WWF

A Sourcebook for Conducting Biological Assessments and Developing Biodiversity Visions for Ecoregion Conservation

Volume II: Freshwater Ecoregions

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WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature by:

- conserving the world's biological diversity
- ensuring that the use of renewable natural resources is sustainable
- promoting the reduction of pollution and wasteful consumption

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Introduction

Summary

Many conservation organizations, governments, and donor agencies have intensified efforts to save life on earth. New tools such as the Global 200 provide a valuable means for identifying terrestrial, freshwater, and marine ecoregions that deserve greater attention because of their outstanding biodiversity value. The Global 200 analysis identifies the most prominent biological features of each priority ecoregion, laying the groundwork for finer-scale analyses to conserve these features. To accomplish this urgent task, conservation groups are relying on landscape-level conservation approaches. World Wildlife Fund (WWF) and The Nature Conservancy refer to this as ecoregion conservation, a rigorous approach at a spatial and temporal scale that allows allocation of efforts for safeguarding biodiversity over the long term. Ecoregion conservation is consistent with WWF's main mission — biodiversity conservation. To meet this goal, we must preserve the ecological interactions and evolutionary mechanisms that generate and maintain species, and this requires us to think, plan, and act over the scales at which nature operates.

A major commitment to the ecoregion approach exists across the WWF network and in many other arenas around the world. One bottleneck, however, has been the absence of guidelines for undertaking this new approach. For terrestrial ecoregions, a workbook published in November 2000 now helps to fill this gap by outlining the major steps involved in conducting a biological assessment and creating a biodiversity vision. This volume, which we call a sourcebook, strives to do the same for freshwater ecoregions. Both volumes, structured as combined guides, teaching tools, checklists, and literature reviews, attempt to answer many of the questions that conservation professionals, partners, and specialists have raised as they have engaged in ecoregion conservation.

These two books, as well as a forthcoming marine volume, are intended to serve as placeholders until biological assessments and biodiversity visions are published for a sufficient number of Global 200 ecoregions across all biomes. It is our hope that a library of biological assessments will soon be available to guide practitioners of ecoregion conservation.

Scope and Objectives of the Freshwater Sourcebook

Tallies of imperiled species tell us that, on average worldwide, freshwater biodiversity is more threatened than terrestrial (Allan and Flecker 1993; Williams et al. 1993; McAllister et al. 1997; Ricciardi and Rasmussen 1999). Of those species considered in the 1996 IUCN (The World Conservation Union) Red List, 20% of reptiles, 25% of amphibians, and 34% of fishes (mostly freshwater) were threatened (Baillie and Groombridge 1996), and the numbers of threatened species have risen in the 2000 count (IUCN Species Survival Commission 2000). At a regional scale, the projected mean future extinction rate for North American freshwater fauna is about five times greater than that for terrestrial fauna and three times that for coastal marine mammals. This rate is comparable to the range of estimates predicted for tropical rainforest communities (Ricciardi and Rasmussen 1999). Inventories of imperiled and extinct species can account only for described forms and, even within well-known groups such as fish, species are apparently going extinct before they can be classified (McAllister et al. 1985).

While the earth's rivers, lakes, and wetlands contain a mere 0.01% of the earth's water, these ecosystems harbor a disproportionately large fraction of the earth's biodiversity. Freshwater fishes alone account for approximately one-fourth of all living vertebrate species, and the estimated number of scientifically named species of all biota in fresh water is 44,000 (McAllister et al. 1997; Stiassny and Harrison 1998). Melanie Stiassny, curator of ichthyology at the American Museum of Natural History, points out that these numbers represent "a tremendous concentration of biodiversity in these very, very vulnerable habitats" (Stiassny and Harrison 1998).

Freshwater biodiversity is besieged by an array of threats operating over a range of scales. These threats include dams, exotic species, overfishing, pollution, stream channelization, water withdrawals and diversions, and the panoply of impacts from development of the terrestrial landscape for logging, agriculture, industry, settlement, mining, and other uses. In no realm is conservation action more urgent than in fresh water, yet until recently conservation planning to protect freshwater biodiversity has been more of an afterthought than a primary goal (Blockstein 1992). WWF is seeking to reverse this trend by focusing on freshwater habitats and species within the framework of ecoregion conservation. Whether an ecoregion has been designated freshwater, terrestrial, or even marine, there is likely a freshwater component for ecoregion practitioners to consider from the start. Waiting to address freshwater species and habitats until after the ecoregion conservation project is well underway will guarantee added difficulty, because real differences exist between freshwater ecoregional planning and the terrestrial model with which people are most familiar (see box at the end of this chapter).

Why should we engage in freshwater ecoregion conservation?

Patterns of freshwater biodiversity differ from terrestrial
For species confined to water, dispersal mechanisms are limited by aquatic connections

Freshwater ecosystems suffer from additional classes of threats
Dams, channelization, nonpoint and point source pollution, and water withdrawals are examples of threats that disproportionately affect freshwater systems

Freshwater conservation cannot ignore catchments (also known as watersheds, basins)
The effects of upland and upstream activities are propagated downstream, so fencing off aquatic areas will not normally secure their protection

Freshwater biodiversity has historically been overlooked
Freshwater biodiversity and the urgency of its conservation are usually lost within larger terrestrial assessments

Objectives

The objectives of this sourcebook are to:

1. Provide an introduction to freshwater biodiversity conservation at an ecoregion scale
2. Address questions regarding how freshwater ecoregion conservation relates to ecoregion conservation in the terrestrial realm
3. Offer suggestions for conducting a biological assessment and constructing a vision for conserving freshwater biodiversity features
4. Illustrate approaches for freshwater ecoregion conservation with examples from biological assessments that are underway within and outside the WWF network
5. Provide background material for those interested in learning more about freshwater biodiversity conservation

This sourcebook can stand alone or serve as a companion to *Volume 1: Terrestrial Ecoregions* (Dinerstein et al. 2000). Many of the guidelines for conducting ecoregion conservation are similar for terrestrial, freshwater, and marine ecoregions, as is much of the theory behind the process. But, WWF's limited but growing experience with conservation planning in freshwater ecoregions has shown that direct application of approaches developed for the terrestrial realm can generate problems. We identify those limitations and offer suggestions for developing new approaches or modifying existing ones. We derive many of these suggestions from empirical studies conducted outside the framework of ecoregion conservation, and as such these suggestions are yet to be tested within a freshwater ecoregion project. Freshwater conservation at any scale presents multiple challenges, and to our knowledge no attempts to conduct ecoregion-scale conservation for freshwater systems have yet reached a stage where their results can be evaluated fully. Ecoregion conservation is itself an innovative approach to conservation, and focusing on freshwater biodiversity adds an extra layer of difficulty — and opportunity — to the process.

This sourcebook is intended for anyone engaged or interested in the conservation of freshwater biodiversity within an ecoregional framework. We recommend that those responsible for conducting a biological assessment or articulating a biodiversity vision for *any* ecoregion, be it freshwater, terrestrial, or even coastal marine, review Chapter 2 at a minimum. Freshwater systems occur in every terrestrial ecoregion and drain to every coast, but it is easy to overlook the importance of these systems and their biota. Familiarizing yourself with the ideas in this sourcebook early in the ecoregion planning process may stimulate ideas about how to incorporate freshwater conservation into your project, even if you choose not to undertake a comprehensive assessment of freshwater biodiversity features.

