Proposed LTER Methods Volume (October 15, 2002)

Title: Principles and Standards for Measuring Net Primary Production in Long-Term Ecological Studies

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Background and Justification.

Recent experience by the authors in synthesizing NPP data across the LTER network of sites clearly demonstrated the need for improvements in the quality, documentation and standardization of NPP measurements. Two recent workshops were subsequently devoted to outlining a volume that would provide guidelines to enable more accurate and well-documented long-term measurements of NPP at field sites throughout the world's biomes. Although many of the principles and approaches for NPP measurements are described in the existing literature, this volume would provide a synthesis and integration of this literature in a form that is more readily accessible and comprehensive in its coverage of topics. The targeted audience for this volume would include ecologists and information managers at LTER, International LTER, Organization of Biological Field Stations sites and other field research facilities.

The approach for this volume would differ from the Soil Methods Volume of Robertson et al (1999). The problems associated with standardization of of NPP measurements are quite different from soils and in particular, site-specific features of vegetation composition and structure, even within biomes, precludes specifying optimal procedures for NPP measurements, Instead, a set of principles and standards for guiding practitioners in designing and documenting their NPP measurement activities will serve as on overall theme for this volume.

Attached is a chapter outline for the volume, a draft of a chapter written by the two volume editors, and more detailed outlines for most of the chapters.

Principles and Standards for Measuring Net Primary Production in Long-Term Ecological Studies

Chapter 1. The need to standardize ecological data. (Waide)

1. Introduction
    a. The enduring legacy of ecological data; why are we fascinated by long-term records?
    b. Understanding ecosystems through temporal and spatial comparison
    c. Local data in regional and continental context: scaling up
2. Benefits to standardizing NPP data
    a. Why do we measure NPP?
    b. Variability in NPP measures and difficulties in comparison
    c. Homogenizing data through statistical treatment
    d. Advantages of standardization
3. Obstacles to standardizing ecological data
    a. The ecologist as individual
    b. Changes in technique and technology
    c. Resource limitation, or show me the money
    d. Distributed data and variation in data descriptions
    e. Lack of standard methods
4. Solutions
    a. Standard methods for NPP measurement
    b. Better management of NPP data
    c. Improved data accessibility and sharing
    d. Convincing the community

Chapter 2: Net primary productivity: Guiding principles and standards for measurement (Fahey and Knapp)

Introduction

Primary productivity is the rate at which energy is stored in the organic matter of plants per unit area of the earth's surface. It is often expressed in units of dry matter (e.g., grams dry weight/m^2-year) rather than energy because of the ease of mass determination and the relative constancy of the conversion from mass to energy (calorific) units for plant tissues. Gross primary productivity is the amount of energy fixed (or organic material created) by plants in photosynthesis per unit ground area per unit time. However, plants use a considerable amount of the organic matter that they produce for their own respiratory needs, and net primary productivity (NPP) is the amount of organic matter that is left after respiration.

All heterotrophic organisms ultimately rely on the organic matter produced by green plants for their food requirements, except for the negligible amounts associated with chemoautotrophs. Hence, our understanding of the dynamics of ecosystems depends fundamentally upon knowledge of patterns and controls of NPP. Recent interest in obtaining accurate measurements of NPP has been stimulated by the problem of rising atmospheric concentrations of CO_2 and consequent greenhouse warming of Earth's climate. The balance between NPP and heterotrophic respiration in natural and human ecosystems largely determines the rate of change of atmospheric CO_2, and the interactions between global climatic change, human activity and NPP will shape the future habitability of Earth. Both accurate measurements of NPP and a thorough understanding of the factors controlling this process in the world's biomes will be needed in the future to facilitate environmental management efforts to protect Earth's ecosystems (Geider et al. 2001).

A long history of study of NPP has accompanied the needs of society to quantify the yield of its managed ecosystems, especially agriculture and forestry. With advances in the concepts of ecology, more formalized study of NPP was undertaken first in aquatic systems then in terrestrial biomes (McIntosh 1985), eventually leading to the development of handbooks to guide the measurement of NPP in forests (Newbould 1966) and grasslands (Milner and Hughes 1968) under the auspices of the International Biological Programme. These handbooks provided a valuable synthesis of methods and approaches for quantifying NPP, and they have been widely cited in the production ecology and related literature since their publication. Research experience in the production ecology of terrestrial and aquatic ecosystems has advanced our understanding of NPP and some aspects of its measurement in ways that move us beyond the IBP Handbooks; however, more recent overviews of methods in ecology and ecosystem science (e.g., Sala et al. 2000) have not provided detailed guidelines for NPP measurement. Moreover, recent experiences of attempts to synthesize the literature on NPP within (Clark et al. 2001a, Gower et al. 2001). and across biomes (Knapp and Smith 2000) has illustrated the need for improving the standardization of NPP measurements.

