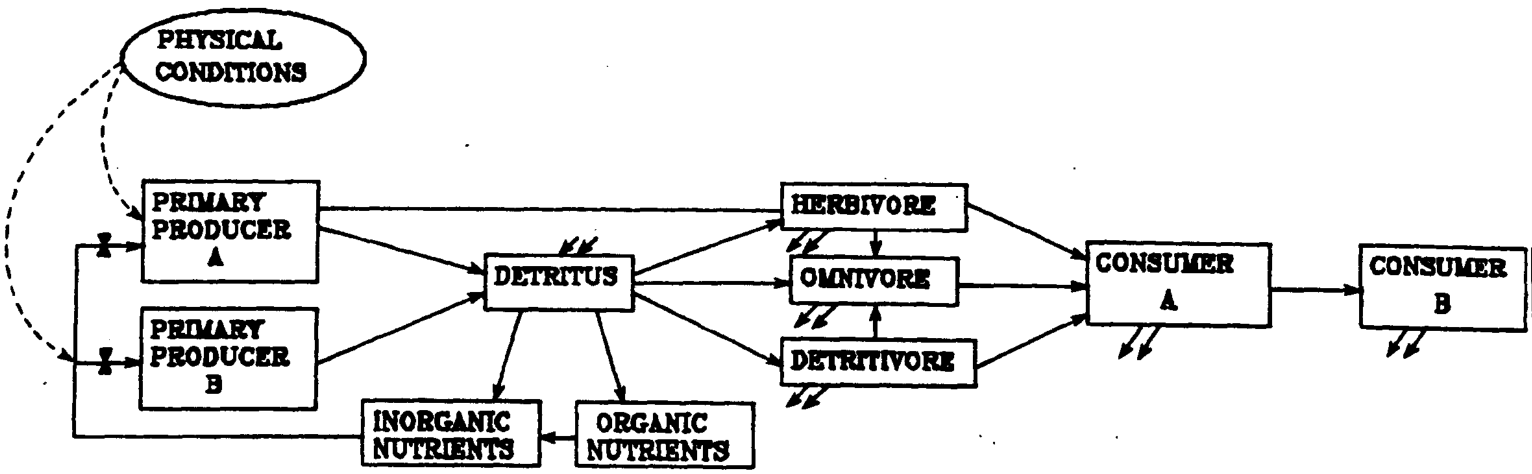
through common state variables related to primary productivity, decomposition and element cycling. The interfacing between the transect and landscape models will involve common state variables relating to spatial location.

II.A. Process Models. Compartmental process models of carbon and nitrogen storage and flux will be developed based on models such as the marsh process model for the North Inlet LTER site (Summers et al. 1980, Summers and McKellar 1981) and a similar model developed previously at the University of Virginia (Zieman and Odum 1977), along with information obtained from the proposed studies of this project. Initially, two methods of coupling the carbon and nitrogen cycles will be explored. One approach will utilize two distinct carbon and nitrogen models that are linked within the primary producer compartments, similar to the approach of Hopkinson and Day (1977), while the other will utilize a mass-flow model where a nitrogen submodel acts as a control on carbon flux, similar to the model of Kremer and Nixon (1978). Aspects of the nitrogen cycle that may serve to control rates of processes (e.g., nitrogen fixation, nitrification and denitrification) will be explicitly included in the models. This has not been done previously for models of coastal ecosystems (Wetzel and Wiegert 1983).

Because of the areal extent of *Spartina* salt marsh landscape unit (Section I.C.) and the importance of marshes in processing both matter and energy, we will focus initially on developing process models for marshes. Following development of prototype models from published sources (there is a large body of extant data) and from data collected previously by our research group for comparable sites, initial field work will concentrate on measurement of pool sizes within each landscape unit (Fig. 6).

Fig. 6: Representation of a possible model structure. Major compartments and fluxes of interest are those to the left and center.



Process models are the traditional modelling paradigm for ecosystem-based modelling studies. A major problem with attempts at using models for comparisons between ecosystems has been that model structures used for different systems are usually very different. As a result, few intercomparative studies are possible owing to the widely varying model structures that have evolved. A central concept in our development of process models is to represent the various ecological units within the larger system using a single model structure with parameters appropriate for each ecological unit.

Because we are comparing landscape units with widely differing environmental conditions (e.g., salt marshes, tidal mud flats, and beach dune communities), we expect wide variation in rate matrices among the different units. Pool and flux values with high numeric values in some units will be essentially zero in other units. By retaining the same model structure, however, the differing sizes (or even existence) of certain pools between the ecological units, and the magnitudes of the fluxes can be directly compared to infer the relative importance of various processes in the units.

II.B. Transect Models. We have considerable experience with computer simulation models of ecological succession based on individual organism response (*e.g.*, Shugart 1984) and we are aware of applications in heathlands (e.g., Van Tongeren and Prentice 1986) and grasslands (Lauenroth, pers. comm.). Succession models have proven capable of predictions that can be used in applications and also have inspired a continued theoretical development of ecological concepts (Shugart 1984).

Most succession models simulate plots of vegetation. The plots do not interact and their location in space is therefore unspecified (i.e., the models are not "spatially explicit"). If between-plant interactions can be ignored when the plants are more than a certain distance apart and if it can be determined which plants should be included in the "competitive neighborhood" of a given target individual, then spatially explicit interactions can be quantified. Transect modelling performs this function in one horizontal direction. If the individuals are catalogued by location along the transect, the interactions among individual plants of differing life-forms, a central problem in the VCR study site due to the mixture of landscape units, can also be included in a transect model.

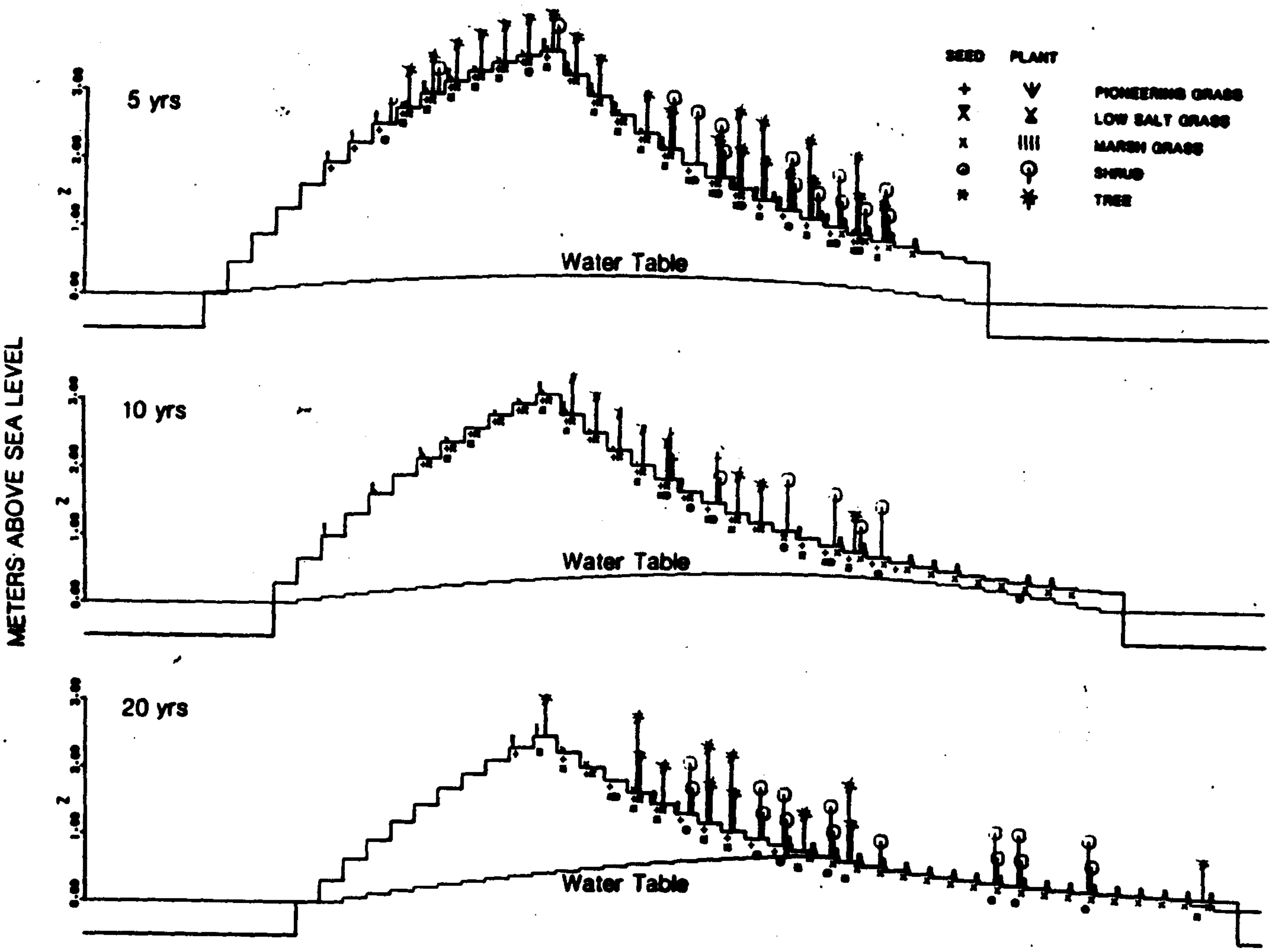
Transect models are most applicable to situations where the community is strongly zoned along some environmental gradient. Ecosystem/environment interactions are frequently conceptualized as responses of transects to gradients (see, for example, the illustrations in Watts' classic 1947 paper). Many dynamic physical processes that contribute to the pattern and responses of ecosystems over time can be simulated by models in a single horizontal dimension. Barrier-lagoon systems are long in the direction parallel to the coastline relative to the direction across the island. Many physical processes are therefore constrained, more-or-less, along transects across the island. Ground water flow, for example, is usually well-described along such transects (e.g., Anderson 1976, Kashef 1977, Ayers 1980).

Shugart et al. (1986) have developed a prototype transect model of vegetation dynamics for a coastal dune ecosystem. In the model, seed availability and environmental factors affect sprouting, growth and mortality. Several important physical variables are simulated dynamically -- notably height of the water table, height of the sand mass at any point and ground- water salinity. The model is driven by the position of the zero- height beach front, the seaward shoreline. A sample simulation (Fig. 7) features the development of a horizontal gradient of vegetative pattern, a reduction in dune height due to aeolian erosion, a landward displacement of the dune system (a consequence of vegetation-mediated aeolian transport of sand), and the eventual development of a back-barrier marsh as the water table moves to the surface behind the dune. This sample output is indicative of the richness of behavior that can be developed from transect models.

