Annual Report for 2003

To National Science Foundation

Baltimore Ecosystem Study

Urban LTER: Human Settlements as Ecosystems: Metropolitan Baltimore from 1797 - 2003

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www.ecostudies.org/bes

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Baltimore Area Master Gardeners
Baltimore-Chesapeake Bay Outward Bound Program

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Baltimore County Forest Conservation District Board
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Activities

How urban and suburban areas function as integrated, ecological systems is poorly known. This gap in knowledge means that basic ecology does not yet understand one of the most widespread and extreme human interventions in the biosphere. It also means that people's ability to assess options for ecological management and restoration in and around cities is limited. The ecological knowledge gap in urban areas is a crucial lapse because urbanization in all its forms is one of the main components of global change, and humans are now a predominantly urban species.

The Baltimore Ecosystem Study LTER (BES) has three components. The first two are the complementary research approaches needed to build ecological knowledge of urban systems. First, social and economic processes are combined with physical dynamics and ecological processes. Second, because cities and suburbs are characterized by rapid change, both retrospective and long-term perspectives are critical. The third component of BES recognizes the responsibilities and opportunities of conducting research in an inhabited system. Education satisfies the responsibility to share ecological knowledge with the widest audience. Applying ecological knowledge to management, environmental quality, and social justice acknowledges society's needs. Finally, the use of new ecological knowledge of urban systems in planning and restoration provides an important opportunity to test ecological theory and to improve urban quality of life.

The scientific knowledge gap, new scientific opportunities, and responsibility to the public have prompted us to pose three questions to guide our scientific research and our interactions with citizens in metropolitan Baltimore:

1. How do the spatial structure of socio-economic, ecological, and physical factors in an urban area relate to one another, and how do they change through time?

2. What are the fluxes of energy, matter, capital, and population in urban systems, and how do they change over the long term?

3. How can people develop and use an understanding of the metropolis as an ecological system to improve the quality of their environment, and to reduce pollution loadings to downstream air- and watersheds?

In our sixth year we have continued and enhanced core long-term activities, and initiated new work that promotes the goals of the Long-Term Ecological Research program. Field studies continue to emphasize the 17,150 ha Gwynns Falls Watershed, with a forested reference watershed at Oregon Ridge County Park, an urban atmospheric flux tower at Cub Hill, and a new initiative focusing on a highly urbanized storm drainage -- watershed 263 -- in West Baltimore (Fig 1). Gwynns Falls includes land that is currently being converted from agricultural to suburban uses, as well as areas that have been intensively urbanized for a long time. The Cub Hill site is on the edge of the city and represents extensive suburban landscapes. In addition to these intensively studied sites, our research also includes 200 sample points spread throughout the city. We list key activities under each of our three guiding questions. Both ongoing and new initiatives are included.

Question 1: *How do the spatial structure of socio-economic, ecological, and physical factors in an urban area relate to one another, and how do they change through time?*

To answer question one, we are conducting the following major research activities:

- Quantify the patch structure of Baltimore.
- Document patch change.
- Discover biotic changes.
- Survey soil heterogeneity.
- Operate a meteorological network.
- Conduct modeling at various scales.
- Compare gradients within Baltimore, and with other cities.

The activities answering question one address the spatial structure, the temporal dynamics, and the integration of the social, ecological, and physical components of the Baltimore ecosystem.

The specific research projects are listed below, and are described in greater detail in the research section of the BES web page at http://beslter.org

I. Patch delimitation
   A. Social patches
      1. Based on:
         a. Demographic data
         b. Socio-economic indices
         c. Market clusters
         d. Built capital
         e. Survey of residents' environmental management choices
      2. Scaling of different social data sets
   B. Ecological-structural patches (surfaces, built, and biogeophysical components)
      1. Employ new, highly resolved, land cover classification system.
      2. Heterogeneity among patches
      3. Heterogeneity within patches (point, and transect methods)
      4. Park and neighborhood survey
      5. Avian biodiversity/patch survey
   C. Comparison and combination of social and biogeophysical patch approaches
      1. Preliminary assessment of relationships of market cluster patches with ecological patch mosaic
   D. IKONOS image analysis
      1. Flood plain analysis
      2. Topography alterations with development
   E. Scoping of the vacant lot habitat type

II. Patch change
   A. Paleoecological cores
      1. ^{137}Cs dating, pH, trace metals, overbank sedimentation.
   B. Land cover changes
      1. Acquisition and scanning of historical maps
      2. Comparison of archival and contemporary air photos
      3. Agricultural census (Red Run catchment)
   C. Land surveys and engineering records
      1. Original property claim boundaries
      2. Stationarity and change in parcel boundaries
   D. History of water and sewer infrastructure
   E. Historical US census data

III. Biotic community change
   A. Permanent vegetation plots; forest plots resampled in 2003
   B. Exotic vines and urban forest gap regeneration
   C. Breeding bird population surveys
   D. Stream biota
   E. Riparian forest structure and composition
   F. Repeated, spatially extensive sample plots (built and biotic components)

G. Spatially extensive forest tree data
H. Exotic/native soil organisms and their demography

IV. Soil heterogeneity
A. Soil survey; fine scale, with urban-relevant classes added
B. Soil invertebrate fauna; composition, distribution, demography, feeding and reproduction
C. Soil and vacant lot contamination
D. Relationship of exotic plant species to soil microbial community

V. Meteorology
A. Reference station in Gwynns Falls watershed satisfying LTER level 4 standards
B. Network of rain gauges throughout Baltimore and intensive networks in sub-watersheds
C. Urban UV radiation flux; total solar, photosynthetically active radiation
D. Substrate temperatures
1. Streams
2. Soils
3. Archival weather data analysis

VI. Modeling
A. Aggregated hydrological models
B. Distributed hydrological models
C. Integrated, spatially distributed models including social and biogeophysical variables
D. Soil and surface water, ground water
E. Ecosystem services data base
F. Housing valuation

VII. Comparisons
A. Urban-rural gradient in Baltimore
B. Comparisons between cities
1. French Zone Ateliers (Paris, Lyon).
2. Budapest invertebrates
3. Exotic invertebrate demography in Baltimore versus “home” habitat

Question 2: *What are the fluxes of energy, matter, capital, and population in urban systems, and how do they change over the long term?*

To answer question two, we are conducting the following major research activities:

- Document human demographic and social processes.
- Quantify stream flow, chemistry, and key biota.
- Measure extreme storm water flows and flooding.
- Measure vegetation processes and nitrogen flux in riparian zones.