The demand for high-quality and standardized NPP data can be highlighted by several contrasting types of uses of these data. Numerous attempts have been made to better understand environmental controls and drivers of NPP within and among biomes (Rosenzweig 1968, Webb et al. 1983, Sala et al 1988, Lauenroth and Sala 1992, Frank and Inouye 1994) by relying on published or unpublished data, often with unknown accuracy and precision. Recently, Knapp and Smith (2000) compiled long-term NPP data from 11 LTER sites to assess controls of means and temporal variation in NPP in North American terrestrial ecosystems. Although NPP data quality in LTER research programs is high (because this process measurement is a core area of research within the LTER network, the limited spatial extent of data available highlights the need for additional data sets from sites that adopt those principles and standards required for meaningful comparative studies.

Accurate NPP measurements also are essential for the development and validation of simulation models that are capable of expanding the temporal and spatial scales of prediction of ecosystem dynamics. Moreover, field NPP measurements can provide a comparative basis for utilizing tower-based, aerodynamic measurements of ecosystem C exchange (Goulden et al. 1996). Taken together these field measurements will be needed to evaluate, enforce and credit the sources and sinks of C in the biosphere, as society grapples with the problem of greenhouse gas accumulation in the atmosphere.

The principal audience for the present volume is ecological scientists who are directly involved in designing programs of research that require accurate measurements of NPP. Many ecologists at established ecological research institutions and sites (e.g., US LTER) can draw upon extensive experience measuring NPP. This group can profit from this volume as a reference work to which they can refer students and technicians. In many areas of the world new programs of ecological research and monitoring are being developed (e.g., ILTER). By adopting the principles and standards described in this volume, these programs will be better equipped to obtain meaningful data that will advance the purposes outlined above.

Principles and Standards

<u>General considerations</u>. As pointed out by Newbould (1966) in the IBP Handbook on Measurement of Forest NPP, "Complete standardization of NPP measurements is both undesirable and impractical, but wide adoption of general principles will help make results comparable." Our experience since that time would reinforce this argument. Although it might seem reasonable that a particular suite of standard methods should exist that would optimize the measurement of NPP in any particular biome (e.g., grassland, deciduous forest), experience shows that the unique features of individual sites, the varying availability of funding and manpower, technological advances, and the differing objectives and time-scales of each particular project dictate against method standardization for NPP. This assessment contrasts with measurements of

climate and to some extent soils. Hence, previous LTER methods volumes (Greenland 199x, Robertson 199x) have successfully described detailed procedures for standardizing climate and soil measurements across the U.S. LTER Network.

The present volume provides an overview of the principles that should underlie a program of NPP measurement in any biome. By following these principles a research group should be able to develop a set of procedures that will meet key objectives that ensure that NPP data collected are of high quality for their own purposes and of maximum value for use by others. These objectives are: 1) accurate and unbiased estimates of NPP at appropriate temporal and spatial scales; 2) an assessment of precision of the estimates; 3) documentation of the measurement program, including primary data, meta-data and synthetic use of the data. Although exact sampling procedures must be adapted to meet the local setting and financial constraints, uniform and guiding principles should provide sufficient conformity of NPP measurement to permit reliable cross-site comparisons, model verification and carbon accounting.

The working definition of NPP for purposes of field measurements must be adapted from the formal definition provided in the Introduction, and in fact such a working definition will differ across biomes. For example, in evaluating methods for NPP measurement in tropical forest Clark et al. (2001b) distinguished actual forest NPP from "NPP* (the measurement), the sum of all materials that together represent 1) the amount of new organic matter that is retained by live plants at the end of the interval, and 2) the amount of organic matter that was both produced and lost by the plants during the same interval" (Fig. 1). The latter component is of particular importance in ecosystems with substantial herbivory and rapid turnover of organic matter (many aquatic systems).

In contrast, for ecosystems in which annual changes in the standing stock of live biomass represent a negligible fraction of NPP (e.g., many herbaceous and aquatic communities) and biomass turnover or loss to herbivores (2 in Clark et al.'s definition) is minimal, the seasonal accumulation of biomass sampled at an appropriate temporal intensity is a reliable estimator of NPP (Sala et al. 1981, Briggs and Knapp 1995).

A key consideration in any program of NPP measurement in terrestrial biomes will be what to do about belowground NPP. Field measurement of root growth is difficult and time consuming; moreover, some of the losses of root organic matter that represent a substantial proportion of BNPP have so far defied attempts at quantification: 1) root herbivory, 2) root exudation and rhizodeposition and 3) root C allocation to mycorrhizal fungi. Hence, on one hand measurement of NPP is incomplete without assessment of BNPP, but even the most intensive program of BNPP measurement may fail to provide estimates of BNPP that are comparable in accuracy and precision to ANPP measurements.