We will improve this prototype model by using data for important ecological processes and site-specific physical information obtained in the course of the LTER monitoring program. For example, the treatment of ground water flow in the prototype model is very simplistic. Improvements will be made by using solutions to the partial differential equations describing hydrogeological behavior of barrier islands, equations that include salt water-fresh water dynamics. A quasi 2-dimensional model will be used initially. Bal (1977) suggests that this approximation is appropriate for the simulation of ground water flow on the Delmarva Peninsula. This assumption will be evaluated for the VCR site during the course of the work proposed here. We will develop solutions

Fig. 7: Sample output from a computer model simulating the pattern and dynamics of vegetation along a transect across a barrier island from shoreface (on left) to back-barrier marsh. Over the time of the simulation, the dune flattens, the island moves landward, watertable rises, and a back-barrier brackish marsh forms. Trees and shrubs come to occupy a position behind the sheltering dune (Shugart et al. 1986).

CROSS SECTION OF ISLAND AT 5, 10, and 20 YEARS



to the ground water equations for holotypic transects. Using results of these simulations, statistical relationships between pertinent hydrological variables and geomorphological variables will be developed in a manner similar to that reported by Bolyard et al. (1979). These statistical relationships will form the ground water component of the successional transect model.

The salt marsh section of the transect model will initially be based on a model developed by Zieman and Odum (1977) and reviewed by Wiegert (1979). This model is composed of repeating species modules for each of the dominant plants. In each module, each species grows as a function of limiting variables. The differing responses of the individual species are incorporated by embedding response curves within each module to characterize the response of given species to the selected environmental variables. Because of the modular structure of this system, other species and driving variables can very simply be added as needed.

II.C. Landscape Models. Our approach to simulation of large-scale change in this highly dynamic landscape will follow from the work of Kessell and Potter and their colleagues (Kessell 1976, Cattelino et al. 1979, Potter et al. 1979, Kessell and Potter 1980, Kessell 1979a, b). The model will be a Markov model with parameters for likelihood of vegetation change at different locations on a landscape. Output of the landscape model will be a vegetation map which will change over time as a function of sea level change and salt water overwash. It should be noted that this model, unlike the transect model, will *not* simulate mechanisms but will involve a statistical representation of the space-time evolution of the VCR.

II.D. Model Integration. Our approach includes three levels of models: a large scale Markov model, an intermediate scale (transect) successional model and small scale ecosystem process models. One of the challenges in large-scale environmental research projects is in appropriately integrating models of such disparate scales. We maintain that for this LTER project, the successional model must occupy a central position and that the other models *must* work toward making the central one as rigorous as possible. The successional models have proven to be most readily "transportable" to sites other than those for which they were developed (i.e., they are most appropriate for intercomparisons involving several LTER sites). We have already exchanged succession models with Dr. McKellar at the North Inlet LTER site, Dr. Lauenroth at the Central Plains LTER site and Dr. Franklin at the Andrews LTER site.

The interface between the largest scale (Markov) model and the successional model is straightforward. The former will be designed to provide the key boundary condition to the latter. That is, the Markov model will provide a temporal sequence for the position of the zero-height beach front, the "toe" that drives the successional transect model.

The small-scale ecosystem (process) models directly reflect the detailed ecological research. These models are applied to areas where very fine-scale measurements are feasible. The transmission of this detailed information to the transect level is not routinely achieved. We anticipate success because we will not try to aggregate the detailed models directly into a "grand" transect model; rather we will summarize the pertinent features of the detailed models using statistical relationships. (See discussion relative to ground water models above.)

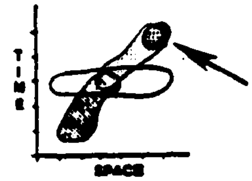
II.E. Initial Use of Models. Models typically are used in ecosystem studies for synthesis, extrapolation and comparison. These roles are implicitly assumed and, at least in part, explicitly described in the previous exposition of the models. The other role that we envision for the models -- Exploration -- is not routinely used. Yet this will be the initial emphasis of our modelling work.

The essential concept in using models in an exploratory mode -- that is, to generate or refine hypotheses and to identify critical uncertainties in knowledge -- is to exercise the model using different parameterizations and to use information on model sensitivity to various processes to isolate areas of deficiency in data. The idea is not new to ecology (e.g., Jeffers 1972, Mar 1974). The procedure for using parameter sensitivity analysis to guide future data collection has been outlined by McCuen (1976).

Our approach in the exploratory mode will use a derivative of the prototype transect model. The model will be run using Monte-Carlo techniques and various indices of the behavior of the model will be noted. One method for a regional sensitivity analysis applicable to such problems is outlined in Hornberger and Spear (1981). The method has much in common with the work of O'Neill, Gardner and their co-workers (e.g. see O'Neill et al. 1982). Such model analysis procedures will be applied to the transect model to identify critical areas of uncertainty. Special attention will be paid to these areas in design of the monitoring program.

The modeling work will also serve to enrich developing theories on the hierarchical nature of ecosystems (Allen and Starr 1982; Allen and Hoekstra 1984; O'Neill et al., in press) by developing models that can be used to explore concepts derived from this theory. As discussed in Section I.A., the problem of coupling models of different time, space and phenomenological scales is a problem of great importance to systems ecology.

III. HOLOCENE LANDFORM DEVELOPMENT



Working Hypotheses. Three working hypotheses guide our study of the developmental history of the VCR landmass:

1. The depositional history of the tide-dominated VCR barrier-lagoon system has been controlled by the interaction of sea level rise, sediment supply and *local* antecedent drainage patterns.

2. The VCR stratigraphic section records the history of landform change on both recent geological (at least 0-3,000 years B.P.) and historical (0-150 years B.P.) time scales. The rates and patterns of change influence the landform structure and, ultimately, the landscape substrates of the VCR.

3. The substrates of the VCR landscape do not develop independently. Rather, there may be both horizontal and vertical feedback between adjacent units.

Objectives.

Reconstruct the depth and morphology of the antecedent surface from the point of the pre-Holocene outcrop at the mainland to the seaward limit of the upper shoreface.

Determine the relationship between the modern back-barrier, inlet and shoreface channelization patterns and the antecedent drainage system.

Determine the rates of island rollover and lagoonal sedimentation related to overwash and foreshore retreat.

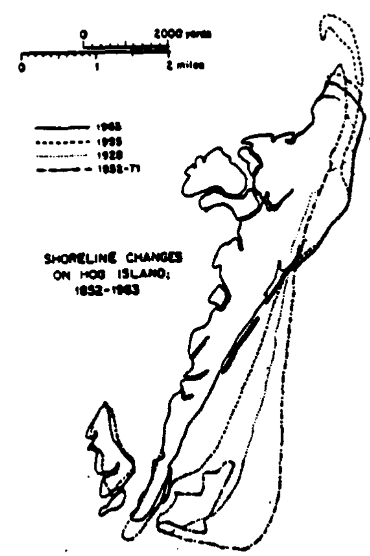
Construct a local rate curve for sea level rise and a series of vertically-stratified landscape sections.

Motivation. Much of the controversy concerning the origin of the Virginia barrier islands stems from the fact that there is not a detailed record preserved in the sedimentary deposits of the processes responsible for their formation (Leatherman

1983). The stratigraphic record is incomplete because the islands have "migrated" through time both vertically and horizontally in response to the relatively rapid late Holocene rise in sea level. However, once the actual barrier islands formed, approximately 5,000 B.P., the sedimentary record preserved in the stratigraphic section more clearly reflects the response of the system to further changes in sea level, changes in sediment supply, and wave and storm climates.

Heron et al. (1984) found that the dominant depositional processes that must be considered in reconstructing the sedimentary history of a barrier island complex are (1) sea level change and associated response of the shoreline and beach, (2) lateral tidal inlet migration and reworking of the barrier island deposits, (3) storm overwash deposition and infilling of back- barrier lagoons, and (4) flood-tidal delta sedimentation in back- barrier environments. These processes all are active on the VCR. Erosion and accretion have produced major changes over the past 100 years.

We plan to couple stratigraphic data from sediment cores with historical and current geomorphological data to produce a time-stratified landscape section of the VCR barrier-lagoon complex. Our focus initially will be on the sedimentary deposits of Hog Island and and the lagoons and marshes of Hog Island Bay. Hog Island is a large island (1,177 ha) in the center of the VCR. This is an area where landform changes have been pronounced over the past 100 years.



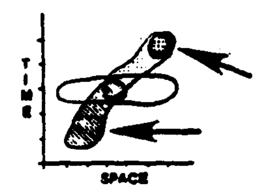
Methods. Vibracoring will be used on the tidal flats of Hog Island Bay, with supplementary high-resolution seismic profiling through tidal channels. High-resolution seismic profiling will be used on the shoreface, with supplementary vibracores. Field data collection and laboratory analyses will be conducted during years 1 and 2.

Approximately half the work is to be accomplished in each year.

Vibracores (approx. 20) will be taken in the interfluve areas of tidal flats between the mainland and Hog Island. Coring will begin adjacent to the mainland and progress seaward to determining the slopes and irregularities on the antecedent surface as well as lithosome preservation between the antecedent surface and the present surface. Ten-meter core liners will be used although the depth of penetration will vary with the depth to pre-Holocene surface. A five-horsepower vibracorer will be used following the technique of Lansky et al. (1979). The cores will be split vertically, logged, photographed, slabbed and x-ray radiographed. Selective samples will be taken from core splits for pollen analysis, C-14 dating and Pb-210 dating.

High resolution seismic profiling will be done with a modified Geopusle Boomer system. Data will be recorded on paper and magnetic tape. Secondary filtering and processing of the data will be done in the laboratory to enhance key reflectors.

IV. RECENT LANDSCAPE DYNAMICS: BARRIER ISLAND AND MARSH DEVELOPMENT AND MIGRATION



Working Hypotheses

1. Development and significant transgression of barrier islands and marshes in the VCR occur on the time scales of decades to centuries.