- Measure biogeochemical pools and fluxes in contrasting upland patch types.
- Quantify meteorological exchanges between surface and atmosphere using flux tower technology.
- Model atmospheric, hydrological and socio-economic fluxes in and across contrasting watersheds.

The research aimed at answering question two takes into account the spatial structure of the Baltimore ecosystem, seeks feedbacks between socio-economic and biogeophysical processes, and has established sites in which long-term status and changes in fluxes are being measured. Integrated models, which incorporate ecological, hydrological, built, human and social capital, are key tools for understanding processes of flux and projecting changes into the future. The specific research projects contributing to answering question two are outlined below and described more fully on our web site.

I. Human demographic and social processes
  A. Network analysis of environmental organizations and agencies
  B. Differential distribution of human, social, and economic capital
  C. Environmental equity
  D. Health and mortality records
  E. Institutional development:
    1. Maryland Forest Service origin, philosophy, structure and activities
    2. Maryland State Park system development
  F. Biodiversity and park versus household environmental management

II. Stream measurements
  A. Relationship to sanitary and storm sewer infrastructure; cross contamination and cross flow
  B. Reference stations on main stem of Gwynns Falls
  C. Small catchment process studies
  D. Flow regime, including extreme storms and base flows
  E. Water chemistry
  F. Stream geomorphology
  G. Biota
    1. Microbes
    2. Water-based pathogens
    3. Invertebrates
  H. Test new, high-flow measurement method for storm sewer outfall
  I. Metropolitan network of 47 stream gauges
  J. Ground water hydrology
  K. Test new, autoacoustic method for low flow measurements in urban streams
  L. Hydrology of constructed wetland at mouth of Gwynns Falls
  M. Assessment of major storm impacts (Dead Run and Moores Run).
    1. Summer thunderstorm flood peaks and distributions
    2. Radar (NEXRAD)
    3. Rain gauge network
  N. Hurricane Isabel effects

III. Riparian processes
  A. Vegetation change -- resample established plots
  B. Water table dynamics and depth
  C. Stable isotope analysis of water sources for riparian trees
  D. Nitrogen dynamics (0-100 cm profile)
  E. Stream channel incision
  F. Trace gas flux

IV. Biogeochemical fluxes
  A. Watershed mass budgets
  B. Permanent plots (upland forest, grass, agriculture)
  C. Household level fertilizer use and irrigation
  D. Relation of fluxes to land use and land cover
  E. Relation of fluxes to exotic species
  F. Trace gas flux

V. Meteorological fluxes
  A. Cub Hill flux tower - first urban flux tower
  B. Characterization of tower site and footprints
    1. Soils and soil organisms
    2. Vegetation
    3. Land cover
  C. Tropical storm and summer thunderstorm meteorology

VI. Modeling
  A. Multiple approaches
    1. Research Hydrological Ecological Simulation System (RHESsys)
    2. Gwynns Falls Landscape Model (GFLM)
    3. Urban Forest Effects model (UFORE)
    4. General Human Ecosystem Model for sustainable economic welfare (ecological and economic components).
  B. New model components
    1. Social capital incorporated
    2. Ecosystem services and valuation incorporated
    3. LIDAR topography models
  C. Modeling extends from small catchment/neighborhood, to Gwynns Falls, to Baltimore regional scale
  D. Test using temporal data

Question 3: *How can people develop and use an understanding of the metropolis as an ecological system to improve the quality of their environment, and to reduce pollution loadings to downstream air- and watersheds?*

To answer question 3, we are conducting the following major education, interaction, and research activities:

- Develop or participate in educational partnerships.
- Analyze the ecological knowledge base and its use in different social contexts.
- Interact with governmental agencies at various levels to exchange ecological knowledge and information.
- Interact with communities, community groups, and non-governmental organizations to enhance ecological understanding.
- Design social and educational assessments to determine the changing role of ecological knowledge in Baltimore.
- Conduct mediated modeling that incorporates the concerns of stakeholders.
- Manage information to enhance flow of data and knowledge within BES, and between BES and agencies, communities, and individuals.
- Participate in assessment of storm drain watershed (263) restoration activities and evaluation.
- Provide internships for secondary, college, and graduate students, and fellowships for teacher involvement in ecological research.
- Focus studies in Minebank Run stream restoration project.

In addressing question three, the partnerships are crucial. Because this question deals with the flow of information and its use, our activities recognize the diversity of sources and users of ecological and other relevant information, and the need to maintain two way flows of information and understanding of ecological issues. Of the three areas of activity in BES, this one is the most fluid and developmental, since it depends on evolving and expanding relationships in the Baltimore region as well as evolving and expanding ecological understanding. Specific activities we are currently undertaking in pursuit of question three are listed below and detailed on our web page:

I. Education partnerships
    A. Approaches
        1. Formal
        2. Non-formal
    B. School-community partnerships
        1. Range of schools involved -- city, county, private
        2. Primary, secondary, post-secondary levels
    C. Schoolyard Long-Term research facilitation
    D. Neighborhood Science Program
        1. Community focus
        2. Washington Village/Pigtown
        3. Part of planning team developing environmental education enrichment program for 6th, 7th and 8th graders in Baltimore City
    E. Baltimore Collaborative for Environmental Biology -- college student mentoring
    F. Curriculum development
        1. Developing a comprehensive after-school curriculum for grades 3-5 where students and their teachers convert their school and local neighborhood

into an urban ecology center, carrying out research, education and stewardship activities

2. Developed nine activities and an educator's guide in collaboration with the Parks & People Foundation Community Forest Program. These are targeted at elementary-age youth for implementation on their own, with their parents or in school
3. Participation in urban design and architecture studios focusing on Baltimore projects