<u>Temporal and spatial variation and principles of site selection</u>. The design of any NPP measurement program must address the problems of scale with respect to temporal and spatial variability. Although inter-annual variation in NPP is often substantial (Knapp and Smith 2000), the annual cycle of climate provides a logical and fixed framework for defining the time scale of NPP measurements for terrestrial systems (one exception would be for evergreen vegetation where there may be substantial incongruence between annual fine litterfall and shoot production). The spatial scale of NPP sampling will usually involve substantial subjectivity on the part of the researcher, and the range of applicability of the NPP measurements both within and across sites must be carefully evaluated both before and after the sampling program. This principle is true for both terrestrial and aquatic ecosystems, but the difficulty of the problem probably depends mostly upon the magnitude of spatial variation in NPP within the study area.

Most study areas will present researchers with a complex landscape where the patterns of NPP are non-uniform, and even the pelagic zones of aquatic systems exhibit very high spatial variability in NPP. Although a purely random or regular sampling system may provide an unbiased estimate of the NPP for the study area, in many cases a stratified sampling program will be more efficient, especially when there are straightforward criteria for stratification. Also, the objective of the NPP measurement program may be not to estimate average NPP for the whole study area, but rather some sub-set of the study area. For example, at the Konza Prairie LTER site, soil depth varies substantially with topographic position, and NPP sampling is stratified by upland, slope and lowland locations. This sampling is further arrayed across fire frequencies (1, 4 and 20 yr intervals between fires). Thus, in both cases, the end points of important gradients are sampled (upland shallow soils vs. lowands and annual fire vs. rare fires) as well as an intermediate point. Nonetheless, often a single value for NPP is needed for the site necessitating spatial interpolation of values. Another suitable approach to the problem of stratification of NPP sampling is vegetation classification, particularly where the environmental factors controlling NPP may be more obscure (e.g., wetlands).

In most NPP measurement programs it will be necessary to delineate areas for different sampling activities, especially to accommodate destructive sampling in ways that do not introduce bias into subsequent measurements. Also, where NPP measurement programs are integrated with other ongoing sampling programs (e.g., heterotroph populations) or with experimental treatments (e.g., fertilization trials), it will be important to coordinate the delineation of sampling areas in ways that will accommodate long-term measurements. Typically, within each vegetation stratum the delineation of a NPP sampling area will be necessary with sub-plots for destructive measurements and sufficient buffer to avoid the introduction of sampling artifacts. The actual lay out will vary depending upon the procedures used for NPP sampling. Because root systems and belowground processes may be sensitive to trampling, careful attention to sampling area access will be important.

<u>Field sampling and laboratory procedures: principles and standards.</u> Net primary productivity can be regarded with equal validity as an energetic flux or as a mass flux. Most studies of NPP have focussed on the latter, presumably in part because it does not require the additional measurement of calorific equivalent of dry weight biomass. Three different conventions exist for NPP units

that express the process in terms of mass flux: dry weight, organic matter (or ash-free) dry weight, and mass of carbon. Strictly speaking the latter two conventions better express the connection between the process of photosynthetic production and the synthesis of organic matter; however, most studies do not explicitly make the conversion from dry weight to organic matter or carbon content of biomass. The carbon concentration in plant tissues ranges from about 47% to 55% dry weight and a conventional conversion factor of 50% often has been used (Fahey et al., in review). The concentration of minerals or non-volatile elements or compounds in plant tissues varies is normally less than 2%; hence, the error introduced into NPP estimates by assuming equivalence between dry weight and organic matter usually will be small. We recommend for ease of comparison the use of the convention of reporting oven-dry weight and a 50% carbon concentration conversion factor when these data are unavailable. Alternatively, careful reporting of actual ash and carbon concentrations is needed.

The standard units of area and time for expressing NPP are more straightforward. There is no particular reason to favor a larger or smaller areal unit (e.g., ha vs m^2) for direct interconversion; however, because the area for which a NPP measurement is representative may commonly be smaller than 1 ha, some confusion could be avoided by standardizing on m^2 basis. As noted earlier, the temporal unit of year will usually apply, but for some purposes expression of NPP flux at some shorter or longer time scale may be appropriate.

The problem of determining the appropriate sample size for field measurements of NPP is complex. The intensity of the field sampling program will vary so much among biomes and study areas that it is not useful to provide general guidelines; rather, the question of sampling intensity is considered within individual chapters of this volume. However, two questions about field sampling that deserve general consideration can be posed. First, is there a minimum level of sampling below which field measurement of NPP is not worthwhile? This is not a trivial question because NPP measurements in some biomes (e.g., tropical forest, open ocean) are so difficult that obtaining useful data may be very expensive and the generation of data from sub-minimal programs may be scientifically counter-productive. A second general consideration about NPP measurement is how to determine when additional sampling effort is not warranted. This problem is amenable to statistical analysis as detailed in Chapter 4; however, the answer to the question will depend upon both the resources available to the study and the questions and designs of the research. Hence, the application of statistical criteria are always context specific.