2. The barrier islands are characterized by relatively bare disturbance patches (or overwash fans) which vary in size from 10'sto100'sof meters in width (along the coast) and 100's of meters to nearly a kilometer in depth (across the coast). The size of these "gaps" is controlled by a number of variables, the most important of which is probably storm recurrence interval.

3. Plant succession on (a) the barrier islands and (b) in the back-barrier marshes is controlled to a considerable extent by the distribution of "disturbance patches".

4. "Young marshes" in the early stages of development can be differentiated from "mature" marshes on the basis of (a) relative sediment accretion rates, (b) vegetation type (including high marsh to low marsh ratio), (c) surface drainage channel morphology, (d) sub-surface hydrology, and characteristics of the marsh soil.

5. Most of the marshes in the VCR are halted at the "young" developmental stage. This partially arrested condition results from (a) a very limited sediment supply for accretion and (b) a temporarily slowed rate of sea level rise.

6. Ignoring large-scale processes, such as sea levelrise, position and migration of specific marsh units is controlled on a small-scale by geomorphological and climatological processes such as overwash events, spit formation, and wind exposure.

7. Marsh development in the VCR is most rapid (a) on back-barrier marshes due to rapid aggradation from overwash processes and (b) in locations which had high late Pleistocene topography.

8. Back-barrier fringe marshes grow more rapidly during time periods of high storm frequency; mid-lagoon and mainland marshes grow more slowly or erode during periods of high storm frequency.

9. Because of low sediment supply, VCR marshes will decline in areal extent during periods of rapid sea level rise. The decline will be most dramatic in mid-lagoon marshes while back- barrier and mainland marshes should remain relatively stable or even expand slightly.

IV.A. Barrier Island Dynamics

Objectives

Continue to update the measurements of (a) the position and dynamics of the beach high water line and (b) the boundary between vegetated sands and active beach sands; initiate measurements of the boundaries between grassland and the shrub savanna zone, the shrub savanna and high marsh zone, and zones within the marshes (see next section).

Determine the return interval and size class of overwash disturbances to better understand dynamics of the barrier island plant communities and for inclusion in the parameterization of the barrier island succession model.

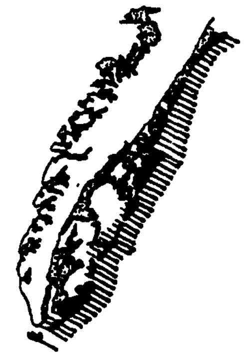
Motivation. Barrier island landforms change rapidly (time scales of decades to centuries) in response to changes in sea level, wave action, storm surge, and sediment supply (Dolan and Lins 1986). During periods of rising sea level, barrier islands migrate shoreward through a process of beach submergence and shoreline recession or transgression (Hicks 1972). Inlets form, fill and reform with important geological and ecological implications (Godfrey 1970). Overwash events transport beach sand completely across the islands to be deposited on the back- barrier edge. Overwash tracks and fans are perturbed frequently during storm events so terrestrial and marsh plant communities must adapt to these disturbances (Fisher and Simpson 1979). Back-barrier marshes tend to develop most rapidly in areas associated with (a) old, filled-in inlets with associated former flood tide deltas and (b) where overwash fans extend completely across the islands and provide a sediment source for marsh accretion (Godfrey 1972).

The landscape dynamics of the VCR appear to be especially exaggerated due to the low sediment supply, the low gradient of the coastline, continuing moderate sea level rise, and local subsidence. Finkelstein (1981) estimates that the Virginia barrier islands have migrated approximately 4 km shoreward during the past 4500 years. Written reports of the islands and intervening marshes from the times of earliest settlement indicate gross changes during the past 200 years. Photographic records date from 1933 and indicate rates of change of the seaward faces of the VCR on the order of 10-13 m/yr (Dolan and Hayden 1983).

Methods. Photographs in the University of Virginia collection are available at approximately pentad intervals up to the early 1960's and yearly or seasonally since then. The more recent data include false color IR and LANDSAT imagery. New acquisitions will be made through NASA/Wallops at least every other year.

Positions of the high water line (HWL) and the transition between bare

Positional data on shoreline dynamics and barrier island vegetation boundaries will be collected and digitized at 100 m intervals along the entire 100 km length of the VCR. Dolan et al. (1978) developed an orthogonal grid mapping system (OGMS) for the analysis of morphology and landcover on VCR islands. The coordinate system consists of shore normal transects spaced at 100 m intervals along the coast.



overwashed sands and grasslands have been mapped at intervals of approximately six yr since the 1930's, based on aerial photography. The data are housed at U. Va. Expansions of this data base to include grassland to shrub- savanna, shrub-savanna to high marsh, high marsh to low marsh and low marsh to lagoonal waters are planned.

IV.B. Marsh Development and Migration

Objectives

Delineate low marsh/high marsh boundaries from aerial photography and ground-level data. Calculate relative areas of low marsh and high marsh at specific sites.

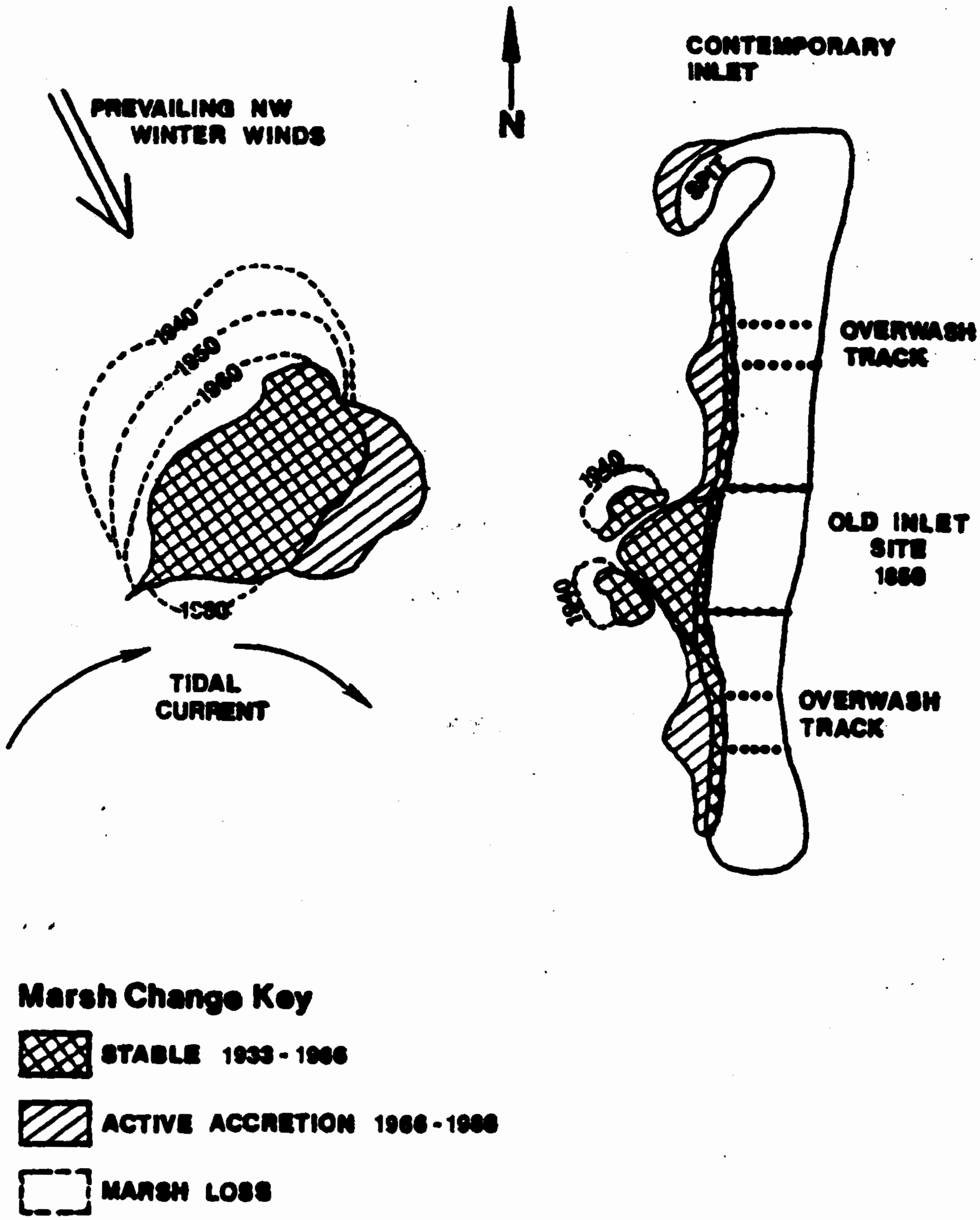
Attempt to differentiate "young", "mature" and "old" developmental stages of marshes based on sediment accretion rates, low marsh/high marsh ratios, tidal creek morphology, subsurface hydrologic measurements, and soil properties.

Carefully analyze marshes along the central box transect from Brownsville to Hog Island for (a) low marsh/high marsh delineation, (b) sedimentation rates using permanent marking rods placed in the marsh, (c) characteristics of the vegetation at permanent quadrats, and (d) developmental characteristics of the marshes listed in no. 2 above.

Analyze the marshes along the Brownsville/Hog Island transect with historical aerial photography to document migration due to exposure to wind fetch, proximity to overwash, plant community type etc. (see Fig. 8).

Expand photographic and ground-level measurements to other sites to test the findings from the Brownsville/Hog Island transect.

Fig. 8: Potential migration of marsh in response to factors such as overwash sites, island spits, wind and wave fetch, and tidal erosion.



Test remaining hypotheses with final data.

Motivation. In a classic work. Redfield (1972) showed that coastal salt marshes develop and migrate in response to a variety of factors including (a) slow to moderate rates of sea level rise. (b) a local supply of sediment. and (c) the growth characteristics and morphology of the marsh plant communities. Vertical accretion rates for salt marshes can be as high as 2-3 cm/yr if suitable supplies of sediment are available (Pethick 1984). Pethick (1981) has demonstrated both experimentally and with model simulations that sediment deposition rates are much higher in the stream-side low marsh than in the high marsh. This was further emphasized by Stumpf (1983) who demonstrated very high deposition rates and "levee" formation in the lowest marshes immediately adjacent to tidal creeks.

Horizontal rates of marsh growth into suitable substrate appear to be limited to 30-40 cm/yr due to limitations of the growth rate of the rhizome system of *Spartina alterniflora* (Redfield 1972). although much higher rates may occur when pieces of rhizome are carried into suitable. unvegetated substrates by current and wave action (personal observations).