G. Resources for educators
   1. Internships for teachers (five interns)
   2. Educational materials for classroom and schoolyard use
      a) One of the BES Ecology Education Fellows is developing a high school curriculum in collaboration with this project

H. Educational internships for college students (four)

I. BES provided financial and scientific support for an internship program that served ten 9th and 10th grade students

J. Training BES natural scientists and student interns to work safely and respectfully in urban neighborhoods

K. Developed partnership to weave BES science education methods and research data into curriculum

L. After school programs
   1. Developed tree-related enrichment activity with literacy links and delivered it to participants at three camp sites
   2. Assisted with special activities such as Career Day and Portfolio Day and developed environmental education curriculum to be piloted Fall 2003

II. Interactions with agencies

A. Facilitation by Parks & People Foundation
   1. Revitalizing Baltimore Technical Committee

B. Diversity of agencies
   1. Federal partnerships
   2. State of Maryland environmental and natural resource management agencies
   3. Baltimore County departments
   4. Baltimore City departments
   5. Formal relationships
      a) Oregon Ridge County Park
      b) Carrie Murray Outdoor Education Center (Baltimore City)

III. Interactions with communities

A. Facilitated by Parks & People Foundation

B. Revitalizing Baltimore
   1. Technology transfer
   2. Link research and community concerns
   3. Public health and environmental processes

        4. Active in Steering Committee, Technical Committee and Watershed/Linkages Committee
            a) Baltimore Neighborhood Indicator's Alliance
                (1) Social capital indicators
    C. Stakeholder workshops
        1. Ecological services and valuation
    D. Modeling
        1. Ecosystem services and economic valuation database
        2. Mediated modeling with stakeholders
    E. Urban designs for abandoned sites, and for Gwynns Falls Trail interactions

IV. Information management
    A. Web page development and management (www.beslter.org)
        1. Public accessibility
        2. Intranet for BES community
        3. Interactions with LTER network
        4. Addition of science and decision making page
    B. Open Research System (ORS) (www.open-research.org)
        1. Metadata and data management portal for BES
        2. Searches based on keywords, maps, and graphical interfaces
    C. Small Watershed Network -- information source for public
    D. Partnership with National Aquarium in Baltimore EMAP web based data sharing and interpretation site
    E. Internet connectivity to enhance interaction with collaborating organizations
    F. Conduct BES Annual Meeting and Quarterly Science meetings open to all partners.

V. Minebank Run restoration project -- before and after
    A. Collaboration with Baltimore County
    B. Geomorphic stabilization
    C. Assessment of ecological processes (N dynamics)

VI. Watershed 263 storm water management research and restoration in Baltimore City
    A. Coordination through Parks & People Foundation
    B. City and Community partnerships involved

Outreach

Outreach is fundamental to the mission and success of the Baltimore Ecosystem Study. As a research question, we are concerned to know how people develop and use knowledge of the metropolitan area as an ecological system. In addition, we have learned from the literature and from a 10 yr social science and community restoration research program in Baltimore predating the LTER effort, that informing and working with communities and constituencies is required to site ecological research in the city and suburbs. Hence we conduct a wide variety of community and educational activities.

Formal public outreach was accomplished through the BES Annual Meeting, attended by scientists, educators, community members, and decision leaders from the Baltimore region as well as by BES researchers and educators. This meeting was attended by 103 people in 2001. We held three additional meetings at roughly three month intervals focused on research planning and results but open to potential collaborators and clients for the information.

The Following is a List of Presentations to be Considered Outreach Activities

Berkowitz , A.R., J.M. Grove, W. C. Zipperer, R. Pouyat, C. Nilon, K.H. Steele, G. Middendorf, K. Szlavecz. 2003. Teacher and student investigations of urban ecosystems with the Baltimore Ecosystem Study. Ecological Society of America Annual Meeting. Savannah GA. August 5.

Burch, W. Jr. 2002. Force human ecosystem framework- Prague. UNEP Science Meeting on Developing Useable Science Knowledge. Prague, Czech Republic. June 12-17.

Burch, W. Jr. 2002. Nature and social life in thin and dense cities –The Chevy Impala Model. Yale School of Architecture International Symposium on Dense-Cities: An American Oxymoron? New Haven, CT. September 20-22.

Burch, W. Jr. 2003. The Patapsco Forest Reserve: Establishing a 'City Park' for Baltimore. Annual Meeting of the Association of American Geographers. New Orleans, LA. March.

Burch, W. Jr, and G. Machlis. 2003. Capacity development and scoping workshop on preliminary principles for an ecosystem approach to urban management. United Nations University. Tokyo, Japan. April 7-10.

Burch, W. Jr. 2003. The Baltimore urban long-term ecosystem research– Making science relevant for people and their habitat. Department of Systems Ecology, Chinese Academy of Sciences, Beijing Forestry University. Beijing, China. October.

Burch, W. Jr. 2003. The human in the human ecosystem framework–Building a world of environmental stewards. School of Policy and Management, Beijing Forestry University. Beijing, China. October.

Burch, W. Jr. 2003. Trends in graduate education for forestry and environmental studies. Graduate Student Symposium, Beijing Forestry University. Beijing, China. October.

Buckley, G.L. 2003. The Patapsco Forest Reserve: Establishing a 'City Park' for Baltimore. Annual Meeting of the Association of American Geographers. New Orleans, LA. March 14-19.

Grimmond, C.S.B. 2002. Trace gas fluxes in urban ecosystems (Examples of carbon dioxide and water). Ecological processes in urban ecosystems: Toward an international synthesis, IGBP-GCTE Focus 1, Global Change and Terrestrial Ecosystems Meeting. Salt Lake City, UT. July.

Grimmond, C.S.B. 2002. Measurement of heat, water and carbon dioxide exchanges at three contrasting urban sites: Baltimore, USA; Marseille, France; and Lodz, Poland. Earth Sciences Centre, Göteborg University. Göteborg, Sweden. June.