<u>Statistical analysis, problems of bias and QA/QC</u>. Although it would be desirable to develop a standard set of guidelines for expressing the uncertainty underlying NPP estimates, the varying nature of the field sampling programs will preclude a uniform approaches. In principle, different sources of error and uncertainty can be distinguished: 1) spatial variability; 2) quantifiable sampling errors – for example, uncertainty associated with allometric conversions; and 3) unknown sampling errors – for example, uncertainty associated with the separation of live and dead tissues or difficulties in separating current year senescent material from previous year's senescent material.   The nature and severity of these different sources of error will vary among biomes and study areas. Nevertheless, it always should be possible for researchers to generate estimates of uncertainty in their NPP measurements using techniques like Monte Carlo simulations, as described in Chapter ?. The general principle that must be followed in all NPP measurement programs is that the researchers must present their best estimate of error and document in detail how they arrived at their error estimates. Although the ideal of perfect intercomparability among data sets is not possible, if this principle is followed, then an objective basis for evaluating the probability of significant differences among sites and years should be available.

Problems of bias are common in field measurements of NPP. For example, Clark et al. (2001b) concluded that most of the procedural problems in field measurements of forest NPP result in underestimating NPP. In contrast, in many grassland systems where positive increments in biomass from sequential harvests during the growing season are summed, overestimation of NPP commonly result (Singh et al. 1984, Lauenroth et al. 1986, Biondini et al. 1991. Hence, methodological problems resulting in bias will be particular to the ecosystem under study, and the general principle is that researchers must be aware of the potential for introducing bias in NPP measurements. Often the most important sources of bias in terrestrial vegetation will include not accounting for 1) C allocation to mycorrhizae; 2) C loss by root exudation/rhizodeposition; 3) C loss to foliage and root herbivory; 4) C loss to VOC production and organic leachates. Most field NPP measurement programs will lack sufficient resources to adequately address the contribution of unmeasured NPP components, but potential biases should be identified and considered explicitly when a sampling program is designed.

Organization of this Volume

Most of the chapters in this Volume (Chapters 5-13) describe methods of NPP measurement specific to particular biomes or groups of biomes with similar physiognomy of the dominant plants. This organizational framework was chosen to minimize redundancy as the methods of measuring NPP for all plants with similar physiognomy are about the same. Each of these chapters begins by identifying what biomes and community types are covered. However, many study sites will support vegetation with a mixture of physiognomic classes (e.g., savanna with trees and perennial grasses). The most appropriate procedures for such sites will consist of a combination of the techniques for each of the “pure” biomes – forests (Ch. 9) and grasslands (Ch. 11) in the case of savannas. Sampling designs in these situations will likely be hybrids of the designs for the “pure” systems.

The content of the chapters describing methods for each biome includes consideration of the question of scale specific to the biomes because of the profound variation among biome groups in spatial patterns of NPP. Also, for each biome group unique aspects of the ecosystem that may strongly influence the design of a NPP sampling program are identified. A table of representative data is provided in each chapter, not from a thorough review of the literature for purposes of scientific synthesis, but rather as a guide to the practitioner in the design, analysis and interpretation of the sampling program. The suite of guiding principles and specific procedures for each biome group have been developed with the objective of providing the necessary information to guide the practitioner in the design of their NPP measurement program. We would emphasize that the optimal sampling strategy will depend upon the question that is being addressed in the research program. For example, a strategy to quantify annual variation within a study site would likely differ markedly from one to quantify spatial variation or experimental treatment effects.

The science of ecological energetics is continually evolving both as new techniques are developed and as new questions confront the ecologist. This volume provides current state-of-the-science descriptions of methodological principles and techniques as well as separate chapters addressing related topics of data and information management (Ch. 3), error analysis (Ch. 4) and approaches for scaling up from plot-level measurements to larger areas. We hope that this volume will contribute to the need for improved standardization of NPP measurement programs across the world.

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Chapter 3. Information Management Standards and Strategies for NPP Data

W. Michener

I. The process of managing NPP data and information
  a. Flow chart illustrating the data management process (Figure 1)

II. Data entry
  a. Approaches
    i. example of data sheet/full screen entry (Figure 2)
  b. Technologies

III. QA/QC
  a. The QA/QC process
  b. Approaches
    i. example code (Figure 3)
  c. Technologies

IV. Metadata
  a. Definition and value of metadata
  b. Existing metadata standards
    i. Ecological Metadata Language (Table 1)
  c. Approaches to implementation
  d. Technologies

V. Data archives
  a. The archive process
    i. existing regional, national, and international NPP data archives (Table 2).
  b. Approaches
    i. file naming conventions
    ii. Metadata revisited
    iii. Other recommendations
  c. Technologies
    i. Storage media, longevity, and other considerations