Frey and Basan (1978) have hypothesized that Atlantic coastal marshes pass through three idealized developmental stages. These developmental stages are not totally time-dependent but also are affected by variation in local conditions such as sediment supply availability and climate. In fact. it is theoretically possible for a specific marsh to remain in an intermediate state for some time if conditions of sea level rise. sedimentation. etc. are balanced.

We have slightly modified Frey and Basan's original characterization as follows. *Young Marsh* - Characterized by (a) substantially greater than 50% low marsh. (b) highly developed surface drainage systems (1st, 2nd, etc. order tidal creeks), (c) relatively rapid sedimentation rates, (d) active accretion both vertically and horizontally, (e) considerable lateral erosion and rotational slumping along marsh creeks, but little net difference in channel size due to compensatory deposition. *Mature Marsh* - Characterized by (a) approximately equal amounts of low and high marsh, (b) highly developed surface drainage in the low marsh, but partially filled-in channels in the high marsh, (c) considerably lower deposition rates than in the young marsh, and (d) much slower accretion both laterally and vertically than in the young marsh. *Old Marsh* - Characterized by (a) substantially higher than 50% high marsh, (b) surface drainage dominated by sheet flow and largely filled-in tidal channels, (c) extremely low deposition rates and (d) slow or non-existent accretion rates.

Furthermore , based on the results of Harvey (1986) and Nuttle (1986) we further hypothesize that subsurface drainage becomes more important in the older marsh stages due to (a) decreased surface drainage channel networks and (b) increased hydraulic head from increased marsh height.

Marsh development in the area encompassed by the VCR appears to be recent, probably within the past 1000 years (Newman and Munsart 1968). Marsh development during recent centuries probably is due to a reduction in sea level rise and higher sedimentation rates due to local subsidence (Shideler et al. 1984).

Sedimentation rates in the VCR region appear to be very low, although few estimates have been made and they are highly variable. Shideler et al. (1984) report rates ranging from 0.03 to 1.0 cm/yr. The higher rate probably occurred in association with a tidal delta or possibly from sample contamination.

Shideler et al. (1984) hypothesize that marsh distribution in the VCR region results from (a) rapid development on back- barrier fringing marshes due to substrate aggradation by overwash processes and (b) extensive development on areas which had relatively high palaeotopography during the late pleistocene.

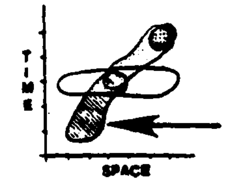
All of these observations suggest that marsh development in the VCR is especially vulnerable to future increases in rates of sea level rise. With a generally low sediment supply to offset future sea level increase, it seems likely that only the marshes on the back fringe of the landward migrating barrier islands will have sufficient sediment to offset increasing relative water depth and a return to largely open water lagoons.

Methods. Photographic and LANDSAT imagery will be analyzed as described in Section IV.A. Information on marsh delineation, tidal creek morphology, etc. will be digitized, placed on the marshlands coordinate mapping system (MCMS) and ultimately analyzed using computer assisted analytical techniques (ERDAS system to be provided by the University of Va. unrelated to this project). Specific marsh areas will be monitored through past time for migration tendencies as related to variables such as prevailing winter wind direction, overwash fan position, late pleistocene paleotopography, etc.

Estimates of parameters such as vegetation type, stem density, soil properties, sub-surface hydraulic properties, etc. will be measured in conjunction with the activities described in Section V at permanent quadrat sites along the Brownsville/Hog Island transect. Permanent stainless steel rods with etched markings will be positioned at the permanent sampling sites to estimate annual and long-term marsh accretion rates.

Both photographic analyses and ground measurements will be expanded in years four and five to sites along the alternate transects or to sites which provide contrasting conditions to the Brownsville/Hog Island transect.

V. LANDSCAPE FUNCTION BASED ON LTER OBSERVATIONS/EXPERIMENTS



Working Hypotheses. Several hypotheses guide our approach to the study of landscape function:

1. The VCR landscape can be divided into distinct ecological units with contrasting patterns of species distribution.

2. Dynamics within each ecological unit can be described with a model with a formulation common to all units.

3. The observable pattern of distribution of ecological units is governed by interactions between units and by constraints imposed by the physical environment. Changes in the pattern can be related to successional changes and changes in the physical constraints (e.g., sea level, climate).

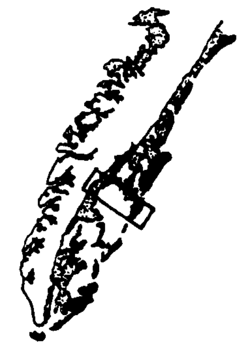
V.A. Physical Controls and Mass Fluxes

Objectives. Characterize the variation of the principal parameters of the atmosphere, surface water, and ground-water environments over daily, seasonal, and annual periods and during extreme events (e.g., storms).

Motivation. The dynamics of the physical environment in coastal areas have a large effect on the overall structure of the landscape mosaic as well as on the internal processes within each of the units of the mosaic. The frequency and intensity of storm events affects the supply and stability of the sediments and thus the lateral growth and vertical accretion of the marshes. Productivity and speciation of wetland vegetation depends on frequency of inundation, salinity, radiation input, and temperature (Zieman and Odum 1977). Water fluxes responsible for transport among units of the landscape are the result of tides or ground-water movement driven by the balance of precipitation, evapotranspiration and tidal inundation.

Methods.

Atmospheric measurements. Two meteorological monitoring stations will be established in year 1, one at each end of the Hog Island box transect in order to capture the extremes of the anticipated range of atmospheric conditions, terrestrial versus offshore island. The monitoring stations will record air temperature, pressure, humidity, wind speed and direction, precipitation and net radiation on at least an hourly basis. Data will be collected and stored digitally and archived after checking for internal consistency.



These data will then be available to characterize baseline atmospheric conditions at any time during the project duration. Evapotranspiration and photosynthetically active radiation and other meteorological variables will be monitored as needed for process studies. We anticipate that trends in such local data can be correlated with the long-term data collected by the continuous monitoring stations.

Surface waters. Continuous monitoring of water temperature, salinity and tide height will be carried out at two stations near the locations of atmospheric monitoring. Data collection and storage will be digital and surveys will be conducted at intervals along the transect to characterize the amount of local variation that occurs in the recorded parameters. Hydrological surveys will be conducted to estimate the freshwater input of all tidal creeks draining the terrestrial boundary of the site. Hydrographical surveys of the tidal currents in the bay will be conducted as needed to characterize mass fluxes of sediment and dissolved material.

Ground water, sediment hydrology. Ground-water movement into the marsh from upland regions, infiltration during precipitation and tidal inundation, and drainage out of the sediment into tidal creeks are potentially important mechanisms for the inter-unit exchange of nutrients and reduced organic and inorganic compounds (Nuttle 1986, Jordan and Correll 1985, Yelverton and Hackney 1986, Agosta 1986, Valiela et al. 1978). Ground-water monitoring of piezometric head and water quality will be carried out as needed to characterize fluxes of nutrients, particularly between the upland and marsh and the island and marsh areas. These fluxes will be studied using the monitoring techniques employed by the authors cited directly above and the techniques for estimating the storage and conductance properties of the sediment and for modeling porewater movement described by Knott et al. (1986), Hemond and Fifield (1982) and Hemond et al. (1984).

We will include the effects of sediment hydrology in our integrative studies of intra-unit processes by monitoring pore pressures continuously, characterizing the observed variation of pressure in terms of frequency and amplitude of variation, and correlating the characteristics of the variability of pore pressure with ecological variables such as productivity, distribution of below ground biomass, and species distribution. Continuous monitoring of pore pressure in the marsh will be done using pressure transducers linked to a digital data acquisition system (Schaefer 1986, Nuttle 1986). The large areal coverage of this project will enable us to correlate characteristics of pore pressure and ecological parameters at numerous points in the successional history of a marsh system.

V.B. Patterns of Inorganic Nutrient Movement

Objectives.

Determine pools of major nutrients (inorganic and total) in each subunit.

Determine rates of internal recycling of nutrients within each subsystem. In particular, the rates of denitrification, nitrification, and ammonification will be measured.

Determine rates of external supply of nutrients to the system.

Determine rates of transport of nutrients between subsystems.

Determine the relative effects of internal nutrient flux, external nutrient supply (either groundwater or overland), and sedimentary input on the primary production and successional development of the salt marshes.

Motivation. One of the basic assumptions of our conceptual model is that all landscape units function similarly in terms of the basic ecological parameters as impacted by control functions such as internal nutrient cycling or external nutrient supply. These functions appear in the model as parameter estimates and pool sizes that should identify each subunit. Initial surveys will examine all the nutrient pools specified to provide information to test the hypothesis of subunit identification. In later years fluxes will be measured at locations selected on the basis of survey data and model analysis.

Methods. Available nutrient pools will be measured in the water column, the sediments, and in the soils in the terrestrial environment. Water samples will be collected quarterly with Niskin bottles or a peristaltic pump. They will then be filtered successively through a precombusted 0.45 um pore-size glass fiber filter for the collection of particulates, and final filtered through a 0.1m membrane filter. Nutrient species to be analyzed include NH_4^+, NO_3^-, NO_2^-, PO_4^{3+}, total N and total P, and $SO_4^=$. Organic N and P will be estimated by difference. Analysis will be done by automated and semi-automated versions of the methods of Grasshoff et al (1983), although we hope to eventually develop ion chromatographic techniques for the various ionic forms. Sediments will be collected by gravity corer or by a diver utilizing a hand corer.

Available nutrients will be extracted with KCl followed by centrifugation, filtration, and analysis as described above. C and N measurements of the total sediments and the particulate filters will be in a Carlo-Erba elemental analyzer. Precipitation will be collected (wet only and bulk collectors) and analyzed to provide data on atmospheric input of chemicals.