To assist those readers who are less familiar with freshwater ecology, we explain technical concepts and give ample background information. We also include numerous excerpts from the current literature that we believe are relevant to ecoregion conservation; these excerpts are generally placed in boxes at the end of chapters. We do not, however, provide a comprehensive explanation of ecoregion conservation in general — that information is found in other documents available through WWF's Conservation Strategies Unit.

This sourcebook has more options and observations than instructions, because many of the ideas are as yet untested and unevaluated. We are forthright with the lessons, both good and bad, that we have taken from our experiences so far. We urge readers to document their own experiences, so that each successive freshwater ecoregion project is progressively more sophisticated and successful.

Structure of the sourcebook

This sourcebook contains 15 chapters that cover the major topics involved in conducting a biological assessment and designing a biodiversity vision. The topics themselves will be applicable to almost any ecoregion, but the specific steps and approaches that we recommend may not be applicable to every situation. We provide examples from actual case studies where possible, although there are presently a limited number of freshwater ecoregions from which we can draw lessons and results.

In Part I (Chapters 1-3), we present basic concepts and strategies. We first review the concept of ecoregions in general, the importance of scale in conservation efforts, and why ecoregion conservation provides a valuable tool for conserving biological diversity and setting conservation priorities (Chapter 1); this material is extracted largely from *Volume 1: Terrestrial Ecoregions*. Next, we introduce freshwater ecoregions and address common questions regarding how they relate to terrestrial ecoregions, why we believe that they are an important tool for developing effective strategies for freshwater biodiversity conservation, and how they are used within an ecoregion conservation project (Chapter 2). We end Part I with a discussion of the data, decisions, and approaches that we recommend for preparing to construct a biodiversity vision, which is one of the key features distinguishing ecoregion conservation from other large-scale conservation approaches (Chapter 3).

Part II of the sourcebook (Chapters 4-13) provides recommendations for conducting a biological assessment and developing a biodiversity vision for a freshwater ecoregion. We first present an overview of those key ecological principles that underlie conservation planning for freshwater systems (Chapter 4). We then discuss fundamental considerations related to conducting a biological assessment and developing a biodiversity vision, including those that may be addressed during an orientation meeting (Chapter 5). We outline basic preparatory steps, including forming the assessment team and designing an expert workshop, and we review basic data requirements and discuss issues related to data quality and quantity (Chapter 6). We also provide recommendations for resolving methodological issues prior to conducting the assessment (Chapters 7-8). We offer a step-by-step approach for conducting the workshop and assessment, beginning with a chapter on understanding and mapping patterns of biodiversity at the ecoregion scale (Chapter 9). We present techniques to assess habitat intactness within the ecoregion and to assess the long-term integrity of selected areas (Chapter 10). We then discuss integrating data on biological importance and ecological integrity to identify where to act first at the ecoregion scale, given staff and funding constraints (Chapter 11).

The biologists who participate in assessments bring vast experience and understanding not only of the biota but also of threats. To capture this valuable information, we offer an approach for assessing threats to biodiversity at ecoregion and priority area scales (Chapter 12). Next, we cover the steps recommended for integrating the results of the assessment into a biodiversity vision (Chapter 13). Finally, in Part III we cover two advanced topics: restoration (Chapter 14) and remote sensing (Chapter 15).

We also provide tools to accompany this sourcebook: (1) a glossary of ecoregion conservation terms, (2) a glossary of biological terms, (3) guidelines for developing a geographic information system (GIS) lab and database, (4) suggestions for conducting successful expert assessment workshops, (5) examples of data sheets for workshops, (6) a description of publicly available global-scale maps, GIS, and satellite data, and (7) contact information for select WWF freshwater staff. All of this information is found in the appendices.

Primary distinguishing features of freshwater ecoregion conservation

- Connectivity[1] is essential to maintaining freshwater biodiversity. This includes connectivity between and within aquatic habitats, connectivity with the riparian zone and floodplains, and connectivity with subterranean systems. Loss of connectivity will fundamentally alter ecosystem processes and negatively affect species.
- Because aquatic habitats are linked to each other, focusing solely on the protection of discrete sites will be an incomplete solution to developing a biodiversity vision, except perhaps in systems characterized by isolated, hydrologically unconnected habitats.
- The recovery of disturbed habitats normally is dependent on the presence of adjacent or connected undisturbed habitats — called spatial refugia — that can serve as sources of recolonization. Among the most effective spatial refugia may be ecologically intact catchments, if they remain.
- Within a catchment, the effects of land-based activities are propagated downhill and downstream, so an assessment must look beyond target freshwater habitats and consider land uses within the larger catchment. Although we know that land use affects aquatic habitats, we generally do not know the degree or extent of effects for different land uses, which complicates the analysis and design of a vision.
- Downstream impacts can also propagate upstream, especially in systems characterized by migratory species. For coastal areas, a vision may need to extend to the marine environment.
- Physical processes may be the most important ecosystem components to protect, particularly for large river systems with active floodplains. One of the primary challenges for freshwater ecoregion conservation is developing approaches to protect hydrologic processes operating over large spatial scales. In altered systems this may include restoration of the natural hydrograph.
- For most freshwater species, we are currently unable to identify minimum population sizes or minimum critical area requirements. This, in turn, constrains our ability to identify the minimum amount of intact aquatic habitat that must be conserved. Furthermore, minimum habitat requirements may be linear versus areal, and a species' habitat needs may vary according to life stage or season.
- Exotic species pose one of the most serious threats to freshwater biodiversity, and the establishment of exotics is often irreversible. When humans introduce new species, either intentionally or accidentally, native species confined to water have limited escape routes. Exotics may also invade habitats when natural dispersal barriers are breached, such as through interbasin water transfers.
- Because humans depend on water sources and often manipulate them, and because virtually all changes to the terrestrial landscape affect aquatic systems, very few freshwater ecoregions remain intact. For this reason, restoration may be a large component of freshwater ecoregion conservation.
- Terrestrial ecoregion boundaries rarely correspond to catchments. When working within a terrestrial ecoregion, boundary issues may complicate an assessment of freshwater biodiversity features. Extending the region of analysis for the freshwater assessment to include whole catchments, if possible, is often the best solution.
- Subsurface freshwater habitats (e.g., groundwater-fed systems such as caves, hyporheic zones[2]), which often contain important but poorly known biodiversity elements, are connected to each other and to surface water habitats in ways that do not necessarily correspond to catchments. In ecoregions containing distinct subterranean biotas, or where groundwater acts as a major input to surface water habitats, mapping groundwater may be required. This task adds an extra layer of complexity to the ecoregion effort. Similarly, wetland habitats may straddle catchments.
- Most non-vertebrate freshwater taxa are poorly known, and for a given ecoregion there may be only one or two experts for groups such as molluscs, crustaceans, aquatic insects, and aquatic plants. Consequently, freshwater visioning workshops will generally have fewer taxonomic groups represented by fewer experts than for comparable terrestrial analyses or workshops. A smaller group creates both opportunities and constraints, and the workshop structure should take these into account.
- At present, widely available remote sensing technology cannot detect most aquatic habitat characteristics, and high-resolution imagery is necessary to identify the generally finer zonation of riparian vegetation.