VI. Conclusion
  a. Data as a resource and scientific community capacity-building
  b. Best information management practices

Chapter 4. Estimating NPP in Grassland and Herbaceous Dominated ecosystems (Knapp and Briggs)

General considerations

- Types of biomes/communities/physical environments covered by this chapter
    - Annual and perennial grasslands, old fields, tundra, alpine
- How NPP is defined for these biomes and the time scale of measurement
- Range of NPP and aboveground biomass (or representative values) for these biomes (Table)
- Unique aspects and primary drivers (climatic and biotic) of NPP for these systems
    - Fire and grazing by large herbivores
    - Water, N and light as co-varying limiting resources
- Importance of belowground NPP in this biome (link to BNPP chapter)

Guiding principles and recommendations

- Review of methods (+, -'s)
    - Harvest methods
    - Non-destructive techniques
    - Indirect methods
- Recommended method(s) – general overview and justification
    - Harvest method
    - Modifications/special considerations due to:
        - Fire
        - Herbivory
        - Growth forms
        - Temporal (seasonal) considerations (C3/C4, tropical, temperate)
        - Spatial considerations (topography, soil depth)
        - Long- vs. short term considerations for sampling herbaceous ecosystems

Specific field and lab procedures (with case studies as appropriate)

- Recommended method(s) (actual details for level of international student)
    - Harvesting plots – sorting by species vs. growth form, litter, rules for defining plot edges
- Temporal sampling recommendations (guidelines for decisions)
    - Peak biomass vs. incremental sampling, moveable exclosures
- Spatial sampling recommendations (guidelines for decisions)
    - Plot arrangements, landscape considerations
- Sample size/effort (recommendations or guidelines for decisions)
    - Plot size, number (case study here) and shape
- Calculations and units
- Recommend level of effort and precision
- Biases in method, probable sources of error and how to minimize

Future research needs for these biomes

Chapter 5. Estimating NPP in Shrub and Succulent Dominated ecosystems
(Young and Huennecke)

I. General Considerations
- A. Types of biomes/communities/physical environments
  1. shrublands - Mediterranean, arid, maritime, riparian, etc.
  2. succulent communities - arid
- B. NPP definition for shrub and succulent systems
- C. Range of NPP and aboveground biomass (Table)
- D. Unique aspects and primary drivers (climatic and biotic) of NPP
  1. temperature - precipitation (amount and timing) interactions
  2. soil and nutrient considerations
  3. fire
  4. biotic: herbivory, vegetative propagation, N-fixation, allelopathy, etc.
- E. Importance of belowground NPP (link to BNPP chapter)

II. Guiding principles and recommendations
- A. Review of methods
  1. harvest method (dimension analysis)
  2. gas exchange
  3. remote sensing (?)
- B. Modifications and considerations due to
  1. leaf habit (evergreen vs deciduous)
  2. determinant vs indeterminant growth
  3. fire
  4. herbivory
  5. vegetative propagation
  6. spatial considerations
  7. long vs short term considerations

III. Specific procedures (case studies if available)
- A. Recommended method
  1. harvest method - litter collection, representative sampling, development of incremental relationships, scaling up, etc.
  2. modifications for succulents
- B. Temporal and spatial sampling decision guidelines
  1. plot arrangement
  2. landscape considerations
  3. when to sample
  4. case studies
- C. Sample size/effort decision guidelines
  1. plot size and number
  2. case studies
- D. Combining multiple growth forms to estimate NPP
  1. especially grasses and forbs
  2. links to other chapters
- E. Calculations and units
- F. Biases in method, probable sources of error and how to minimize

IV. Future research needs
- A. More field studies - perhaps the most under represented growth form or biome with regard to accurate NPP measurements.
- B. Development of accurate methods requiring less effort

Chapter 6. Estimating ANPP in Forest Dominated Ecosystems

Brian Kloeppel and Mark Harmon

I. General considerations

- Types of biomes/communities/physical environments covered by this chapter
  - Broadleaf forests
  - Coniferous forests
  - Tropical forests
- How ANPP is defined for these biomes and the time scale of measurement (annual)
  - Definition and derivation of ANPP
  - Theory and equations for GPP, NPP, ANPP, etc.
- Range of ANPP and aboveground biomass (or representative values) for these biomes (Table)

- Unique aspects and primary drivers (climatic and biotic) of ANPP for these biomes
  - Water, N and P, and light as co-varying limiting resources
  - Insect herbivory
  - Moss and lichen production in boreal biomes
  - Shrub production in many forested biomes
  - Vine production in tropical and other biomes
- Importance of belowground NPP
  - Link to Fahey "Belowground Production…" chapter