Central to the comparison of nutrient fluxes within units will be measurements of the dominant microbial transformations and exchanges: nitrogen fixation, nitrification, denitrification, ammonium mineralization, and sulfate reduction. Our approach to determining these nitrogen transformations and rates will be a combination of *in situ* exchange studies using large field chambers and laboratory studies utilizing ^{15}N isotope tracers utilizing sediments and water collected from each ecological unit. Benthic remineralization of ammonium will be determined *in situ* using opaque 260 l chambers and periodic sampling of the enclosed water. Sulfate reduction rates will be determined with ^{35}S tracer methods detailed by Herlihy and Mills (1985). Benthic nitrification and denitrification will be estimated using sediment cores and ^{15}N incubations and will follow the methods of Jenkins and Kemp (1984). Ammonium production and consumption in sediments will follow the general procedures outlined by Bowden (1984). Nitrification in the water column will be estimated using isotope dilution techniques (Koike and Hattori 1978). Denitrification will be estimated using acetylene blockage and analysis of N_2O concentration over time (Seitzinger et al. 1984; Seitzinger and Nixon 1985). Ammonium remineralization will be estimated using ^{15}N isotope dilution and time series analysis (Glibert and Goldman 1981, Glibert et al. 1982). All incubations will be carried out in opaque chambers at ambient temperature. All water samples will be taken within 1 week of each other and at slack water before flood tidal conditions.

Inorganic and organic nitrogen concentrations will be determined using the methods of Grasshoff et al. (1983). ^{15}N tracer concentrations and enrichment ratios for the dilution experiments will be determined using emission spectrometry. N_2O analyses will be done using gas chromatography and will follow the methods of Seitzinger et al. (1980).

V.C. Pattern and Control of Primary Production

Objectives.

Determine primary production of marsh plants, epiphytic algae, and phytoplankton.

Monitor annual changes in above and below ground biomass of marsh plants.

Determine below-ground production of marsh plants (year 3).

Determine production and biomass of marsh plants as a function of nutrient regime and successional status.

Determine litter fall in marshes.

Motivation. The measurements proposed in this section have several important functions. First they give an indication of the current state of the health of the marshes, and their state of development. In addition, these measurements allow direct intercomparison with other studies, both in the literature as well as ongoing studies at sites like the North Inlet LTER. Finally, these will become important values to be incorporated into the modeling studies. Measurements made at certain places and times will be used in the model generation and parameterization process, while others will be used for verification in the later stages of the project.

Roots and rhizomes represent an important mechanism for retention of carbon and energy as well as other nutrients within the marsh sediments. The magnitude of the contribution of Below Ground Production (BGP) to total marsh productivity is only beginning to be understood and knowledge of the role of BGP in estuarine productivity (movement from the marsh sediments to the estuary) is even more limited. Estimation of below ground productivity will greatly enhance our understanding of the carbon and energy fluxes within and between subsystems.

V.C.1. Plant Species Distribution

Methods.

Salt marshes. The distribution of plants within the salt marshes will be monitored in two ways. Boundaries between plant zones, such as the high marsh/low marsh bounds, will be identified with computer-assisted aerial photographic interpretation (see Section IV). These boundaries will be checked during monitoring of ground-level parameters. The second type of monitoring will involve detailed ground-level monitoring within permanent quadrats. Bimonthly estimates will be made of (a) dominant vegetation (percent area determined with a sighting device), (b) shoot density, and (c) standing crop. The last two will be estimated with the clip harvest technique described in Section V.E. Sampling will be concentrated initially along the Hog Island Bay transect and then expanded to contrasting areas during the last two years of the proposed study.

Terrestrial Plant Communities. Monitoring of the pattern and changes of the terrestrial plant communities will utilize permanent sample quadrats for each of the life form of plants in the terrestrial environment. The spacing of the quadrats will be on the order of 50m to make the scale compatible with that of the landscape modeling work and thus suitable for use as ground truth site for the air photo interpretation. The sample methods for terrestrial plant communities have been reasonably well-developed over the past several decades. It is our plan to sample the trees in a fashion that is compatible with the Coweeta LTER site (*ca* 0.1 ha circular quadrats with location, species, DBH and height of each tree). We will use sampling protocols from the Jornado LTER site for our shrub sampling, and will adopt a sample methodology identical to those at the Central Plains LTER site for our grass and herbaceous plant sampling. We will use ancillary experiments to determine germination requirements, tolerance to shading, salinity and other factors. These experimental plots will be used to fill in information that is needed for the transect model parameters and will be located well off the permanent transects.

V.C.2. Annual Primary Production

Methods.

Phytoplankton Production. Primary production (carbon fixation) will be estimated for phytoplankton in the water column of open water areas and marshes by measuring the rate of incorporation of $^{14}C\text{-}HCO^3$ (Davis and Williams 1984, Peterson 1980, Steeman Nielsen 1968). Modifications of this method will also be used to determine the contribution of algae at the surface of the marsh sediment, and intertidal mudflat areas. Additional initial sampling of terrestrial areas will help to determine if those areas need to be considered during the regular sampling. These determinations will be made at selected station along the transect at intervals determined based on the survey sampling undertaken during the first year. Stations will be allocated among all of the subgroups depicted in Figure 4.

Marsh Plant Production. Above ground production of marsh plants will be estimated using the clip-plot technique of Wiegert and Evans (1964) as modified for salt marshes by (Kirby and Gosselink 1976). Sampling will be done with 0.25 m^2 quadrats bimonthly and will be concentrated along the Brownsville - Hog Island transect. During the last two years of the proposed study, contrasting locations will be selected for additional estimates.

Production by roots and rhizomes of marsh plants may be several times greater than that of the above ground biomass (Howes et al. 1985, Schubauer and Hopkinson 1984, Valiela et al. 1976). Methods for measuring BGP have been reviewed by Howarth and Hobbie (1982) and briefly by Howes et al. (1985). Comparison of estimates of BGP give remarkable consistent results even though a wide variety of techniques have been used to measure productivity (see Table 2).

BGP will be monitored along the transect at time intervals to be determined during the initial survey work (initial 2-3 times per month during periods of greatest metabolic activity - June through Sept- and once per month the remainder of the year) using CO_2 evolution from sediment cores as described by Howes et al. 1985. At several sites along the transect total macroorganic matter will also be determined as an alternate method of estimating BGP.

Terrestrial Production. Terrestrial production will be based on remeasurement of the permanent plots in the case of the slower-growing woody species and will be determined by clipping on small plats located off of the main transect for grasses and herbaceous species. The availability of productivity data for many of the components in the terrestrial system, coupled with our initial emphasis on the salt marsh for more detailed process, mandate that the terrestrial productivity studies will be initiated as the need for such work is made obvious by our model analysis. We feel that an adequate data base exists ,including a substantial unpublished U.Va. masters thesis (Schnieder 1983), to begin with reasonable estimates of above-ground terrestrial productivity.

V.D. Pattern and Control of Organic Matter Accumulation in Surface Layers and Sediments

Objectives.

Table 2. Published values of above- and belowground net productivity for *S. alterniflora* and *S. cynosuroides* estimated with harvest techniques. (After Schubauer and Hopkinson, 1984)

Location	Species	g dry mass m^{-2} yr^{-1} net primary production above	below	total	Reference
Nova Scotia	S. alterniflora	803[1]	1051[7]	1851	Livingstone and Patriquin, 1981
Massachusetts	S. alterniflora	420[2]	3500[4]	3920	Valiela et al., 1976
New Jersey	S. alterniflora short	500[6]	2300[3]	2800	Smith et al., 1979
North Carolina	S. alterniflora				
	short	650[5]	460[5]	1110	Stroud and Cooper, 1968
	tall	1300[5]	500[5]	1800	Stroud, 1976
Georgia	S. alterniflora				
	short	1350[1]	2020[3]	3370	Gallagher and Plumley, 1979
	tall	3700[1]	2110[3]	5810	Gallagher et al., 1980
Georgia	S. alterniflora medium	2840[1]	4780[2]	7620	Schubauer and Hopkinson, 1984
Georgia	S. cynosuroides tall	2200[1]	3560[3]	5760	Gallagher and Plumley, 1979
Georgia	S. cynosuroides tall	3080[1]	4628[2]	7708	Schubauer and Hopkinson, 1984

Key to productivity estimation methodology:

1 incorporating turnover

2 summing periodic changes in masses of live and dead material through an annual cycle as per Smalley, 1958

3 maximum - minimum mass of total macro-organic material

4 maximum - minimum mass of dead material

5 maximum - minimum mass of live material

6 not reported

7 maximum functional (live) biomass

Determine litter fall in marshes.

Determine decomposition rate (weight loss, C, N) of marsh plant litter in the bay, on the marsh surface, and in the wrack zone.

Determine rate of below ground decomposition of roots and rhizomes.

Motivation. Because of its key role in the recycling of material throughout the landscape, and its role (in combination with production) in sediment accumulation, investigations of the differences in mechanisms and quantity of decomposition will be compared among the ecological units. Part of our goal in experiments within the LTER framework will be to examine innovative approaches to the examination of decomposition in field situations. Initially however, traditional methods will be utilized to provide a data base for comparison between subunits and for comparisons of results with other LTER sites and studies conducted outside the LTER framework.

The decomposition of below-ground plant material appears critical in terms of the assertion by Frey and Banus (1978) that most of the organic matter accreting in sediments is derived from the roots and rhizomes of the plants in marshes of the Mid-Atlantic region. Thus it is necessary to determine the rates of belowground decomposition to ascertain the contribution of belowground productivity to sediment accumulation and organic matter deposition. With few exceptions (Morris et al. 1986) this process is largely ignored.

Methods. Plant species utilized will consist of the dominants from each of the subunits. Litterbag decomposition studies for that plant will be made within its native subunit, and also within any subunit that might receive the vegetative material by some transport mechanism using the techniques of Zieman et al. (1984). The final species utilized will be determined following the surveys but will definitely include *Spartina* *alterniflora*, *Spartina patens*, and leaves of the appropriate terrestrial trees and shrubs. Decomposition experiments will be initiated several times throughout the year in order to examine the decomposition process in a more complete manner than is done by single season experiments. Materials will be collected from traps that are used to determine litter fall over an annual cycle. In the decomposition experiments, measurements will be made of the changes in ash free dry weight (AFDW), carbon, and nitrogen in the decomposing material. Changes in microbial abundance and activity in the decomposing litter will be made. Other work in Chesapeake Bay and South Florida, has shown that microorganisms represent only a very small fraction (ca 1%) of the total mass of material in the detritus complex (unpublished data). Furthermore, microbial productivity (incorporation of detrital plant organic carbon) as measured by the rate of 3H-thymidine incorporation into DNA (Moriarity and Pollard 1982) was consistent with weight loss data when respiration of the microbes was taken into account. These measurements will be continued in the proposed study and will include time-dependent changes in microbial productivity associated with the decaying material in each of the ecological units.