Hom J., S. Grimmond, D. Golub and B. Offerle. 2002. Studies on carbon flux and carbon dioxide concentration in a forested region in suburban Baltimore. USDA Natural Resources Management to Offset Greenhouse Gas Emissions Symposium. Raleigh, NC. November 19-21.

Grimmond S., D. Nowak, J. Walton, M. Mitchell, and C.T. Driscoll. 2002. Flux-towers: Studying surface-atmosphere exchanges in urban areas. Environmental Quality Systems Symposium. Syracuse, NY. October 29-30.

Grimmond C.S.B., J. Hom, B. Offerle and D. Golub. 2002. Carbon dioxide, energy and water fluxes from Cub Hill, Baltimore Suburban Environment. AmeriFlux Annual Meeting. Boulder, CO. October 22-23.

Grimmond C.S.B., B.D. Offerle, J. Hom and D. Golub. Observations of local-scale heat, water, momentum and CO2 fluxes at Cub Hill, Baltimore. 4th Urban Environment Symposium, AMS. Norfolk, VA. May.

Grimmond C.S.B., B. Offerle, T. Oke, K. Fortuniak, J. Hom, J. Salmond, and D. Golub. 2002. New energy and mass flux results from three contrasting urban environments (Marseille, France; Lodz, Poland; and Baltimore, USA). Association of American Geographers. Los Angeles, CA. March.

Heisler, G.M., R.H. Grant, D.J. Nowak, W. Gao, D.E. Crane, and J.T. Walton. 2003. Inclusion of an ultraviolet radiation transfer component in an urban forest effects model for predicting tree influences on potential below-canopy exposure to UVB radiation. SPIE, the International Society for Optical Engineering. San Diego, CA. August 6.

Heisler, G.M., R.H. Grant, W. Gao, J.R. Slusser, C. Ehrlich. 2002. Solar ultraviolet-B radiation in urban environments: Baltimore, Maryland. SPIE, the International Society for Optical Engineering. Hangzhou, China. October 25.

Pouyat, R., K. Szlavecz, P. Groffman, and A. Lorefice. 2003. The effects of urbanization on forest soil dynamics. Annual Meeting of the Society of Environmental Journalists. New Orleans, LA. October 3.

Szlavecz, K, R.V. Pouyat, V. Giorgio and Cs. Csuzdi. 2002. Earthworms and soils in the Baltimore Metropolitan Area: Is there and urban-rural gradient? BES 5th Annual Meeting. Baltimore, MD. October 24-25.

Harris, J. and K. Szlavecz. 2002. The distribution of earthworms in suburban neighborhoods and forests. BES 5th Annual Meeting. Baltimore, MD. October 24-25.

Stiltz, J. and K. Szlavecz. 2002. Neighborhood scale assessment of soil arthropod diversity. BES 5th Annual Meeting. Baltimore, MD. October 24-25.

Placella, S.A., K. Szlavecz and M. Cavigelli. 2003. Sustainable agro-ecosystems: Alternative farming methods and soil fauna. Council for Undergraduate Research: Posters on the Hill. Washington, D.C. April 1.

Troy, A. and J.M. Grove. 2003. An ecological economic framework for characterization of social and economic patches. US Society of Ecological Economics. Saratoga Springs, NY. May 23.

Findings

Question 1: Structure, Integration, and Dynamics of Ecological, Socio-economic, and Physical Factors in the Baltimore Ecosystem

1. Patch delimitation

Social patches. Social patch delimitation has used demographic data, socio-economic indices, market clusters, and features of the built capital. These methods that have proven robust for analyzing the temporal, spatial, and hierarchical dynamics of urban social patch dynamics. The approach has also proved useful for emerging interdisciplinary studies in Boston (Urban Ecology Institute) and Canberra (CSIRO, Australia).

Scaling of different social data sets. The data sets for social patch delimitation have been converted to the same statistical and spatial scale. They now link seamlessly into a single, unique data base, which will support analyses of social processes, and the relationship of social with biogeophysical processes. This scaled database has permitted initial analyses of the relationship between social, market cluster patchworks, and the structural patch mosaic described below.

Structural patches. We have refined and finalized the novel, compositionally well resolved land cover classification system developed for Baltimore. The refinements were based on ground truthing, and assessment of internal consistency. The classification is being employed using air photos in four test regions of metropolitan Baltimore. We have determined that the system works well for both air photos and the IKONOS imagery. Associated with the patch classification is an evaluation of the components of heterogeneity within patch types. This analysis has confirmed the aggregate differences among patch types, and has stimulated new questions for linkage with social processes and structures. The patch classification has been used to evaluate the structural context of schoolyards, to understand “green resources” for different schools, and to guide restoration options.

IKONOS imagery has been obtained for Baltimore, and initial has been completed. The data are now available for comparative and integrative studies. Primary use to date has been in hydrological modeling and flood studies. LIDAR imagery has also been obtained, and has improved our ability to model topography at the fine scales necessary to calculate urban water budgets. In addition, we are documenting the variety of ranges and kinds of topographic changes that accompany commercial and residential development.

2. Patch change

Land cover changes. In Agarwal et al. (2002), we presented a novel framework for analyzing and categorizing land use/land cover models. This study continues to be of use to land use/land cover modelers and researchers both inside and outside of BES. This paper has been used as a course book in graduate seminars in land use/land cover modeling at Pennsylvania State University and University of California, Santa Barbara.

Riparian patches have been greatly influenced by overbank sedimentation in the Gwynns Falls watershed. However, use of Cr as a novel tracer and development of a chemical database for the Red Run riparian sediments, has indicated that comparatively early European settlement caused earlier changes in sediment flux than those predicted by the regional models (Jacobson and Coleman 1986). Hydrological processes connected with urbanization, such as the increase in impervious surfaces, stream incision, and lowering of the water table have led to "hydrological drought" and consequent shifts in wet to dry tolerant species in riparian zones.