II. Guiding principles and recommendations

- Review of methods (positives and negatives)
  - Wood productivity (biomass increment)
    - Repeated tree diameter measurements
      - Diameter tape
      - Dendrometer band
      - Reconstructing past wood productivity
        - Increment core ring widths for temperate and boreal biomes
        - Nearly impossible for tropical biomes
    - Use of allometric relationships
  - Foliage productivity
    - Litter baskets
    - Use of allometric relationships
  - Mortality of trees
    - Annual tree census data
    - Difficulty of reconstructing past ANPP without mortality measures
- Recommended method – general overview and justification
  - Wood productivity
    - Repeated tree diameter increments (during dormant season)
  - Foliage productivity
    - Litter basket collections
  - Special considerations
    - Herbivory
    - Growth forms
    - Temporal (seasonal) considerations
    - Considerations for sampling mixed growth form (subalpine) biomes

III. Specific field and lab procedures (with case studies as appropriate)

- Harvests to generate allometric equations
  - Importance of site specific equations
- Recommended method(s) (actual level of details for international student)
- Temporal sampling recommendations (guidelines for decisions)
  - Dormant season for wood growth increments
- Spatial sampling recommendations (guidelines for decisions)
  - Plot shape
- Sample size/effort (recommendations or guidelines for decisions)
  - Plot size
  - Plot number (case study here)
- Calculations and units
  - Reconstructing biomass values from $\log_{10}$ corrected and bias corrected allometric equations
  - SI: g m^{-2} $year^{-1}$
- Recommend level of effort and precision
- Biases in methods, probable sources of error, and how to minimize
  - Link to Harmon and Phillips "Bias, Error, and Uncertainty…" chapter

IV. Future research needs for these biomes

Chapter 7. Estimating NPP in Urban Ecosystems [Martin]

General considerations

- Urban structures
    - Range and diversities of urban systems
    - Urban land use effects on urban land cover characteristics and plant distribution
    - Impacts of hierarchical ecosystem process interactions on urban plant distribution - urban as a nested phenomenon
    - Urban as disturbance
- How NPP is defined for urban ecosystems and the time scale of measurement
- Range of expected NPP values and aboveground biomass for urban systems
- Unique aspects and primary drivers (abiotic and biotic) of NPP in urban systems
    - Human domination of urban systems: sociological and technological factors affecting urban landscape design
    - Impacts of urban on climate (water, temperature, light, humidity, atmospheric pollutants, greenhouse gases)
    - Impacts of urban on physical/chemical properties of soil
- Importance of belowground NPP in urban systems (link to BNPP chapter)

Guiding principles and recommendations

- Review of methods (links to Freshwater aquatic, forest, shrublands, and grasslands chapters)
    - Destructive or harvest methods
    - Non-destructive techniques
    - Indirect methods
- Recommended methods – Overview and justification
    - Extensive non-destructive methods
    - Intensive destructive methods, experimental plots
    - Allometry (link to error/bias/allometry chapter)
    - Remote sensing (link to scaling up chapter)
    - Modifications/special considerations due to:
        - Spatial considerations (land use management, property ownership, land use ordinances and access restrictions, government regulations)
        - Horticultural management practices
        - Mixed canopies
        - Temporal considerations (link to grasslands, forest chapters)
        - Spatial considerations (topography, soil restrictions)

IV. <u>Specific field and lab procedures</u> (including case studies as appropriate)

- Recommended methods (details for international application)
    - Extensive non-destructive methods – sorting by land use, urban-climate interactions, species vs. growth form, litter, turf grasses
    - Intensive destructive methods, experimental plots - temporal considerations, horticultural practices
    - Allometry - species, life form, horticultural management practices
    - Use of remote sensing
- Temporal sampling recommendations (guidelines for decisions)
        - Peak biomass vs. incremental sampling
- Spatial sampling (guidelines for decisions)
        - Plot arrangements, horticultural management considerations
- Sample sizes/effort (recommendations or guidelines for decisions)

        - Plot size, plot number, (case study here) and plot shape in relations to urban structure
- Calculations and units
- Recommendations of level of effort and precision
- Minimizing methodological biases, probable sources of error

IV. Future research needs for urban biomes

Chapter 8. Belowground NPP: approaches and challenges (Fahey)

I. General Considerations

A. Types of biomes/communities considered
1. Forests
2. Grasslands
3. Shrublands

B. Defining belowground NPP
1. Belowground C allocation and root respiration
2. Allocation to mycorrizae
3. Exudation & rhizodeposition
4. Herbivory

C. Plant Root Systems
1. Morphology: sizes, hierarchy
2. Root function: specialized tissues (storage)
3. Root turnover, phenology and demography
4. Mycorrhizae