[1] In this sourcebook, connectivity is used broadly, referring to linkages of habitats, species, communities, and ecological processes across multiple scales. In essence, it is the opposite of fragmentation (Noss 1991, as cited in Federal Interagency Stream Restoration Working Group 1998). In hydrologic terms, connectivity refers to the exchange of water between the river channel and its floodplain (Armantrout 1998).

[2] The hyporheic zone is, in essence, the river-groundwater interface.

Nevertheless, because of the linear nature of stream-riparian systems, only one or two imagery swaths may be needed to cover the area. A combination of high-resolution and hyperspectral imagery shows considerable promise for identifying riparian zone vegetative cover as well as some instream features such as woody debris.

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PART I:

Conserving Biodiversity at the Scale of Ecoregions

The Biological Basis of Ecoregion Conservation

1

Introduction

WWF constantly tries to improve its effectiveness in conserving biological diversity. Increasingly, we find ourselves working at multiple scales, from saving an endangered species that is confined to a single forest fragment, to ameliorating the effects of global climate change. Most of our field efforts to date have been with country or subregional programs, consisting typically of projects that are restricted to relatively small areas (e.g., a community-based project, buffer zone program, or protected area) for relatively short periods of time (1-3 years). These projects are the building blocks of conservation. To halt the global extinction crisis that we now face, however, we must conduct conservation planning over larger scales and longer time frames than ever before. This task requires analysis and planning at the landscape level or larger scales, with most actions implemented locally.

This chapter reviews the biological basis of ecoregion conservation and describes goals and targets. We cover what makes ecoregion conservation unique relative to other large-scale conservation approaches, and we suggest exercises that will help readers evaluate how current and planned projects relate to an ecoregion-scale project. In this chapter we discuss ecoregions in general; in the following chapter we refine these ideas for freshwater ecoregion conservation.

The issues of scale and conservation effort

Landscape-level planning and action, exemplified by ecoregion conservation, is rapidly emerging as a necessary strategy for achieving massive conservation results and for linking human development opportunities to that which sustains life on Earth — biological diversity. Conservation strategies that are formulated at the ecoregion scale have the potential to address the *fundamental goals of biodiversity conservation* (modified from Noss 1992):

1. Representation of all distinct natural communities within conservation landscapes[3] and protected-area networks
2. Maintenance of ecological and evolutionary processes that create and sustain biodiversity
3. Maintenance of viable populations of species
4. Conservation of blocks of natural habitat that are large enough to be resilient to large-scale stochastic and deterministic disturbances as well as to long-term changes

These goals have become widely adopted as the foundation of the science of conservation biology. They focus on such biological features as gene flow maintenance; local and hemispheric-scale animal migrations; predator-prey interactions; large herbivore and plant interactions; animal dispersal; and natural areas of sufficient size to accommodate disturbance events such as fires, floods, and hurricanes. The scales at which these processes operate require conservation planning and implementation at landscape and ecoregional scales (see discussion of scales in Chapter 3).

[3] A conservation landscape is a large area determined to be a priority for conservation and for which a detailed conservation strategy is designed within an ecoregional plan.

The importance of scale for analyses

The traditional divisions of scale that community and landscape ecology recognize are relevant when thinking about ecoregion conservation methodology. Ecologists often consider global, continental, regional, landscape, and community geographic scales. We believe that working at the scale of the ecoregion is a compromise between large-scale (e.g., regional) and small-scale (e.g., community or smaller) analyses. There are existing biodiversity analyses at very large scales, but the units of analysis cannot be applied easily to conservation planning (e.g., Gaston and Williams 1993; Williams and Gaston 1994). Moreover, although gathering point locality data for all species at a very small scale may be an ideal approach for identifying biologically important areas (e.g., proposed by Frietag and van Jaarsveld 1995), it is impractical for many parts of the world and would take vast resources to complete.

When conducting a biological assessment for an ecoregion, we often apply measures of species diversity. Most often, we examine measures of gamma, alpha, and beta diversity, generally starting at the coarsest scale and moving to finer analyses as a detailed conservation plan evolves. For a landscape (an area including more than one kind of community), we measure gamma diversity. We measure alpha diversity, or within-habitat diversity, at the community level. These measures of diversity are referred to as types of "inventory diversity." Beta diversity, also known as between-habitat diversity, is a kind of "differentiation diversity"; it is the change of species along an environmental gradient or among the different communities of a landscape (Whittaker 1979). Areas with high levels of beta diversity may require special conservation strategies to protect species fully (see Chapter 4 for more information).

The ecoregion concept

What is an ecoregion? An ecoregion is a relatively large unit of land or water that contains a distinct assemblage of natural communities sharing a large majority of species, dynamics, and environmental conditions. A terrestrial ecoregion is characterized by a dominant vegetation type, which is widely distributed — although not universally present — in the region that gives it a unifying character. Because the dominant plant species provide most of the physical structure of terrestrial ecosystems, communities of animals also tend to have a unity or characteristic expression through the region. Delineations of freshwater ecoregions, on the other hand, are based primarily on the zoogeography of obligate aquatic species, rather than on vegetation patterns. We discuss this delineation approach in Chapter 2. Delineation of marine ecoregions is based primarily on distinctive marine biota and ecosystem types, which are a result of water mass characteristics and underlying physical features.

Ecoregions are suitable units for conservation planning because they:

- correspond to the major driving ecological and evolutionary processes that create and maintain biodiversity,
- address the maintenance of populations of those species that need the largest areas, an element of biodiversity that cannot be accommodated at the site scale,
- encompass a logical set of biogeographically related communities for representation analyses,[4] and
- enable us to determine the best places to invest conservation efforts and to understand better the role that specific projects can and should play in the conservation of biodiversity over the long term.

Analyses and planning at these large scales provide a strong basis for establishing conservation priorities. Local actions designed and implemented without considering the ecoregional, regional, and even global environments in which those actions are embedded may

[4] Put simply, a representation analysis is a check to ensure that all habitat types are included in a conservation portfolio. This analysis is based on the assumption that different habitat types support different species assemblages, and that protection of all habitats will confer protection to the broadest array of species. Normally, a representation analysis is conducted for each subregion. This topic is covered in more detail in Chapters 5 and 7.

have limited effectiveness over the long term. By understanding the biological context of the local situation (as well as the social and economic context), we can make better informed decisions about the best places to work and the most appropriate actions to take.