Land surveys and engineering records. The mosaic of original property boundaries in the Gwynns Falls watershed has been mapped on current, georeferenced base maps, and checked against current digitized property boundaries to assure quality. The mosaic of original properties becomes more complex as one moves from the Middle Branch of the Patapsco River to the headwaters of the Gwynns Falls. The mosaic is resilient and might be damping other gradients of landscape heterogeneity resulting from urbanization. We have discovered that the area available in large parks is related to land claims made in the colonial and early federal eras. Approximately 9 % of the original property lines within the Gwynns Falls watershed are persistent and visible in the present landscape, showing a strong legacy that may inform ecological structure.

3. Soil heterogeneity

Soil arthropod composition is different in the urban (Leakin Park) and the rural (Oregon Ridge Park) forests. The urban park is dominated by macroarthropods. Terrestrial isopod abundance is especially high in urban forests. In Oregon Ridge, mesofauna (springails, mites, ants) are more dominant. Preliminary data show that both the density and the biomass of earthworms are greater in the urban forest than in the rural forest. Our question is whether this pattern holds up for abundances along a more completely sampled transect. At the same time, diversity is greater in urban forests, due to the large number of introduced species. The proportion of introduced species within the same taxonomical group is greater in cities than in rural areas.

4. Comparisons

Soil invertebrates. The introduction of *Chaetophiloscia sicula* was a recent event. The species must show high plasticity in order to survive the winter in Baltimore, because its original habitat is Mediterranean shrub-grasslands. Activity and reproductive period differ between the region of origin and Baltimore. The "urban ecosystem convergence hypothesis" is being tested for soil fauna in Baltimore and Budapest. The degree of convergence for these organisms is taxon-specific. We tested whether the contrast in composition and density between urban and rural soil invertebrate faunas depended on food abundance or quality. Although soil arthropods respond to the nutritional quality of litter, the contrasts are due to tree species identity rather than location along the urban-rural gradient. Stage of decomposition was a more important factor in consumption rather than urban versus rural origin.

We have discovered great variation in earthworm density at the neighborhood scale. Differences exist both between land cover types (lawn, flowerbeds, forest), and among neighborhoods. Currently, correlations with soil physical data are being examined to explain the variation discovered. Earthworms are important to soil permeability and nitrogen dynamics.

Landscape and ecosystem features are related to biotic diversity and abundance in specific sites. Earthworm biomass was positively correlated with pH, and negatively correlated with soil organic matter. Forest fragmentation strongly reduced carrion beetle diversity and abundance, and was more important than urbanization per se.

Additional elements of biodiversity continued to be discovered in the urban matrix. We discovered another species new to science in 2002. The species, *Bimastos sp. n.* inhabits wet areas, and has so far been found only in rural forest stands.

The urban ecosystem convergence hypothesis, mentioned above with respect to soil invertebrates, is currently being cast in the context of carbon loss and sequestration. Initial comparisons with various cities in both arid and mesic biomes suggests the hypothesis has merit.

French urban systems. BES scientists were instrumental in interactions that led to the French *Zone Ateliers* joining the International Long-Term Ecological Research network. This formalization has facilitated the initiation of our collaborative work on urban infrastructure and ecological processes between BES, Paris, and Lyon.

Question 2: Fluxes of Energy, Matter, Capital, and Population in the Baltimore Ecosystem

5. Human demographic and social processes

Institutional development. The research on the founding and early work of the Maryland Forest Service (Buckley and Grove 2002) has been applied by current staff of that agency in re-evaluating institutional goals. The Maryland Forest Service's founding director's archives have been located and made available to BES researcher G. Buckley. The development of Maryland's state forest system shows early ecological and multiple management motivations. Its relationship to the Baltimore City park system was also a driving factor of the choice of the Patapsco as a first state forest in Maryland. Lifestyle groups show significant "Kuznetz curves" with an inverted U shape, for household nitrogen inputs into the hydrologic cycle. Significant linear relationships exist between lifestyle groups and biodiversity of avian species in Baltimore and in Phoenix, AZ. In order to facilitate the empirical integration of social and biogeophysical parameters, we have developed a framework of biocomplexity. This framework identifies differing degrees and kinds of spatial heterogeneity, organizational connectivity, and historical contingency, as the three dimensions of biocomplexity required to integrate social and biogeophysical factors in models.

6. Stream measurements

Stream, soil, and infrastructural flows. Spatial patterns of surface soil moisture, shallow groundwater levels, stream channel discharge, and stream water chemistry differ between urban and forested catchments. Forested catchments show strong correlation of surface soil moisture with topographic wetness indices, while landscape drainage practices during the agricultural era, and current sanitary and storm drainage infrastructure and road networks cause regular departures in the soil moisture patterns. In developed catchments, bottomland soil moisture is typically lower than areas immediately upslope due to drainage redirection by infrastructure and infiltration of groundwater into sanitary sewer lines. We have also documented lowered water tables in urbanized areas.

Long-term watershed studies. Our analysis of several years of watershed data on nitrogen (N) and phosphorus (P) losses showed that urban and suburban watersheds consistently had much higher N and P losses than the completely forested reference watershed, with nitrate yields ranging from 2.7-7.1 kg N ha^{-1} y^{-1} and phosphate yields ranging from 9-151 g P ha^{-1} y^{-1} in the urban and suburban watersheds compared with < 1 kg N ha^{-1} y^{-1} and < 10 g P ha^{-1} y^{-1} in the completely forested watershed. Nitrate represented from 60-97% of the total N yield in the urban and suburban watersheds, with the lowest percentages in the most urban watersheds. Only 17% of the N yield from the completely forested watershed was NO_3^-. Phosphate represented 28-61% of the P yield. There was a higher correlation $R^2 = 0.86$, $p < 0.01$) between percent residential land use and NO_3^- yields than between land use and NO_3^- concentration $R^2 = 0.71$, $p < 0.10$), suggesting that hydrologic changes associated with urbanization influence variation in N yields. There was no correlation between land use as measured by Anderson-type land cover classes, and PO_4^- yield or concentration. Retention of N was surprisingly high, from 70-80% of inputs, which were dominated by home lawn fertilizer (16-27 kg N ha^{-1} y^{-1}) and atmospheric deposition (7-10 kg N ha^{-1} y^{-1}). Detailed analysis of mechanisms of N retention, which must occur in the significant amounts of pervious surface present in urban and suburban watersheds, and which include storage in soils and vegetation and gaseous loss, is underway. We have documented altered soil C and microbial biomass as potential contributing factors.