D. Primary drivers of BNPP across biomes

E. Relationship of NPP to BNPP across biomes (with table)

II. Guiding Principles and Recommendations

A. Review of Methods

B. Choosing a Method
1. Objectives
2. Time-frame
3. Cost
4. Site

C. Recommended Methods
1. In-growth or sequential cores
2. N and/or C budgets
3. Minirhizotrons
4. Radiocarbon

?5. Soil respiration - root respiration

D. Further considerations
1. Steady-state assumption
2. Coarse vs. fine root production

III. Specific field and lab procedures (with case studies)

A. In-growth or sequential cores

(Include the following for each of the 5 methods)
1. Detailed instructions
2. Temporal recommendations
3. Spatial recommendations
4. Sample size
5. Calculations, units
6. Recommended precision
7. Biases

B. N and/or C budgets

C. Minirhizotrons
D. Radiocarbon
?E. Soil respiration - root respiration

F. Comparisons between methods

IV. Future research needs

A. Further methodological improvements
B. Better understanding of controls on BNPP

Chapter 9. Estimating NPP in Marine Pelagic Ecosystems

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I. Introduction

A. Types of biomes/communities/physical environments in the world's oceans
    i) biogeochemical provinces ("biomes") of the world's oceans
B. Definition of NPP
C. Time and Space scales in marine ecosystems
    i) contrast marine & terrestrial systems – significant differences
    ii) marine systems tightly coupled to physical forcing
    iii) marine time & space scales influence sampling strategies
D. Average World Oceanic Production
    i) brief summary of literature values
E. Factors limiting NPP in pelagic ecosystems
    i) Light (visible and UV)
    ii) Macro- and micro-nutrients
    iii) Grazing by micro- and macrozooplankton
    iv) Sedimentation
    v) Advection
    vi) temperature & sea ice cover

II. Guiding Principles and Recommendations

A. Review of Methods
    i) Experimental (14C, O2 production, etc.)
    ii) Indirect methods (in vivo chlorophyll fluorescence, induced fluorescence, etc.)
    iii) Remote Sensing
    iv) Modeling (from light absorption, etc.)
B. Methodological Limitations and Recommendations
    i) Experimental (effect of microzooplankton grazing, bottle size, etc.)
    ii) Indirect Methods (assumptions, etc.)
    iii) Remote Sensing (inherent sampling bias, chlorophyll depth profiles, etc.)
    iv) Modeling

III. Field and Laboratory Approaches (with case studies as appropriate)

A. Methods
    i) 14C and 13C (in situ, simulated in situ, PI curves)
    ii) Oxygen Production and Respiration
    iii) In vivo chlorophyll fluorescence
    iv) Induced chlorophyll fluorescence
    v) Ocean color (CZCS, SeaWIFS, MODIS, AVHIRRIS)
    vi) Models
B. Method Intercomparison
C. Sampling
D. Spatial and Temporal Considerations
E. Recommendations on methods based on biomes

IV. Present Needs and Future Research

Chapter 10. Estimating NPP in Salt Marsh and Mangrove Dominated Ecosystems [Morris and Twilley]

III. General considerations

- Types of biomes/communities/physical environments covered by this chapter
  - Intertidal communities dominated by perennial grasses or mangrove forests
  - How NPP is defined for these biomes and the time scale of measurement
- Range of NPP and aboveground biomass (or representative values) for these biomes and the method used (Table)
- Unique aspects and primary drivers (climatic and biotic) of NPP for these systems
  - Relative elevation and tidal amplitude = frequency and duration of inundation
  - Nutrients (N limitation in Spartina, N or P in mangroves, depending on soils)
  - Salinity
  - Latitude/degree days
- Importance of belowground NPP in this biome
  - The unique importance of BNPP here is the contribution to sediment volume and wetland stability in the face of sea level rise.
  - Ratio of aboveground to belowground NPP across gradients in I.C above

IV. Guiding principles and recommendations

- Review of methods (+, -'s)
  - Harvest methods.. Mention of Smalley method and variants thereof, Refer to Knapp's chapter on grasslands.
  - Non-destructive techniques (census technique for S. alterniflora). Dimension analysis for mangroves
  - Litter fall methods vs leaf tagging studies
  - Indirect methods… CO_2 flux in chambers (these are indirect? – net carbon exchange is pretty direct)
- Recommended method(s) – general overview and justification
  - Allometric method for Spartina for temporal variation, harvest for spatial variation.
  - ANPP of Mangroves: Dimenstion analysis of wood production plus litter fall rates; plots vs transectsBNPP of Mangroves: Ingrowth root bags; plots vs trees
  - Modifications/special considerations due to:
    - Fire
    - Herbivory
    - Growth forms (special problems with scrub mangrove forests)
    - Temporal (seasonal) considerations (C3/C4, tropical, temperate, wet/dry season)
    - Spatial considerations (topography, soil depth, zonation)
    - Long- vs. short term considerations for sampling herbaceous and forest ecosystems