Ecoregion conservation as a new paradigm for conservation

How does ecoregion conservation improve on current efforts to conserve biodiversity? The cornerstone of ecoregion conservation is a biodiversity vision that goes far beyond the current configuration of protected sites and management practices. To conserve the full range of biodiversity in most ecoregions over the long run, conservation areas will need to be much larger and more numerous than what currently exists on the map today. In addition to putting more natural habitat under protection, other related conservation activities — more sustainable use of natural resources, protection of river basins, establishment of strong nongovernmental organizations (NGOs), supportive legislation, and environmental education — need to be greatly expanded in scope and effort. Thus, in every ecoregion, we ask from a conservation perspective: What should the ecoregion look like 10, 20, and 50 years from now? The creation of a biodiversity vision highlights our commitment to the restoration of biologically valuable but degraded landscapes, the implementation of strong legislation and enforcement programs that protect native biodiversity, and the nurturing of an ecoregion-wide conservation movement.

All of these actions take time. The biodiversity vision requires us to plan conservation activities over larger spatial and longer temporal scales than in the past. To create a vision, conservationists are challenged to define what success looks like in the context of conserving an ecoregion's biodiversity. This picture of success depends greatly on the biological assessment — a record of the distribution of species, communities, and habitats in the ecoregion, of the ecological processes sustaining that biodiversity, and of the current and future threats impinging on it. Without a biodiversity vision, ecoregion conservation is only an incremental improvement over existing approaches. The creation of a vision and the implementation of a conservation plan depend on the active involvement of numerous parties: host governments, experts from many disciplines, local conservation groups, development organizations, and residents of multiple jurisdictions. WWF's role will vary in each ecoregion and throughout the life of an ecoregion conservation initiative. In this sourcebook, we emphasize the contribution that the scientific community can play in developing rigorous biological assessments and creating ambitious biodiversity visions.

In addition to the vision, a second distinguishing feature of ecoregion conservation is that it highlights the conservation of ecological processes, important evolutionary phenomena, higher-order diversity (at the genus and family levels), and rare habitat types, in addition to the more traditional taxonomic indicators of priority-setting — species richness and endemism.

Third, in ecoregional biological assessments, we highlight intact or near-intact species assemblages as vital conservation targets because of their increasing rarity worldwide, with an emphasis on keystone species and habitats. Power et al. (1996) define a keystone species as "one whose impact on its community or ecosystem is large, and disproportionately large relative to its abundance."[5] We take a broader approach to defining keystone elements here, considering those species, habitats, or resources whose removal or decline would have a disproportionate negative effect on the persistence of other species or ecological processes in the ecoregion.

Finally, ecoregion conservation attempts to identify and address the overarching threats to biodiversity that operate over multiple areas within an ecoregion (and sometimes outside of an ecoregion), rather than attacking those threats on a site-by-site basis.

Conservation targets to achieve the goals of ecoregion conservation

The term biodiversity describes the full expression of life on the planet, from genes to species to ecological interactions to whole ecosystems. The ecoregion conservation approach is designed to address the conser-

[5] Power et al. (1996) list examples of documented keystone species in freshwater systems. In lakes and ponds, these include planktivorous and piscivorous fish, harbor seals, and salamanders, all of which exert a disproportionate influence through consumption of other species. In rivers and streams, keystone species are piscivorous and omnivorous fish, and beavers; these exert effects through consumption, and the beaver also through habitat modification.

vation requirements of the full expression of biodiversity; thus, the fundamental goals of biodiversity conservation help shape the overarching vision for an ecoregion. Throughout this sourcebook, we emphasize representation — capturing the full range of biodiversity of a given biogeographic unit within a system of protected areas. Conservation professionals, unfortunately, cannot conserve every element of biodiversity at the scale of an ecoregion. Though we may be unable to ensure the protection of every species, we should still design our conservation strategy around the protection of conservation targets. To be rigorous and effective, we should focus activities on five specific biodiversity-driven targets:

1. Distinct communities, habitats, and species assemblages (distinct units of biodiversity)
2. Large expanses of intact habitats, and intact native biotas
3. Keystone habitats, species, or phenomena
4. Large-scale ecological phenomena
5. Species of special concern

We describe these targets in detail in Chapter 5. We note here that conserving aquatic targets may require, in large part, focusing efforts on protection or restoration activities in the terrestrial realm, coupled with attention to the physical processes that shape aquatic habitats. In other words, although the targets will be linked directly to aquatic biodiversity, conserving those targets may require thinking as much about abiotic as biotic factors. In any given ecoregion examples of all target categories may not exist; for example, large expanses of intact habitat may be nonexistent in lowland areas that have been heavily settled and converted for agriculture.

What is the relationship between ecoregion conservation and ecosystem management?

Ecoregion conservation is part of a worldwide effort to develop strategies on the spatial and temporal scales that account for ecological processes, which in turn determine the properties of ecosystems. The first approach that recognized the importance of planning at large spatial scales was termed ecosystem management (EM). EM was initiated as an effort to expand thinking beyond single species of concern to focus also on their habitats and on interactions among species. Ecoregion conservation builds on the successes of EM by developing some key concepts more explicitly and incorporating them into long-term visions of conservation goals for an ecoregion.

If anything separates EM from ecoregion conservation, or ecoregion conservation from other approaches, it is our central goal of a vision to conserve the full expression of biodiversity of an ecoregion. To establish this ambitious vision, we strongly recommend using historical information to create a blueprint of the past prior to heavy disturbances by humans. Often, this is taken to be the pre-industrial condition (Angermeier 1997). EM does not require an examination of historical trends to conserve the full expression of biodiversity, but instead is focused on sustainable management of existing resources for human societies.

Second, ecoregion conservation is based explicitly on the four fundamental goals of biodiversity conservation, which the conservation biology community has widely accepted as the basis for its work. These goals are not fundamental to EM.

Third, ecoregion conservation sees core protected areas as critical conservation targets, whereas EM does not identify these as vitally important. It should be noted that core protected areas for freshwater biodiversity may take a different form than those designed around terrestrial targets.

Fourth, ecoregion conservation addresses the overriding importance of representing all habitats and ecosystems in a network of protected areas. Representation is perhaps the most important aspect of ecoregion conservation as practiced by WWF and The Nature Conservancy. EM does not explicitly address this goal.

Finally, ecoregion conservation addresses setting minimum requirements to maintain viable populations of wide-ranging or area-limited species, or to maintain critical processes. This goal is fundamental to ecoregion conservation, but not to EM.

What is the relationship between freshwater ecoregion conservation and integrated river basin management?

Integrated catchment (or watershed)[6] management, integrated river basin management (IRBM), and integrated water resources management (IWRM) are equivalent terms for a specific kind of EM — one in which the unit of analysis is a hydrologic catchment. Catchments, as described in the following chapter, serve as good units for freshwater ecoregion conservation planning, largely because there are strong terrestrial-aquatic and upstream-downstream interconnections. In this sense, catchment management and freshwater ecoregion conservation are similar.

Catchment management, in its broadest form, is intended to be an integrated approach to addressing all aspects of water quality and quantity and related natural resource management. However, the management of water resources is a loosely defined goal, begging the question: Management of water resources for what purpose? In most cases, the unstated goal is the maintenance of a reliable and safe water supply for human use. Achieving this "vision" may involve some of the same actions as those required for maintaining an ecoregion's freshwater biodiversity features, but the differences could be acute.