Flow regime. We have produced a continuous data stream, published annually, with some station data available in near real time. Our intensive rain gauge networks, LIDAR data, and storm radar data have permitted us to track and monitor individual thunder storms, and to quantify their hydrologic impacts and flood intensities. We have demonstrated that urban streams regularly (e.g., 3 of every 5 years) experience flood peaks that would typically occur once every 100-500 yr in undeveloped watersheds.

Water chemistry. Stream nitrate concentrations are highest in low density development (>2 acre zoning) due to the use of septic systems, yielding nitrate levels as high as in agricultural catchments. Despite apparent high loading of nitrate into urbanized streams due to a set of sources including lawns and leaking sanitary systems, even significantly impacted stream channels appear to show appreciable nutrient processing and retention. Preliminary N budgets indicate substantial retention in natural or semi-natural areas of the suburban matrix, comparable to forest systems.

Water contamination. We have documented excessively high levels of fecal coliforms in some reaches of the Gwynns Falls drainage. BES partners have begun to document non-consumptive modes of transfer of pathogens to humans from urban fishing, an activity that is much more common than seemingly assumed by the regulatory agencies that post fish consumption recommendations.

7. Riparian processes

Vegetation change. The vegetation in the riparian zone of the Gwynns Falls watershed shows a gradient from species that prefer wetter sites in the upper sections, to species preferring drier habitats in the downstream sections of the valley. A comparison of the average basal area of trees in the Gwynns Falls riparian zone with non-urbanized riparian zones in the Maryland Piedmont shows that the upper reaches with rural and suburban development are more similar to basal area of trees in non-urbanized Piedmont floodplains than are the downstream riparian stands. In the riparian zones, 50% of herbaceous species are exotics. The distribution of each exotic species is highly patchy, with few having widespread distribution throughout the Gwynns Falls valley. The majority of native herbs in the lower reaches of the valley are upland or dry habitat species. The majority of exotic species are of upland origin.

Riparian nitrogen dynamics. In our analysis of nitrate dynamics in three forested urban and suburban and one forested reference riparian zones, two of the three urban and suburban streams were more incised and all three had lower water tables in their riparian zones than the forested reference stream. Urban and suburban riparian zones had higher NO_3^- pools and nitrification rates than the forested reference riparian zone likely due to more aerobic soil profiles, lower levels of available soil carbon and greater N enrichment in the urban and suburban sites. At all sites, denitrification potential decreased markedly with depth in the soil profile. Lower water tables in the urban and suburban riparian zones thus inhibit interaction of groundwater-borne NO_3^- with near surface soils that have the highest denitrification potential. These results suggest that urban hydrologic factors can increase the production and reduce the consumption of NO_3^- in riparian zones, reducing their ability to function as sinks for NO_3^- in the landscape.

8. Biogeochemical fluxes

Long-term study plots. Analysis of our two-year *in situ* nitrogen mineralization and nitrification data set showed that growing season (May - November) mineralization ranged from 30 - 50 and that nitrification varied from 4 - 15 kg N ha^{-1} y^{-1}. The magnitude and annual variation in these internal, natural nitrogen processes is significant relative to anthropogenic fluxes of N. For example, annual atmospheric deposition of nitrogen (measured in suburban Maryland by CASTNET) ranged from 8 - 11 kg N ha^{-1} y^{-1} from 1989 - 1999 (http://www.epa.gov/castnet/sites/bel116.html.). Food in and sewage out fluxes for one of our suburban watersheds were estimated to range from 31 - 41 kg N ha^{-1} y^{-1}. These estimates suggest that the natural and semi-natural areas represented by these plots contribute to N retention in the urban and suburban matrix.

9. Meteorological fluxes

Data from the BES Solar Radiation Monitoring Station have been used for comparison of above-canopy UVB radiation in Baltimore to UVB flux in more rural areas (Grant et al. 2002) in late spring and early summer. Baltimore UVB was lower by approximately 4% than rural Queenstown, MD, with most of the difference occurring during the afternoon. There was a positive correlation between UVB and ozone, although only one of the five highest ozone events corresponded with high UVB, indicating that urban ozone precursors were probably more important than UVB in causing peak ozone. UV radiation in urban ecosystems has several implications for human health. Routine exposure to UV radiation can have adverse health effects, especially for young children (Grant and Heisler 2000). Stratospheric ozone reductions have caused measurable increases in UVB radiation in mid-latitudes.

Cub Hill flux tower - first urban flux tower.
Radiation Balance: Observations began in May 2001.Observations of the radiative components show the expected seasonal pattern, with a reduction in net all wave radiation in the wintertime, due to the reduction in the incoming short-wave radiation

Energy Balance: The seasonal change in radiative energy limits the available energy that can be partitioned (Fig 2). The seasonal data allow us to see clearly how the importance of latent heat flux decreases as the leaves fall off the trees (cf November with summer months). In virtually all months, the turbulent sensible heat flux is the dominant mechanism to remove heat from the surface. The storage heat flux term (ΔQ_S) is determined as a residual in the surface energy balance (SEB). Inevitably this means it accumulates all the errors due to measurement and neglected terms (Grimmond and Oke, 1999). It is a significant term at this site in the summertime, consistent with results at other suburban sites (Grimmond and Oke, 2002)

Carbon dioxide fluxes: Though primarily a residential area, in the flux footprint of the Cub Hill site has patches of forest (their relative importance vary with wind direction). The impact of this is particularly evident in the F_{CO2} in Fig. 3. For all months when leaves are on the trees, the site functions as a net carbon sink. This is an interesting result, highlighting the potential significance of suburban ecosystems to offset the emissions of CO_2 known to occur in urban environments. Natural processes of photosynthesis and respiration dominated the C budget. While a human signal appeared in higher carbon dioxide output on weekdays compared to weekends and holidays, carbon uptake was similar to a natural deciduous forest, potentially due to a longer growing season for lawns and supplemental water and nutrients.