V. Specific field and lab procedures (with case studies as appropriate)

- Recommended method(s) (actual details for level of international student)
    - Selecting permanent plots…size=f(stem density)
    - Establishing transects in mangroves
    - constructing boardwalks to access sites
    - Tagging: using plastic number coded bird bands for salt marshes; aluminum tags and markers for mangroves
    - Dimensions of salt marshes - measuring stem heights; Dimensions of mangroves – measuring diameter and heights

- recording the measurements in the field, keeping a map of each plot
- Temporal sampling recommendations (guidelines for decisions)
    - Salt marshes: incremental sampling
    - Mangroves: Frequency of dimenstion surveys; litter baskets; in growth bags; leaf longevity
- Spatial sampling recommendations (guidelines for decisions)
    - Salt marshes: landscape considerations (high marsh, low marsh)
    - Mangroves: geomorphic and ecological settings, zonation
- Sample size/effort (recommendations or guidelines for decisions)
    - Salt marshes: Plot size, number (case study here) and shape
    - Mangroves: Plot size, Points on PQM, length of transects, replication, number of litter baskets, replication of root cores,
- Calibration
    - Salt Marshes: stem weight vs length regressions)
    - Mangroves: equations for biomass of forest dimensions
- Recommend level of effort and precision
- Software
    - Organization of input data files
- Biases in method, probable sources of error and how to minimize
    - leaf turnover
    - Dead trees/mortality
    - BNPP depth esimates
    - Above ground root turnover
    - Dimensions of aboveground root biomass

VI. Future research needs for these biomes

a. LIDAR/LASER technology
b. LAI

Chapter 11. Freshwater primary production and respiration

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A General considerations

Photosynthesis (GPP) vs. NPP (O2-GPP, 14C –primary production, somewhere between NPP and GPP)
Pelagic vs. benthic
Time scale of measurements relative to terrestrial measurements
Review of some different estimates

B. Guiding principles and recommendations

1. Review of methods
   a. Chamber methods for pelagic and benthic.
      i. Pelagic 14C and O2
      ii. Benthic O2 and 14C
   b. Whole-system O2 budgets
      i. Theory
      ii. Lake approaches
      iii. Stream approaches
2. Recommended method depends on question
   a. System-level question then use ecosystem O2 budget
   b. Subsystem question – chambers
3. Macrophyte production-reference grassland chapter for these methods since the methods are so different

C. Field and laboratory approaches

1. Whole system
   a. reaeration correction
      i. empirical
      ii. literature/modeled approaches
   b. Lake method (will include detail on probe placement, calculations, probe calibration and error analysis)
   c. Stream method
2. Chambers
   a. Benthic
      i. design
      ii. use
   b. Pelagic (bottles). 14C and O2 methods

Chapter 12. Methods for Scaling Up Ecosystem Measurements

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1. What Is Scaling Up?
   - Our definition: Scaling refers to the translation of information from one scale to another across space, time, or organizational levels. Our focus is on spatial scaling, but most of the methods are also relevant to temporal scaling.
   - Other related concepts: grain, extent, resolution, support, coverage, extrapolation, interpolation, fine-graining, coarse-graining

2. Why Scaling Up?
   - Most empirical measurements in ecology are conducted over small areas and short time periods, and they are frequently upscaled to obtain the whole-ecosystem or landscape-level properties.
   - Principles and methods for dealing with multiple scales and hierarchical linkages are indispensable for understanding and managing ecological systems.
   - Most environmental issues, such as resource management, landscape planning, biodiversity conservation, and global change, need to consider patterns and processes over a wide range of scales.

3. Scaling Up Methods

   3.1. Simple Averaging
   - Simple Averaging uses the averages of field measurements or outputs of a local model to obtain estimates at the ecosystem or landscape scale.

   3.2. Spatially Explicit Summation
   - Spatially Explicit Summation obtains the large-scale estimates by, in the case of using a model, first running the local model with input parameters and variables for each element of the system (e.g., pixel, or patch) and then adding up model outputs for all the elements.

   3.3. Mathematical Expectation
   - Mathematical Expectation treats model arguments (i.e., input parameters and variables) as random variables and uses expected values derived from the model to calculate large-scale estimates.

   3.4. Scaling Up by Equivalent Parameters
   - A commonly used upscaling procedure in hydrology and soil sciences in which the system-level estimates are achieved by running the local model with “representative” or “equivalent” parameters and input variables.

   3.5. Allometric scaling
   - Similarity principles
   - Fractals/multifractals

   3.6. Hierarchical scaling
   - Hierarchical patch structure of ecosystems and landscapes
   - The scaling-ladder approach
   - Other hierarchical scaling approaches

4. The Role of Remote Sensing and GIS in Scaling Up

- A brief review of RS and GIS applications in scaling up
- RS and GIS can help scaling by facilitating the change of grain and extent as well as by providing multiple-scale data
- Scale and accuracy issues with RS and GIS

5. Guiding Principles and Recommendations