Additionally, decomposition experiments will be undertaken in which roots and rhizomes are extracted from sediments, placed in bags and buried in the sediments at the various sites. Clearly, the amount of disturbance to the site and to the plant material is likely to preclude a large number of samples to be collected frequently. Nevertheless, these measurements will aid in determination of between-site differences as well as differences in processes with greatly different time constants (e.g., litter accumulation, organic matter burial).

V.E. Consumer Processes

Objectives.

Develop a checklist of the organisms present in each subsystem and their relative abundance, as indicated by trawl and bottom grab samples.

Determine the trophic base of selected consumers in differing ecological units by means of stable isotope analysis.

Motivation. The surveys will determine the presence and relative abundance of the consumers, especially the dominant ones in each of the ecological units. Many of the consumers utilize detrital material that may originate in another ecological unit and be transported across unit boundaries. Certain organisms are migratory while feeding, and may forage and rest in different areas, while others are seasonal migrants. The studies in this section will determine which organisms are present within specific ecological units, and will aid in delineating how these organisms are using each of the differing habitats.

Methods. To determine trophic linkages both within and between ecological units, consumers will be collected for stable isotopic analysis. Faunal sampling will utilize trawls, throw nets, and sled nets for mobile fauna and hand sampling for plants. Samples from the decomposition experiments will be subjected to analysis to determine isotopic changes during decomposition.

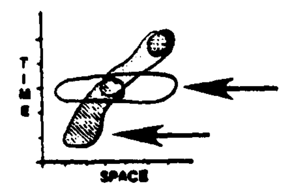
After collection all samples for isotopic analysis will be rinsed in sea water to remove sediments and transported on ice to be processed. Where necessary samples will be acidified to remove adhered carbonate and oven dried at 45° C or lyophilized, ground in a Wiley mill, and stored in scintillation vials over silica gel.

Animal samples will be from white muscle tissue. Samples will be frozen if immediate processing is not possible. Prior to isotopic determination all samples will be oven dried at 45° C for 24 hours and homogenized in a Waring blender. The powdered samples will be stored in vials on silica gel. Muscle tissue is used because it is efficiently sampled and has been reported to have ^{13}C values that are representative of the whole organism (Fry 1981).

Most samples for isotopic analysis will be composite samples consisting of equal weights of tissue from 5-10 individual grass blades, crabs, or other sample organisms. Pooled samples from 5- 10 individuals have been found to yield an accurate estimate of the ^{13}C value (Fry and Parker 1979).

Stable isotope ratios, particularly of carbon, nitrogen, and sulfur, have proved highly useful in tracing of food webs and the sources of organic matter (Fry 1981, Peterson et al. 1984; Zieman et al. 1984). Measurable and distinct isotopic ratios exist between terrestrial material, salt marsh plants and detritus, and phytoplankton. We will use stable isotopic ratios of organic material to determine exchanges of organic matter between the different ecological units. This study will focus on two major transfers between the units: (1) the transport of plant material and detritus by water currents between the units, and (2) transport by consumers which may reside in one unit but forage within an adjacent unit.

VI. SPATIAL AND TEMPORAL DISTRIBUTION OF POPULATIONS SELECTED TO REPRESENT TROPHIC STRUCTURE



Working Hypotheses. Three hypotheses guide our approach to the study of population distribution and abundance:

1. The biogeographic history of an insular biota is influenced by factors ranging from climate change on geological time scales (Brown 1971) to natural catastrophes on ecological time scales (Schoener and Schoener 1983).

2. The insular biotas of the VCR must have been assembled over the past 5,000 years. Except for the plant and microfossils contained in the sediments, however, there are no temporal records of development for the insular floras and faunas.

3. The most certain route to understanding how these biotas came to be -- and how they might respond to future environmental change -- is through a combination of long-term observations (e.g., Diamond and May 1977) and experimentation (e.g., Crowell 1973, Simberloff 1976*a*, *b*).

VI.A. Insular Distributions of Vertebrates

Objectives. Two predictions will be tested with biogeographical survey data, based on the results of Dueser and Brown (1980):

From the species-area relationship $S+1 = 0.27A^{0.38}$, an island of area A should support S species of small mammals.

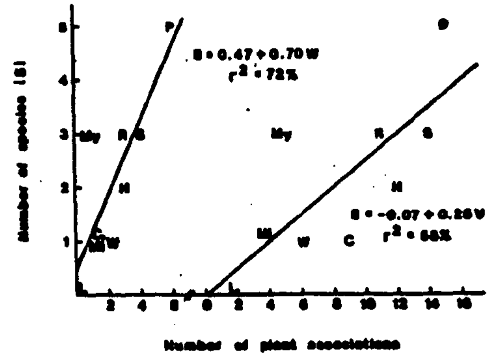
From the species-habitat relationship $S = 0.47 + 0.70W$, an island having W woody plant associations should support S species of small mammals.

A third objective is to compare the pattern of ecological correlates of species diversity for taxa of relatively low vagility (small mammals) and relatively high vagility (breeding birds, and reptiles and amphibians).

Motivation. Dueser et al. (1976) compiled species lists for the mammals, breeding birds, and reptiles and amphibians on seven islands. This survey has since continued on a less intensive basis (R. Dueser, R. Rose, B. Truitt, unpubl.).

Dueser and Brown (1980) examined the relationship between the number of rodent species (0-5) and eight island attributes. Measures of biotic habitat complexity, such as vegetation height (r^2 = 79%) and number of woody plant associations (73%), have at least as much predictive power as physical factors, such as area (69%) and elevation (73%) and much more than isolation (20%). These results provide a first-cut basis for predicting probable trends in species diversity as islands undergo physical changes such as erosion or accretion and biotic change such as succession. Analyses of ecological correlates for breeding birds and reptiles and amphibians would reveal the extent to which the insular diversity of these groups is similarly (or dissimilarly!) affected by these attributes (e.g., Gibbons and Coker 1978).

Methods. The actual number of **small mammal** species on six presently unsurveyed islands will then be determined using the cross-island permanent transect sampling of Dueser et al. (1979). Studies by Porter and Dueser (1982) on Assateague Island and J. Merritt (pers. comm.) on Parramore Island validated the reliability of this procedure for detecting species presence. Observed and expected species numbers will be compared and examined for any systematic deviation.



In one such test, Dueser and Porter (1986) used the species-area regression to predict the number of small mammal species on Assateague Island (predicted 7.1, found 8). The species regressions will be recomputed to include the new data on species distributions (Adler and Wilson 1985). Resurveys of selected islands and new surveys will be undertaken during year 1. Because long-term, recurrent census data has the potential to reveal both colonizations and extinctions, resurveys are planned for years 3 and 5. Targeted surveys will follow any extreme storm events.

There is no factual basis for predicting the number of **breeding bird** species to be found on an island. Species lists compiled by Dueser et al. (1976) undoubtedly were incomplete for heavily vegetated islands. Landbirds will be surveyed using either the transect sampling procedure which Dueser et al. (1978) adapted from Emlen (1971) or an LTER convention. Nest counts for colonial marsh, wading and shorebird species have been conducted annually since 1974. These censuses will continue to be sponsored by the Virginia Commission of Game and Inland Fisheries (K. Terwilliger, pers comm.) and archived in the Cornell Colonial Bird Registry. Seasonal waterfowl censuses will continue to be conducted by the VCGIF and the U.S. Fish and Wildlife Service. Cape Charles, on the southern tip of the Delmarva Peninsula, is an important bird-banding location during the annual fall migration. Banding records are available for the past 21 years at the USF&WS Patuxent Bird Banding Laboratory.

Extensive reconnaisance is required for compiling complete species lists for **reptiles and amphibians**. A reliable survey procedure was developed by Dr. Roger B. Conant (1975) during numerous VCR sampling trips. Active reconnaisance will be conducted on an on-going basis. Voucher specimens will be maintained in an LTER reference collection. All species distributional data will be entered into the island biogeographic mapping system (IBGMS), a radial coordinate system focussed on the geographic center of each island.

VI.B. Abundance of Insular Vertebrates

Objectives. Species abundances may vary through time at a location, between locations on an island, between islands, and between islands and mainland.

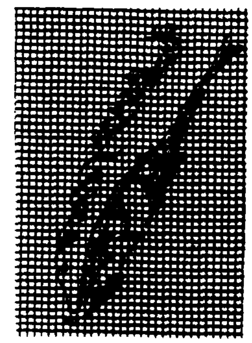
Test for inter-island uniformity of species-habitat associations for small mammals and passerine birds (cf. Dueser et al. 1976).

Test for "density inflation" and "habitat shifts" by insular populations of selected species (Crowell 1962).

Test for differences in life-history attributes between mainland and insular populations of selected species (Gliwicz 1980).

Motivation. Based on their study of habitat use by 7 small mammal species on Assateague Island, Dueser and Porter (1986) concluded that habitat structure exerts relatively more influence on the local abundance of a species than does interspecific competition. If species-habitat associations are relatively uniform and persistent, then the species may be differentially susceptible to long-term successional changes in habitat structure (Dueser and Shugart 1979). Successional changes in island vegetation could potentially facilitate persistence of some species and promote extinction of others. The same arguments apply equally to breeding bird species (Shugart and James 1973).

Methods. Long-term live-trapping on permanent cross-island rectangular grids will provide information on both temporal variation in abundance and species-habitat associations for **small mammal** species. Replicate grids on an island will provide estimates of site (i.e., intra-island) variation. Grids located in comparable habitats on the mainland will provide the data to test for density inflation, habitat shifts and/or significant mainland-island differences in demography.



Breeding birds will be censused on the same grids, during June through August each year. The Hog Island grids will be part of the initial intensive box- transect. Detailed sampling methods for both mammals and birds will be worked out in conjunction with similar efforts at other LTER study sites. These permanent grids will be mapped on the ground relative to the UTM coordinate system.