Question 3: Development and Use of Ecological Understanding in the Baltimore Region

10. Education partnerships

The curriculum of the School Learning for Urban runoff Reduction Program of the Living Classrooms Foundation was infused with BES science education methodology, as well as BES data. A BES intern began developing a high school curriculum unit for the Agricultural Transformations Biocomplexity project. BES provided resources and scientific support for the Environmental Science Summer Research Experience for Young Women at the Roland Park Country School. Conducted by a Master Teacher, this program served 10 female students from the 9th and 10th grades. (http://faculty.rpcs.org/brockda/essre.htm).

11. Interactions with communities

Ecological and environmental valuation has been a keen interest of agencies and some communities. Valuation of trees in urban areas of the United States has been modeled by BES members. Total compensatory value for trees in cities in the US ranges from $101 million in Jersey City, NJ, to $5.2 in New York City. Total compensatory value for urban forests in the 48 contiguous states is estimated at $2.4 trillion, valuing individual trees as structural elements and using standard methods of the Council of Tree and Landscape Appraisers and field data from eight cities (Nowak et al., 2002). Estimates of carbon sequestration by urban trees in the 48 conterminous states of the US amount to 700 million tonnes C (for a monetary value of $14,3000 million), based on field data from 10 cities (Nowak and Crane, 2002). New demographic data for the urban tree population became available in 2003, indicating a serious deficit in the tree population over the long term. This information has been transferred to the user community through the Revitalizing Baltimore Technical Committee.

KidsGrow, an after school program conducted by Parks & People Foundation, brought BES educational resources to 45, 3rd, 4th, and 5th graders in Baltimore City. The students were predominantly African American. An educational curriculum was prepared for piloting in Fall 2003.

SuperKids Camp, a summer reading enrichment program for rising 4th and 5th graders in Baltimore City, conducted by the Parks & People Foundation, exposed approximately 100 African American youth to tree related activities generated by BES. The activity has literacy links.

The Green Career Ladder, a monthly program, again conducted by the Parks & People Foundation, focused on middle school students. The program brought environmental educational enrichment to 20 6th, 7th, and 8th graders in Baltimore City. The students were primarily African-American.

12. Information management

Important synergies have continued between the BES database system and other active NSF funded projects. The first, "A web-accessible knowledge base for the integrated analysis and valuation of ecosystem services" is producing the Ecosystem Services Database, capable of hosting data and models under a consistent interface. This system serves as a model exploration tool and a bulletin board where researchers can not only access spatially and temporally explicit data, but also run simulated scenarios and share them along with modifications to the models with others to explore (Villa et al., 2002). Connections with the Open Research System data base have been made seamless. Ecological Markup Language (EML) has been adopted by BES.

Small Watershed Network. The Small Watersheds Network web page has been created as a prototype watershed based educational tool kit that can be further applied to small watershed in the Baltimore area (http://iee.umces.edu).

The Linking Science and Decision Making page (http://www.beslter.org/frame9-stuff.html) has been activated, and is the focus of interaction between the user community and BES. The page is fodder for new content and ultimately a publication being jointly prepared by managers and researchers.

Publications and Products

Journal Publications

Bain, D. J., and G. S. Brush. *Submitted*. Placing the pieces: Reconstructing original property mosaic in a meets and bounds watershed. Landscape Ecology.

Binder, C., R. M. J. Boumans, and R. Costanza. 2003. Applying the Patuxent landscape unit model to human dominated ecosystems: the case of agriculture. Ecological Modelling 159:161-177.

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Groffman, P., N. L. Law, K. Belt, L. E. Band, and G. T. Fisher. *In press*. Nitrogen fluxes and retention in urban watershed ecosystems. Ecosystems.

Grove, J. M., M. L. Cadenasso, W. Jr. Burch, S. T. A. Pickett, K. Schwarz, M. A. Wilson, and C. G. Boone. *Submitted*. The social ecology of prestige: Group identity and social status of ecological structure and its implications for urban watershed dynamics in the Baltimore Metropolitan region, Baltimore, Maryland. Society & Natural Resources.

Heisler, G., R. H. Grant, and W. Gao. 2003. Individual- and scattered-tree influences on ultraviolet irradiance. Agricultural and Forest Meteorology 120:3-7.

Helly, J. J., T. T. Elvins, D. Sutton, D. Martinez, S. E. Miller, S. Pickett, and A. M. Ellison. 2002. Controlled publication of digital scientific data. Communications of the Association for Computing Machinery 45:97-101.

Herberlein, T. A., M. A. Wilson, R. C. Bishop, and N. C. Schaeffer. *Submitted.* Rethinking the scope test as a criterion for validity in contingent valuation. Journal of Environmental Economics.

Higgins, J. A., K. T. Belt, R. Russell-Anelli, J. S. Karns, and D. R. Shelton. *Submitted*. Prevalence and molecular characterization of Enteropathic *Escherichia coli* in stream waters in a metropolitan area. Proceedings of the National Academy of Science.

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Law, N. L., L. E. Band, P. Groffman, K. Belt, and G. T. Fisher. *In press*. Water quality trends and determinants in developing urban-suburban watersheds. Hydrological Processes.

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Contributions

Contributions within the discipline and to different disciplines

In the sixth year of the Baltimore Ecosystem Study (BES) we have continued to extend the scope of ecology to the urban realm, which has formerly been largely neglected ecologically. The increase in urbanization, both in the United States and globally, makes ecological attention to urban systems both practically and scientifically important. Because BES is such an integrated project involving many disciplines, we combine the discussions of contributions to individual disciplines and contributions to different disciplines. In order to show how the BES contributes to scientific knowledge, we highlight contributions that have emerged or developed during the past year. Many of our contributions are ongoing, and the value of contributions reported in prior years grows with additional years of data collection.