Like EM, then, catchment management does not explicitly require a long-term vision, and biodiversity-related targets do not necessarily drive its goals. A catchment management project could, in theory, be virtually identical to a freshwater ecoregion conservation project if it: (1) included a biodiversity vision, (2) was based on the fundamental goals of biodiversity conservation, (3) included core protected areas, (4) incorporated representation principles, and (5) identified minimum requirements for the maintenance of focal species or processes. In fact, evolving approaches to catchment protection and restoration incorporate many of these elements (see Williams et al. 1997).

Unquestionably, we need diverse tools for conducting large-scale conservation. Each NGO and agency will want to develop an effective strategy by building on its own experiences and those of others, and this may include experiences with approaches such as EM or catchment management. We believe that conducting large-scale conservation based on the principles of ecoregion conservation makes good biological sense. In essence, freshwater ecoregion conservation is an evolutionary step this reflects best practice in catchment management. Certainly, in the process of moving from a biodiversity vision to a conservation strategy, rationalizing resource use with conservation will be a central concern.

Steps to adjust thinking to the ecoregional level

We suggest the following exercise to prepare for involvement in an ecoregion conservation project.

1. List and review the outstanding biological features of your ecoregion and the overarching threats to them. You may also want to identify any physical processes (e.g., flooding) that are critical to maintaining these outstanding features.
2. Organize the outstanding features under the five conservation targets listed in this chapter.
3. Review the current portfolio of field projects (of WWF and other NGOs or donors) in the ecoregion, if applicable. How do they relate to the four fundamental goals of ecoregion conservation and to the five conservation targets?
4. In the context of ecoregion conservation, review the activities that you are currently pursuing to conserve biodiversity in your area by answering the following questions:
   - What is the scale at which you plan your activities? Are the boundaries ambitious enough to encapsulate fundamental large-scale ecological or physical processes? If so, what are these boundaries?
   - Were your field activities derived from a clearly articulated vision of what is required for the long-term conservation of biodiversity and ecological processes? Has your thinking gone beyond what is on the map today?
   - Have you planned your activities on relatively large scales (on the order of 1000 km^2 or larger) and for more than isolated units such as national parks and buffer zones?
   - Did you establish minimum levels of representation of species assemblages, habitats, and com-

[6] In this text, the term "catchment" will be used to refer to the area draining to a river or lake, because its meaning has universal acceptance. We will sometimes refer to a specific "basin" (e.g., Amazon River basin, Tennessee River basin); this has the same meaning as "catchment."

munities as a critical component of your conservation plan? List these levels of representation and identify features that have not been captured (gaps in representation).

- Have you considered minimum habitat requirements for maintaining area-sensitive species, processes, and phenomena? What species, processes, and phenomena did you consider? Are there others that you have missed?
- Did you address connectivity between protected areas and other types of managed lands?
- Have you identified the need for restoration in your ecoregion? Do any projects involve restoration?
- Have you developed effective partnerships, particularly with biodiversity specialists and other NGOs, to help design landscape-scale projects and provide scientific peer review to your program?
- Have you evaluated the causes of biodiversity loss to determine if certain human activities are having a disproportionate impact (e.g., causing greater than 50% of habitat loss)?

The goal of this sourcebook is to help you scale up conservation efforts to the level that you can answer yes to all of these questions by the end of the ecoregion planning process.

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An Introduction to Freshwater Ecoregion Conservation

2

In most instances, the distribution of aquatic organisms is not linked to a particular vegetation type (there are exceptions, a striking one being peat swamps...) but to geomorphology. History and stream morphology determine communities of aquatic organisms, just as history and land morphology determine vegetation types.

— Maurice Kottelat (1999)

Unlike terrestrial biota, or even such aquatic biota as the many insect groups that have terrestrial life stages, strictly riverine freshwater fish are very poor dispersers. They tend to be confined to river systems which behave, in biogeographical terms, very much like elongated islands separated from each other by uninhabitable territory across which dispersal is difficult to impossible. Dispersion of freshwater fish between river catchments is difficult and slow, and occurs primarily through stream capture, diversion and redirection of water flows resulting from uplifts, and similar geomorphological events.

— Robert M. McDowall (1996)

Introduction

The previous chapter dealt with some basic concepts fundamental to ecoregions and ecoregion conservation in general. This chapter revisits some of those same concepts for the specific case of freshwater systems and attempts to address many basic questions regarding ecoregion conservation in the freshwater realm. In subsequent chapters we explore the mechanics of actually conducting a biological assessment and developing a vision for conserving freshwater biodiversity features.

What do we mean by "freshwater"?

Fresh water can be defined as water containing less than 1,000 parts per million (ppm) of dissolved solids of any type, or water with salinity less than 0.5 (parts per thousand) dissolved salts. Following this, we can define *freshwater* as "of, relating to, living in, or consisting of water that is not saline." Using this definition, freshwater habitats would include all inland flowing and standing water habitats, both above and below ground, except for saline or brackish-water habitats such as saline lakes. Freshwater species would be those living in these watered habitats for all or part of their life cycles. For the purposes of ecoregion conservation, we have expanded upon this definition to include all inland bodies of water, whether fresh or saline.

In this document we reserve the term *wetlands* for those transitional lands between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water. In this scheme, rivers and streams, lakes and ponds, and springs and groundwater habitats are not classified as wetlands, although we are aware that the Ramsar Convention and certain other organizations classify all wet habitats in this manner (Ramsar 1999). These distinctions are largely semantic, since many wetlands are linked to rivers and lakes. In floodplains in particular, it can be very difficult to distinguish between terrestrial and aquatic species and habitats, given the dynamic nature of the ecosystem (Junk et al. 1989). In this document we devote less attention to those wetlands that are hydrologically unconnected to rivers, lakes, or springs, because the terrestrial ecoregion model better addresses their conservation requirements (see *Volume I: Terrestrial Ecoregions*).

The wide range of definitions for the terms *freshwater* and *wetlands* may always generate some confusion. As with all terminology used in the ecoregion process, everyone involved in a project should use the same definitions. The outstanding biological features of an ecoregion, rather than terminology, should drive the process.

For the purposes of this sourcebook, we define a freshwater animal as one that lives in fresh water (or any inland water) for all or part of its life. This category includes most waterbirds, as well as aquatic mammals (e.g., river otters, river dolphins), amphibians with an aquatic life stage, and aquatic and semi-aquatic reptiles (e.g., river turtles, crocodiles). This definition does not address species that rely on fresh water but do not live in it, for example, piscivorous land mammals and birds of prey, or floodplain-dependent animals.

For plants, the freshwater definition would apply to all aquatic species, as well as to those found in wetlands and floodplains. Here the definition becomes quite broad, because many plant species (as well as some animals) are water-dependent in part of their range and purely terrestrial elsewhere.