VI.C. Genetic Measures of Isolation and Colonizing Ability

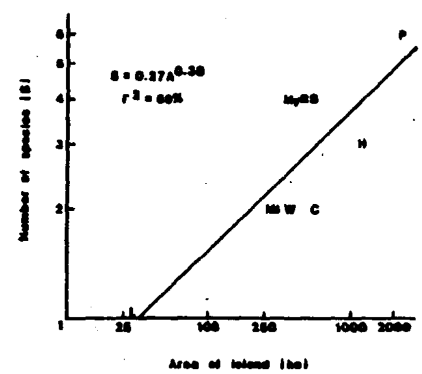
Objectives. One hypothesis has been identified for testing with genetical data drawn from insular and mainland populations:

Genetic divergence of insular populations from mainland populations (and also from each other) is inversely proportional to the incidence of that species on the islands of the VCR.

Motivation. Measures of genetic relatedness may be used to determine the degree of isolation of island populations and the colonizing ability of the species inhabiting the barrier islands. It may also be possible to identify the source of the colonists of particular islands and to detect instances of multiple colonizations.

Despite the fact that "molecular clocks" do not keep very good time (Johnson et al. 1986), there is a rough proportionality between the amount of genetic difference between populations and the time elapsed since their separation. Populations of species with good colonizing ability, as evidenced by their occurrence on most of the islands, should therefore show little genetic divergence from one another. Those of species with poor colonizing ability should, on average, have been isolated longer on the islands on which they occur and should therefore have diverged to a greater extent from the source population and from each other.

The rodent species of the VCR exhibit pronounced differences in incidence. *Oryzomys palustris* is ubiquitous and occurs on at least nine large VCR islands. At the other extreme, *Peromyscus leucopus* is known to occur on only one large island in the VCR. *Microtus pennsylvanicus* is of moderate incidence and is known to occur on four large islands. All other things being equal, we would rank these species as *Oryzomys*, *Microtus* and *Peromyscus* in decreasing order of colonizing ability or increasing probability of significant genetic divergence between populations.



Methods. The method of choice for studies of this kind is the restriction analysis of mitochondrial DNA (mtDNA) (Avise et al. 1979, 1983; Ferris et al. 1983; Solignac and Monnerot 1986). The strict matroclinal inheritance of mitochondria makes it possible to construct maternal lineages without the confounding effects of segregation and recombination. The mtDNA of individual animals is mapped by restriction with a battery of enzymes and the pattern of restriction sites is subjected to analysis by one or more methods for generating trees (e.g., Felsenstein 1984). Restriction analysis has been applied to similar problems in our laboratory. Stine (1986) has used these methods to establish the place of origin of the *Cepaea nemoralis* introduced into the United States, and a study of speciation in *Partula* is now in progress (Murray and Stine, in preparation).

We propose to investigate insular and mainland populations of *Oryzomys*, *Microtus*, and *Peromyscus* in an attempt to show the relationship between genetic similarity and colonizing ability in these species. Animals will be collected live for analysis from known populations during year 2.

VI.D. Threatened and Endangered Species

Objectives.

Determine habitat requirements of the threatened and endangered vertebrate species of the VCR.

Predict the probable future trajectories of habitats occupied by threatened and endangered species in the VCR.

Motivation. The VCR is home to seven threatened and endangered species of vertebrates, including the peregrine falcon (*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), piping plover (*Charadrius melodus*), and the green (*Chelonia mydas*), Kemp's ridley (*Lepidochelys kempii*), leatherback (*Dermochelys coracea*) and loggerhead

(*Caretta caretta*) sea turtles. An eighth species, the Delmarva fox squirrel (*Sciurus niger cinereus*), occurs on the adjacent mainland. These eight species are among only 13 federally-recognized threatened and endangered vertebrate species in the region (White 1985).

These species live in a dynamic environment in which their habitats may prove to be ephemeral. VCR habitats might be ephemeral for at least three reasons: (1) catastrophic changes wrought by stochastic events such as storms, (2) successional changes resulting from the absence of disturbance (e.g., stabilization of sandy habitats by vegetation, or (3) changes caused by biotic agents such as plant pests and diseases. Studies of the habitat requirements of these species, in conjunction with a study of habitat disturbance and succession, will provide a basis for predicting the probable responses of these species to future habitat changes in the VCR.

Methods. Species-specific study methods will be developed as needed. Dueser (unpubl.) recently initiated such a study for the Delmarva fox squirrel, designed to identify potential release sites for the propagation of additional populations in Virginia. This species was extirpated from Virginia. A population was introduced to Chincoteague NWR in 1969. This population expanded but may now be threatened because of the effects of an outbreak of pine bark beetles on the forest.

At the very least, critical habitat will be mapped on the IBGMS mapping system. Research activities in the vicinity of such critical habitat will be scheduled to minimize disturbance.

VI.E. Diversity and Abundance of Fouling Organisms

Objectives.

To monitor the setting rate of fouling organisms.

Identify and quantify the fouling organisms.

Use this data as an indicator of subtle changes of the environment and an indicator of water quality.

Motivation. The water quality of our inshore and estuarine waters is often overlooked until drastic reduction of the biota has occurred. Often the only indicator of water quality degradation is a decline in the traditional commercial harvest of fish and shellfish. The causes of the degradation are usually anthropogenic. There is strong suspicion that sublethal doses of combinations of chemicals are often degrading our coastal waters.

A monitoring program using extremely vulnerable biota or vulnerable life stages of candidate biota as bioindicators may be a mechanism for keeping a continual check on environmental conditions and for determining ambient levels of variation. Most invertebrates which have external fertilization and embryogenesis are vulnerable to very low doses of many of the anthropogenic chemicals found in coastal waters. Rather than culturing bioassay organisms to test for the chemicals, a relatively simple program of qualifying and quantifying setting of common fouling organisms would give a numerical value of water quality.

Methods. Fouling panels of roughened 5 by 5 cm styrene plastic would be placed at pre-chosen stations on the Hog Island box transect. These will be replaced at monthly intervals. The panels will be brought into the lab, subdivided and assayed. Randomly selected subsamples are identified as to species and the number which has set within the sample period of 30 days. The length of time would be adjusted to compensate for seasonality of the setting. This monitoring program will be implemented through a subcontract with the VIMS Eastern Shore Laboratory (Castagna) beginning in year 1.

VI.E. Finfish and Shellfish

The Virginia Marine Resources Commission routinely assembles harvest statistics (poundage and dockside value) for commercial fisheries in most of the bays of the VCR, including Hog Island Bay. Data from 1973-onward are readily available to anyone interested in mounting a major monitoring and/or research program on the VCR (J. Travelstead, VMRC, pers. comm.)

VII. DATA MANAGEMENT

As discussed in the text of this proposal, six independent data bases will be established and/or augmented (Fig 9). These are necessary because of the unique requirements of the diverse studies planned for the VCR. The data bases will be linked by a central software system, a cross-file data entry system.

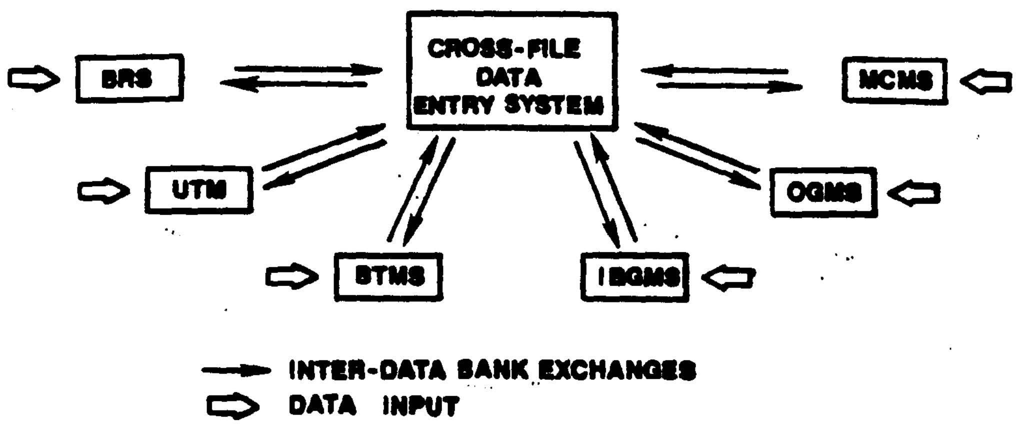
The data management system will be designed to a) provide a controlled, quality-assured flow of data from researchers to the data base; b) provide error-checking reports; c) provide routine reports on the status of the data bases; d) enable extraction of data subsets in formats usable by statistical and graphical display programs; e) provide cross links between the individual data bases; and f) archive data in a reliable way, i.e., in a protected but accessible form.

The actual data storage will almost certainly consist of a series of ASCII files that can be created or accessed by the system as well as off-loaded to other systems to provide rapid transfer to other programs or to other individuals. Multiple copies maintained on at least two physically separate systems at U.Va. (e.g.. one on the CDC mainframe and one on a Bernoulli cartridge) will ensure the security of the data from unauthorized modification and from loss due to inadvertent problems with storage media. An off-line microfiche service is available through the U.Va. Academic Computing Center, to provide efficient hard-copy storage as needed. University and departmental computing facilities and services are described in Appendix 6.

The data management task is complex and demands skilled attention. We intend to hire a full-time specialist in data management to oversee activities on this project. We do have considerable experience in managing large data sets but, before committing to a particular management scheme, we will evaluate commercially available management systems vis-a-vis those that have been developed at U.Va. and will contact the P.I.'s of the other LTER sites to learn from their experience. At that time (approximately six months after the initiation of the project) we will develop a detailed plan for accomplishing the data management objectives.

There is another aspect to data management: curating of voucher specimens of plants and animals. We are experienced with the preparation and maintenance of voucher specimens, and plan to establish a permanent on-site reference collection at Oyster.

Fig. 9 Relationship of the six mapping systems described in the text to the central cross-file data entry system. The orthogonal grid mapping system (OGMS) and the universal transverse mercator coordinate system (UTM) already are in place on the VCR. Benchmark research sites (BRS) will be established as needed for site-intensive projects. The box-transect mapping system (BTMS) will organize data across the VCR, from sea to land. The island biogeographic mapping system (IBGMS) will organize extensive survey data on a radial coordinate system. The marshlands coordinate mapping system (MCMS) is used to record and measure the asymmetrical expansion/erosion of marshes.