This year contributions toward improved understanding of urban ecosystem heterogeneity and function include these:

- *The use of scaled, coordinated social and ecological data sets.* Preliminary analyses have explored the connections between socio-economic data, represented by spatially explicit market clusters, and the novel, high resolution ecological classification of the urban mosaic. This information has helped understand the spatial distribution of environmental decision making by households across the metropolitan area. We also discovered unexpected patterns relating home value to lawn fertilization practices.

- *Refinement of a novel land cover classification.* Much of contemporary landscape ecology, planning, and environmental prediction is based on common, but rarely evaluated land use/land cover classification schemes. We have generated a new system that avoids the limitations of the common systems. This system has proven of interest to various disciplines.

- *Measurement of soil microbes associated with exotic plants.* Preliminary analyses address a potentially powerful functional correlate of exotic plant species. This relationship promises to help unify microbial and macroscopic approaches to exotic species.

Contribution to education and human resources

We contributed to education and increasing the breath of human resources available to ecology through three methods: 1) we provided tools to educators, 2) we shared information with educators, 3) and we trained students and teachers. Examples of the tools we shared with the educational community include databases, GIS software, and curricular materials. We shared information through the Internet, classroom lectures in schools and universities, and field trips for the public and students. We provided summer fellowships for teachers to help develop curricular materials based on BES science. Finally, BES trained Research Experiences for Undergraduates students, contributed to the training of students in the Baltimore Cooperative for Environmental Biology, established internships for secondary and college students, and provided summer employment for undergraduates in scientific research. Our commitment to education this year extended from K-12 through graduate, included under represented populations, and used an inquiry based philosophy. Our commitment to diversification of the human resources available for science is exemplified by the demographic break down of our student population for summer 2002: NUMBERS African Americans, ? Asian American, and ? Caucasians. Highlights this year include:

- *Providing Internet connectivity.* We continued to work with the Carrie Murray Outdoor Education Center, a partner with BES in establishing an urban ecology field station, to established high speed Internet connectivity. The Center serves a large, diverse population in Baltimore City, and acts as a node for communicating BES science with the larger public.

- *Recruited underrepresented populations.* We worked with the Washington Village Community Center through the Parks & People Foundation, to establish a Green Career Ladder for city youth, and to help community members generate a local environmental assessment.

- *Contributed to an after school educational program.* KidsGrow provided BES with the opportunity to add scientific content to an effective literacy program for elementary students.

- *Contributed educational content to a summer reading-based program.* SuperKids Camp was the locus for tree-based ecological content to complement the focus on reading and a structured, yet informal context for elementary school students.

- *Developed curricular materials for schools.* Products for 2003 included an eco-history of Baltimore, and an urban ecosystem brochure.

Contribution to institutional and information resources for science and technology

Our ongoing contributions to information for science include databases and integrated models. BES also acts as a conduit for scientifically useful data available in public and community hands, such as the Baltimore Neighborhood Indicators Alliance. In addition, ongoing work includes the development of a network of cooperating sites in the Baltimore metropolis to act as a dispersed, urban ecological field station. Highlights for 2003 include:

- Contribution to International LTER network building by collaborating with French scientists in Zone Ateliers. This interaction continued with the comparative study of nitrogen dynamics, and history of sewer infrastructure.

- Successful, continued operation of the first urban atmospheric flux tower. The "Cub Hill" tower, located just outside the city limit of northeast Baltimore, has become an important focus for integrated research for BES.

- Development of a framework promoting the use of the concept of biocomplexity in coupled human-natural systems. The framework comprises dimensions of spatial heterogeneity, organizational connectivity, and historical contingency. It is appropriate to both biogeophysical and socio-economic disciplines.

- Study of cost effective measures of storm sewer outfalls. The quantification of peak storm flows remains elusive. We are exploring methods to reliably capture this problematic hydrologic parameter. This information is important for estuarine hydrological and sediment budgets, and understanding the land-water margin.

- Participation in the developing Urban Ecology Collaborative, headquartered at Boston College, and establishing a network of research and application in seven cities in the Northeast, Mid-Atlantic regions (Baltimore MD, New York NY, Philadelphia PA, New Haven CT, Pittsburgh, PA, Boston MA, Washington DC).

Contribution to public welfare beyond science and engineering

Both the general public and governmental agencies desire the integrated spatial models and data we are developing. Through our annual and quarterly science meetings we have learned that significant elements of the public are primarily concerned with pollution, neighborhood restoration, and watershed protection. Agencies are concerned with effective data sources, integrated ecological processes in urban areas, and the effects of different infrastructural features on one another and on the environment. This awareness has shaped some of the research we do, how we communicate the results, and additional interactions we pursue. Highlights of contributions during 200 are these:

- *Meeting with the Revitalizing Baltimore Technical Committee*. This meeting brought a large number of BES scientists together with the management, policy makers, and designers associated with neighborhoods, and with city, county, state and federal agencies, to discuss common needs and understanding. Several key insights were shared with the constituencies during this meeting, and several key research initiatives were highlighted.

- *Identified pathogen contamination in urban streams.* BES members and partners have identified bacterial and gastrointestinal parasites associated with streams or with the activity of urban fishing. The impact of urban fishing is much broader than previously thought. New pathways of pathogen transmission have been identified. These have been communicated to agency and leaders through the BES Annual Meeting.

- *Intensive study of storm water dynamics.* Storm flooding has been measured and modeled, combining radar and rain gauge data with topographic data. New thresholds for potential damage in focal watersheds have been identified, suggesting the need for different emergency preparedness and threat guidelines than currently in place.

- *Preparation of urban designs and plans incorporating ecological knowledge.* Collaboration with the Columbia University Graduate School of Architecture, Planning, and Preservation led to two ecologically informed studios – one in urban design and one in architecture – that focused on Baltimore. Design ideas and ecological benefits were communicated through the Parks & People Foundation to community and policy leaders concerned with areas chosen for the studio work. A book is being prepared to communicate the process and insights to the architectural and design communities.

- *Identification of "urban legends" that may impede ecologically informed urban design and management.* A poster has been prepared and shared with the public and policy leaders in agencies and communities highlighting 9 ideas about the structure and function of urban systems that may lead to inappropriate recommendations at some scales and in some situations. This poster can be obtained through the BES website.