The question of estuarine or deltaic species often complicates biological assessments for freshwater systems draining to a sea or ocean. There is no definitive rule for deciding which species to include in an assessment. For example, in the lower Mekong River Basin of Indochina, the boundaries between the freshwater, estuarine, and marine habitats fluctuate on a daily and seasonal basis, creating a complex intermediate zone (Kottelat 1999). In the Mekong delta area, estuarine and marine fish species often penetrate up river arms when the water becomes brackish, yet isolated freshwater swamps in the immediate vicinity may host a strictly freshwater community. In his desk study for the lower Mekong ecoregion complex, Kottelat (1999) chose to analyze the fish fauna of all waters inhabited by freshwater fish species (the "primary" and "secondary" fish families), but excluded areas inhabited only by species unable to survive permanently in fresh water.

Subsequent chapters discuss the particular details of conducting assessments and developing visions, but here we offer a cautionary word about conservation targets (see Chapter 1 for definition). Consultation with an ecoregion's experts will help to determine what taxa or habitats will be the focus of a biological assessment. There is no reason why an assessment cannot incorporate information on species that rely on, but do not live in, water. We recommend against making these species the primary focus, however, even if far more information about their distributions or habitat requirements exists than for aquatic species. We also suggest that waterbirds should generally not drive priority setting, because a focus on well-studied birds (which tend to have wide distributions) can obscure the needs of lesser known but equally important aquatic taxa with narrower habitat requirements. However, there are certainly cases where the breeding requirements of charismatic species like colonial waterbirds can provide critical information for setting conservation goals like flow regimes.

The definition of freshwater ecoregions

The term "ecoregion," commonly used by conservation planners, comes from "ecosystem region" and was first coined by J.M. Crowley (1967). Bailey (1983) defines ecoregions as "large ecosystems of regional extent that contain a number of smaller ecosystems. They are geographical zones that represent geographical groups or associations of similarly functioning ecosystems." Omernik (1987) defines them as "regions of relative homogeneity in ecological systems or in relationships between organisms and their environment," and The Nature Conservancy describes them as "relatively large land areas, determined by such factors as geology, topography, climate and vegetation." These definitions provide the foundation for a number of ecoregion maps, all of which use geoclimatic features (e.g., climate, geology, and landform) as their primary criteria for delineation.

WWF describes an ecoregion as "a relatively large area of land or water containing a geographically distinct cluster of natural communities. These communities (a) share a large majority of their species and ecological dynamics, (b) share similar environmental conditions, and (c) interact ecologically in ways that are critical for their long-term persistence." This definition departs only slightly from those of Bailey and Omernik, but WWF applies it more widely, creating ecoregion maps for the terrestrial, freshwater, and marine realms. There is no debate that terrestrial ecoregion maps fail to capture patterns of marine biodiversity. Why do we delineate separate ecoregions for freshwater features?

Like terrestrial habitats, geoclimatic features such as elevation, relief, slope, landform, soil, and drainage density largely determine the character of freshwater systems (Maxwell et al. 1995). But although aquatic habitat types are tightly linked to the terrestrial landscape, the animal species that occupy those habitats are not necessarily tied to the type of vegetation found on land. Instead of using vegetation as the basis of our delineation for freshwater ecoregions, we can look directly to obligate aquatic species (e.g., fish, molluscs, crayfish) to inform our delineation. Fish are normally the best studied of these taxa, and their distributions tend to be at a scale that is most appropriate to ecoregions; molluscs, for example, often have very localized distributions in comparison. For this reason, ecoregion delineation often begins with an examination of fish distributions. But do we know how fish or other aquatic species are distributed?

Satellite imagery allows us to develop a coarse image of how major vegetation types are distributed across the terrestrial landscape, and we can refine this image with aerial photos or ground surveys. Terrestrial ecoregions are based largely on the patterns that emerge in these images. Unfortunately, we do not yet have a similar capacity when it comes to freshwater species — even the most sophisticated technology in existence will not produce an image of how aquatic faunal communities are distributed. If we wanted to generate aquatic community maps at a landscape scale, we could overlay species (or genera) distribution maps and look for broad patterns of congruence — but, with the exception of the best-surveyed parts of the world, we simply lack good enough maps for this kind of exercise. The Nature Conservancy and a few other organizations are working on developing methods for predicting which species should occur in particular river and stream reaches, but at present these methods are data-intensive and generally infeasible for application in poorly known areas (see, for example, documents available at http://www.freshwaters.org/ccwp/science.html). Because of these constraints, we take a more iterative approach to developing freshwater ecoregions that begins with catchments rather than with species maps.

The main ecological unit of surface water systems is the catchment, also known as a watershed or drainage basin (Lotspeich 1980). Catchments have physiographic boundaries that, except in rare cases, encompass the dispersal routes of species confined to fresh water. This is an important distinguishing feature between the freshwater and terrestrial realms, because species inhabiting the latter typically have less rigid barriers to dispersal. Furthermore, current distributions of obligate freshwater organisms have largely been determined over evolutionary time by the same geoclimatic processes that have created catchment divides and that distinguish the physiographic patterns of catchments (Maxwell et al. 1995).[7] Other, more mobile freshwater taxa may not be limited by catchment boundaries, yet they are nonetheless inhabitants of a catchment ecosystem. Dynamic ecosystem processes, such as flood events, occur over areas defined by catchments, and such events have consequences for both obligate and non-obligate aquatic species (Bisson 1995).

Because the species and ecological dynamics within a catchment are strongly connected and relatively isolated from those in other basins, the catchment serves as a logical starting point for delineating freshwater ecoregions. In effect, we can combine what we know about species distributions (or what we suspect, in the case of unexplored areas) with catchment maps, to evaluate how catchments are similar to or different from neighboring ones. Communities and dynamics between two or more major catchments may be similar enough to warrant combining them into a single ecoregion or, in other cases, it may be necessary to split catchments to capture distinct biotic differences. For instance, a barrier to dispersal within a catchment, such as a large waterfall, may be so strong that different biotas have evolved on either side. Or, on some mountaintops, altitude and associated climatic effects have created conditions whereby the biotas inhabiting the headwaters of multiple catchments are more similar to each other than to those downstream. In this case, a "mountaintop" ecoregion might best represent the biological reality. The same might be true when the species in the headwaters of one catchment are similar to those of an adjacent catchment because of stream capture (when the headwaters of one river are diverted into the rapidly eroding headwaters of another river). Highly distinct lakes or endorheic (closed-basin) systems may even warrant the creation of an ecoregion-within-an-ecoregion. In coastal areas, numerous short catchments forming a long strip may support similar assemblages, because the majority of species are marine-derived or can disperse through saltwater. Whatever form they take, freshwater ecoregions delineated primarily using aquatic faunal distributions will almost certainly look different than if vegetation were the principal determinant.[8]

Catchments are hierarchical units nested within one another. The level of catchment at which to start delineating ecoregions depends on the particular region, but one can start with the largest catchments (based on size of drainage area) and subdivide within

[7] This may be particularly true for faunas that were "reset" by glaciation. In unglaciated areas, the distributions of ancient species may be a function of environments that existed prior to the creation of present-day catchments.