VIII. SCHEDULE OF ACTIVITIES

The major activities to be undertaken can be separated into three distinct categories: (1) Initiation and staffing, (2) Site survey, and (3) Active data collection and analysis. We anticipate that 6 mo will be necessary to initiate the project (Nov. 87 - Apr. 88). During that period we will acquire the necessary equipment, hire the appropriate staff, and make appropriate renovations to the site facilities provided by TNC. During the initiation period and the beginning of the survey period, we will complete development of the data management system. The second period will occupy about one year (Apr. 88 - Apr. 89). During that period, the various models will be tested on the VCR system using data collected by the staff and investigators as the survey of the main transect. At the end of that period, decisions will be made as to how to approach the routine sampling and monitoring to be carried out during the next

3.5 yr (Apr. 89 - Oct. 92). We anticipate that the survey work in conjunction with the modelling activities will provide information for release in the form of meeting presentations and manuscripts early in the third year of the project (late 1989).

IX. ORGANIZATION AND MANAGEMENT

The VCR/LTER will be staffed primarily by the faculty of the Department of Environmental Sciences of the University of Virginia. Co-P.I. G.F. Oertel is in the Department of Oceanography of Old Dominion University. Mr. John M. Hall (TNC) is Director of the Virginia Coast Reserve.

Raymond D. Dueser will be the project and site director and will have overall responsibility for the project. He was involved in the initial VCR ecosystem study in 1974-76, and has conducted a number of research projects on the VCR since that time. The project director and data manager will be the individuals primarily responsible for communication and coordination with other LTER study sites. A full-time site manager will be employed to maintain monitoring equipment, coordinate routine data collection, and coordinate facilities use. We anticipate that the site manager will be a post-doctoral appointment with a degree of independent research responsibility.

The U.Va. P.I.'s will form an executive committee responsible for decision-making. Project direction will be set by the P.I.s. who will meet biweekly during the academic year and at least monthly during the summer. Because each P.I. will be directly involved with the field investigations, we will interact frequently on the study site. The U.Va. P.I.s have a long history of research collaboration with one another, dating back to the early 1970's for most of us. We are thus confident that integrated, cooperative research activities will prove productive from the start. Synthesis and publication are an accustomed enterprise for these investigators. The P.I.s unanimously support central control and coordination of LTER research activities, with each P.I. taking part in addressing the overall objectives of the research program as well as pursuing his/her own particular specialities. Again, past experience gives cause for optimism that this strategy will produce exceptional synergies. This strategy also assures continuity of project focus and leadership should there be changes in personnel.

An outside advisory panel has been appointed for the project, including five distinguished scientists representing disciplines important to the research program:

Dr. John C. Kraft
University of Delaware
Coastal geology

Dr. Robert C. Harris
NASA Langley
Geochemistry

Dr. F. J. Vernberg
Baruch Institute
Estuarine ecology

Dr. Thompson Webb, III
Brown University
Climatology

Dr. Richard G. Wiegert
University of Georgia
Systems ecology

The advisory panel will be kept informed of research progress on a quarterly basis, and will meet with the P.I.s for an annual information meeting and to review the VCR/LTER annual report. The first such meeting will be scheduled for Winter 1988, prior to the onset of field work and modelling.

The project leader and the Director of the VCR will coordinate VCR and LTER activities. Our discussions and negotiations to date suggest that conflict is unlikely. The research activities proposed here already have approved by the Director. The limitations and restrictions imposed on the research program by official VCR management policy are minimal. The principal limitation is set by a prohibition of combustion- engine vehicles on the islands. Easy access by boat to the perimeters of the islands renders even this limitation inconsequential. Caution, nonetheless, dictates that the working agreement already agreed to in principle by Dueser and Hall be formalized before the onset of the research. The successful arrangement between TNC and Kansas State University at the Konza Prairie Research Natural Area LTER site may provide a useful model for this agreement.

The P.I.s view site promotion as an important management responsibility. Site promotion will take several forms: an occasional newsletter to be distributed to members of the advisory committee, to heads of university science departments in the mid-Atlantic region and to selected state officials; frequent speaking engagements by the P.I.s; invitations to visiting investigators; occasional meetings hosted by the VCR/LTER, the Department of Environmental Sciences and the U.Va. (e.g., we will host the Second Annual Landscape Ecology Symposium in March, 1987); and a visiting investigators small grants program (after year 2). Given the status of the VCR as a MAB biosphere reserve and given the relative importance of coastal zone environments in many of the debates about regional and global environmental change (Risser 1986), we anticipate that the site will attract prominent researchers from many disciplines. Promotional assistance from TNC should further this cause.

Appendix 1: LITERATURE CITED

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Appendix 2: LETTERS OF INSTITUTIONAL COMMITMENT

DEPARTMENT OF ENVIRONMENTAL SCIENCES

CLARK HALL . UNIVERSITY OF VIRGINIA . CHARLOTTESVILLE, . VIRGINIA . 22903
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To Whom It May Concern:

The Department of Environmental Sciences of the University of Virginia is delighted and pleased to enthusiastically support this proposal for the creation of an LTERS at the Virginia Coast Preserve. This undertaking represents an important addition to our longstanding record of interdisciplinary research.

We have eight faculty (from a department of 25) committing substantial time and effort to the project. They represent expertise in all areas of the Department (e.g. ecology, geology, atmospheric science, and hydrology) and form a truly ecosystem-oriented aproach to monitoring and understanding a complex system. Given the level of enthusiasm and dedication displayed by this group and their associated investigators at VIMS and Old Dominion, I am certain that considerable additional research funding will be sought from other sources to support related research at the Virginia Coastal Reserve site.

The Department of Enviromental Sciences is particularly well suited to undertake an LTER project. Our faculty have successfully tackled several large interdisciplinary projects either partially or fully NSF supported and aimed at specific ecosystems (e.g. the Lake Anna acid mine drainage project; the Shenendoah Watershed Acidification Study which monitors the effects of acid precipitation on a Appalachian watershed; and the long-term comparison of tidal freshwater and salt marshes).In addition, all of our principal investigators have worked in the area of the Virginia Coastal Reserve and published in excess of 150 papers and books dealing with barrier island/lagoon systems.

In terms of facilities, we are in a particularly strong position. The Nature Conservancy has been very generous in providing facilities and support at a number of points within the Virginia Coastal Reserve (e.g. laboratory and housing at Oyster, Virginia; laboratory and housing on Hog Island; boat mooring and access at Brownsville; access and experimental priviledges to all acreage within the VCR). Furthermore, specialized laboratory space (running seawater, specialized equipment) along with dormitory space and boating storage facilities have been made available at the VIMS eastern shore laboratory at Wachapreague, Va.

On the campus of the University of Virginia we have extensive equipment and computer facilities which are described in detail within the proposal. Most exciting of all, newly constructed laboratory space for the ecologists will be available in the early winter 1987 in our Halsey Hall research complex.

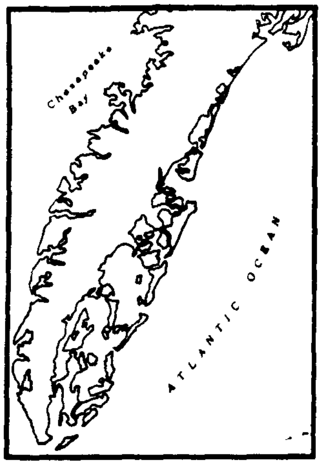
The Department of Environmental Sciences is demonstrating its support for the project by putting forth $35,000 of our precious research overhead recovery funds to match twice this amount promised by Dean Hugh Kelly. The University is also scheduled to supply a variety of boats and equipment through the Governors Equipment Trust fund. Finally, both myself, as chairman, and the Department of Environmental Sciences are totally dedicated to support of the Virginia Coastal Reserve LTER project.

In conclusion, I feel personally that this is a particularly attractive proposed site and program to add to the LTER system. First, we have a site which is an excellent representative of barrier island/lagoon systems north of Cape Hatteras. Second, we have a site which is guaranteed in perpetuity to remain protected and available to research by the Nature Conservancy. Third, we have a site which, more than any other existing LTER site, represents an opportunity to monitor and study the effects of strong, controlling physical factors (sea level rise, coastal storms, etc.) on ecological processes such as marsh peat accretion and barrier island plant and animal community response to periodic stress. Fourth, this is a site which enables us to measure important inputs (gases, carbon, nitrogen compounds) and effects (impacts from sea level rise) associated with global processes. Finally, we have an exceptional group of investigators led by Shugart's modeling group, the coastal geologists and climatologists, and a group of coastal ecologists who have extensive field and laboratory experience in barrier island/lagoon/marsh systems.

I hope that you sense our great enthusiams and dedication to this proposed undertaking.

Sincerely,

William E. Odum
Professor and Chairman
Dept. Environmental Sciences



The Virginia Coast Reserve

The Nature Conservancy
Brownsville
Nassawadox, Virginia 23413
(804) 442-3049

October 29, 1986

Raymond D. Dueser, PhD
Department of Environmental
Sciences
Clark Hall
University of Virginia
Charlottesville, VA 22903

Dear Ray:

The Nature Conservancy (TNC) and the staff of the Virginia Coast Reserve (VCR) are excited by the possibility of working with you on the establishment of a Long-Term Ecological Research project on the Eastern Shore of Virginia.

The Virginia Coast Reserve is designated by the United Nations as part of the international network of Biosphere Reserves. This network of protected examples of the world's major ecosystem types are devoted to the conservation of nature and scientific research. VCR is also a Registered Natural Landmark designated by the Department of the Interior for its exceptional environmental value. The 43 mile long reserve is made up of 13 Atlantic barrier islands that include beaches, dunes, maritime forests, ponds, salt marshes, bays, and tidal creeks. In addition to the 35,000 acre preserve, TNC also owns an adjacent 7,500 acres of mainland seaside farms, forests, and marshes.

TNC science department and the VCR staff will offer its support, data, and local expertise toward beginning this project on the best possible foundation. Every effort will be made to insure access to all areas of the reserve needed for research. The Conservancy owned field station located at Oyster Harbor will be available to the LTER project and includes two buildings with living facilities, lab, and lecture areas. The Machipongo Station (a former coast guard building) located on Hog Island will also be available for LTER researchers on a cost per day basis. The station has caretakers, generators, living quarters, boat service, and storage/work areas. TNC also owns a third large building (Newman Estate) near Oyster Harbor. It can be made available if expansion in the project occurs.

The Nature Conservancy is committed to insuring the preservation of this coastal ecosystem and research is a very important part of our stewardship goals. We are looking forward to working on this with you.

Sincerely,

John M. Hall
Director

JMH:kh