[8] Some approaches to ecoregion delineation use present-day vegetative cover as an indicator for land use, which in turn is known to influence water chemistry, stream hydrology, and biota (Harding and Winterbourn 1997). Because we are interested in the historic distribution of species and habitats, original vegetative cover would be a better indicator of habitat and biotic attributes than present-day cover. Moreover, such an approach appears to be more appropriate for describing differences among habitats and assemblages at smaller spatial scales, such as at the river reach.

them to capture distinct biotas. Starting at the scale of the smallest identifiable catchments and then combining them into progressively larger units is a more systematic approach, but it requires more detailed information than is normally available for all but the best-studied regions.

Inclusion of additional biota

No single set of biogeographic units is optimal for all taxa. Ideally, ecoregions reflect the best compromise for as many diverse taxa as possible. Freshwater ecosystems support much wider arrays of species than those used to delineate ecoregions, and many species not confined to water for the entirety of their life cycles (e.g., aquatic insects, riparian plants) are integral to the ecological functioning of the system. Admittedly, the distributions of many of these non-obligate aquatic species correspond poorly with catchments, and there is no good evidence that the distributions of these taxa correspond well with obligate aquatic species. This lack of correspondence, however, should not invalidate our approach for delineating freshwater ecoregions. Because ecoregions represent the arenas in which dynamic physical and ecological processes operate, they should serve well as conservation units for all component species. Freshwater ecoregions are a conservation tool, and we urge anyone working within a given ecoregion to consider the finer-scale distributions of all target species and to refine the region of analysis accordingly.

We acknowledge that static and shifting transition zones are common and suggest viewing ecoregions as encompassing logical areas for more detailed analyses and strategies. Ecoregions are intended to depict the estimated original extent of natural communities prior to major alterations through recent human activities, although original distributions can be difficult to reconstruct. Ecoregion delineation is an iterative process, and changes to ecoregion boundaries can be incorporated if new information becomes available.

The conservation value of catchments

Catchments not only have zoogeographic relevance, but they also serve as the most appropriate units for the conservation of freshwater biodiversity (Noss and Cooperrider 1994), with the scale determined by the conservation goal. The reason is obvious: the quality of freshwater habitat at any given location is a function of all upstream and upland activities, and sometimes downstream activities as well.[9] Many of the threats to freshwater systems are the result of land-use practices that occur within the catchment, and it is there that they must be addressed. Protection of natural communities or processes, therefore, must take into account these important catchment boundaries.

We recognize that freshwater ecoregions based on catchments may fail to provide perfect representation of the distributions of all taxa relying on freshwater habitats. For example, headwater, middle, and downstream portions of catchments contain different aquatic habitats and species adapted to them, just as different species will be found in the littoral, benthic, and pelagic zones of a large lake. Nonetheless, these catchment-based ecoregions should serve as the best units for identifying and conserving the most important elements of freshwater biodiversity, and a freshwater ecoregion conservation project can always work outside the boundaries of a defined freshwater ecoregion if target species or processes occur there.

Issues of scale

The concept of a catchment is relatively straightforward, but we can define it at almost any spatial scale (see Box 2.1). A catchment can range in size from the area draining to a first-order stream, to a major catchment as big as the 6,144,727-km^2 Amazon River Basin[10] (Figure 2.1). With the exception of catchments with no external drainage or those draining to the ocean, all catchments are nested within larger ones. When we speak of using catchments within a freshwater biological assessment, what do we mean?

[9] For example, in salmon streams, salmon migrating upstream may act as "nutrient pumps," transporting marine nutrients that may be crucial for maintaining high stream productivity. Overfishing of salmon at sea may therefore significantly affect the ecological health of spawning streams hundreds or even thousands of miles away (Francis 1997; Curtis Freese, Senior Fellow, WWF-US, personal communication).

[10] Among the number of methods for ordering the size of streams, "stream order analysis" (sensu Strahler 1957) is one of the most widely used. Ward (1998) provides a brief explanation of the method: "First-order streams are headwater segments without tributaries that drain first-order catchments. The confluence of two first-order streams forms a second-order stream, two second-order streams join to form a third-order stream, and so on. The world's largest rivers are twelfth-order and greater." Examples of major rivers are the Amazon, Congo, Mississippi, and Yangtze.

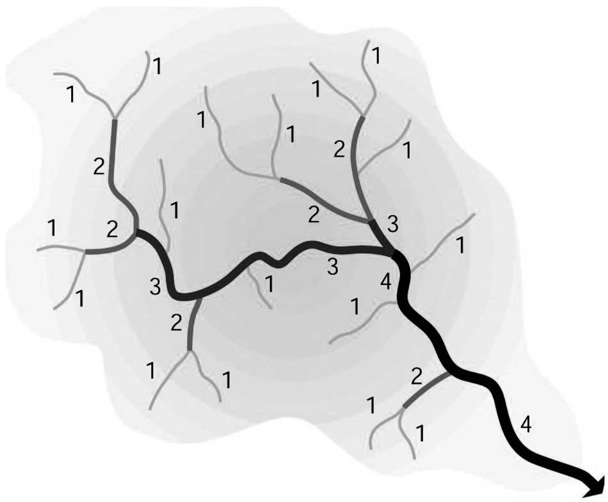


Figure 2.1. Stream orders. (Taken from: Federal Interagency Stream Restoration Working Group 1998. Reproduced with permission.)

The answer to this question depends on the particular ecoregion. In general, freshwater ecoregions are composed of a single or multiple "major" catchments (those catchments defined by the largest rivers of a region), but there are also cases where the biota of one or more subcatchments, or portions of subcatchments, is distinct enough to justify delineating a separate ecoregion. For the biological assessment, you will probably rely heavily on a map of finer-scale catchments within the ecoregion. When considering what level of catchments will be most appropriate to your analysis, start with a map of the finest available delineation of catchments. Then decide whether or not to scale up to larger catchments on the basis of the relative size of the particular ecoregion and the resolution of the biological data. For most places it is not possible to obtain maps or imagery showing first- through third-order streams or their catchments.

Most freshwater ecoregions — indeed, most ecoregions in general — are so large that it can be difficult to conceptualize how to conserve biodiversity over such vast areas. Conducting a biological assessment at the scale of an ecoregion, and developing a vision from the results of that assessment, ensures that large-scale biodiversity patterns and processes are taken into account. Areas that are prioritized within a vision may be large as well, but strict protection of the entire priority area may or not be the ultimate recommendation. This is especially true for prioritized catchments within which there is already a strong human presence — which characterizes nearly all catchments around the world.

A vision and subsequent implementation plan might be comprised of work at several scales. For example, in the Murray Darling Basin, WWF-Australia prioritized work at three scales: (1) Local-scale, site- or species-specific projects that were both strategic and had charismatic value and enabled the program to achieve quick successes to build credibility and support (e.g., wetland conservation on the downstream ends of key tributary rivers); (2) Subcatchment-scale projects to demonstrate medium- to long-term solutions to major threats (e.g., maintaining a 'free-flowing' major tributary, establishing a market-based solution to salinization); and (3) Basin-scale policy solutions, drawing on field experience to put in place the laws, programs, and market settings needed for long-term conservation (e.g., changing tax treatment of conservation, regulating new water abstraction proposals).

Freshwater-terrestrial confusion

By defining both freshwater and terrestrial ecoregions, WWF has diverged from other conservation organizations that are embarking on ecoregion conservation. The delineation of two sets of overlapping ecoregions (Figure 2.2) generates a number of important questions. Why do we have separate ecoregions when they cover the same areas (all non-marine environments)? Does freshwater ecoregion conservation look exclusively at freshwater habitats, or does it include surrounding terrestrial habitats as well? Where do wetlands fit in? What do you do if priority freshwater and terrestrial ecoregions overlap, but their boundaries are different? Will two sets of ecoregions confuse policy makers and make conservation more difficult? The remainder of this chapter addresses these questions, using examples from ongoing ecoregion conservation projects where appropriate.

Why do we have both freshwater and terrestrial ecoregions, if all freshwater habitats are included in terrestrial ecoregions?

First, neither the distribution patterns of many freshwater taxa nor the ecosystem processes that sustain these species correspond well to terrestrial ecoregions. An illustrative example is that of the Tennessee-Cumberland freshwater ecoregion, found in the southern Appalachian region of the southeastern United States (Figure 2.3a).

This ecoregion is defined by the combined catchments of the Tennessee and Cumberland Rivers. By any

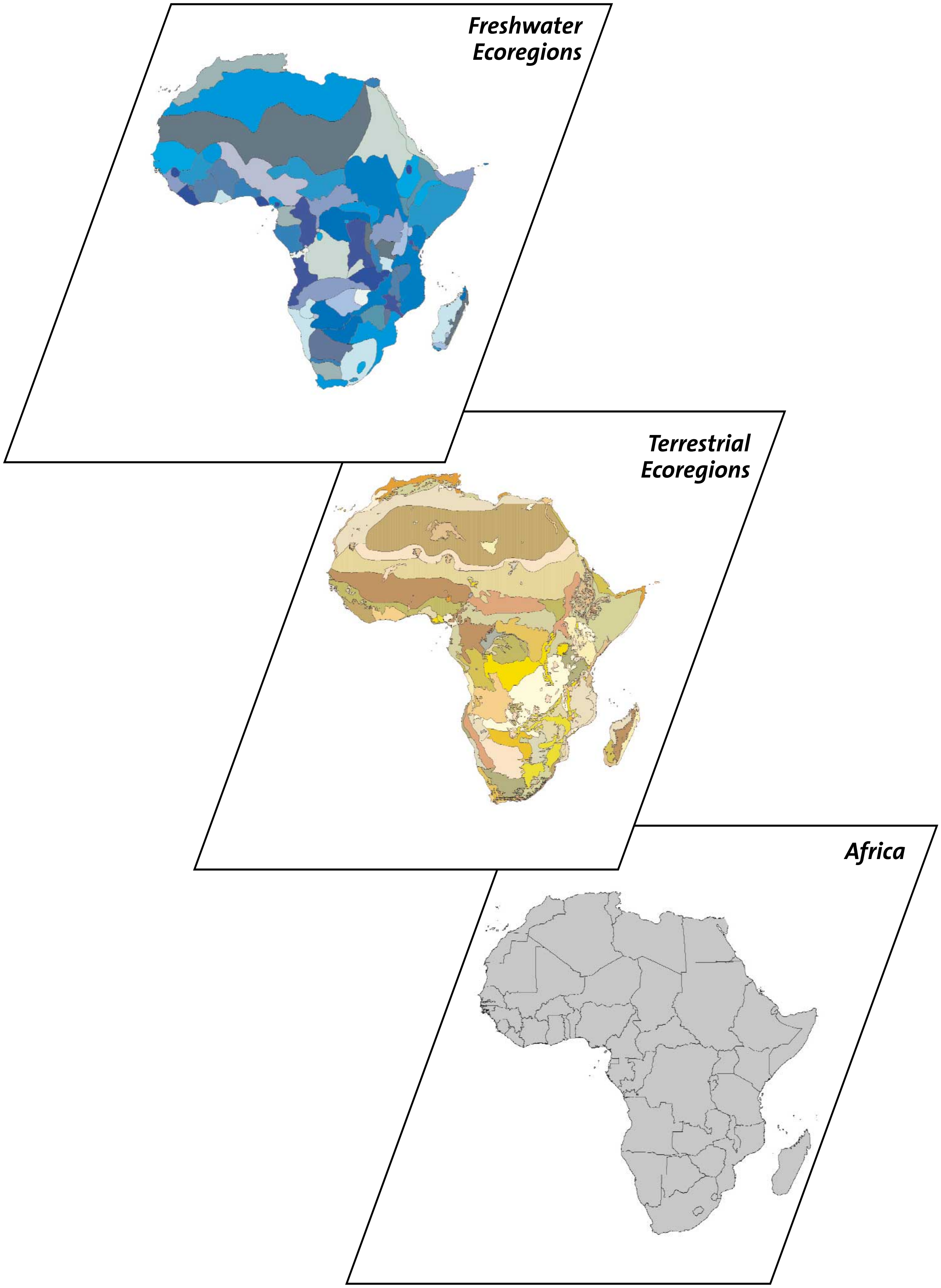


Figure 2.2. Overlapping terrestrial and freshwater ecoregion maps for Africa.

measure, this ecoregion harbors a level of freshwater biodiversity that is among the highest for temperate river and stream systems worldwide and higher than even most tropical units. By our calculations, the Tennessee-Cumberland ecoregion supports 232 species of native freshwater fish, of which 29% are endemic. Sixteen percent of its 125 unionid mussel species are endemic, as are 62% of its 65 crayfish species.

The Tennessee-Cumberland catchment is sliced primarily among three terrestrial ecoregions (Figure 2.3b). These terrestrial ecoregions are outstanding as well, with extraordinary richness in tree species and vertebrate groups such as lungless salamanders (Family Plethodontidae). If we used terrestrial ecoregions for our analysis, however, only a handful of the fish, mussel, or crayfish species endemic to the freshwater Tennessee-Cumberland ecoregion would be considered endemic to any of the three terrestrial ecoregions. With its endemism patterns diluted, the area covered by the Tennessee-Cumberland ecoregion might still be highlighted for its high species richness, but one of the most important features of its biodiversity — its distinct species — would be overlooked. From a freshwater perspective, an ecoregional strategy for the Tennessee-Cumberland area must focus on safeguarding its aquatic endemic species, which in turn requires protecting the catchments in which they are found. Using only terrestrial ecoregions risks overlooking important elements of freshwater biodiversity and potentially designing ineffective conservation strategies.

Freshwater habitats and species also suffer from additional classes of threats. While virtually all of the threats that plague terrestrial systems also impinge on freshwater systems, the opposite is not necessarily true. For example, conversion of forests for agriculture or timber production can influence downstream freshwater habitats through increased sedimentation, siltation, chemical pollution, and water temperature; increased runoff and altered hydrology; and decreased organic matter inputs. On the other hand, construction of an instream impoundment or a channelization project[11] may affect nearby upland habitats, but most of the terrestrial landscape within the catchment is likely to be relatively unaffected. Obligate or near-obligate freshwater species may also be less able than terrestrial fauna to escape threats such as exotic species or pollution.

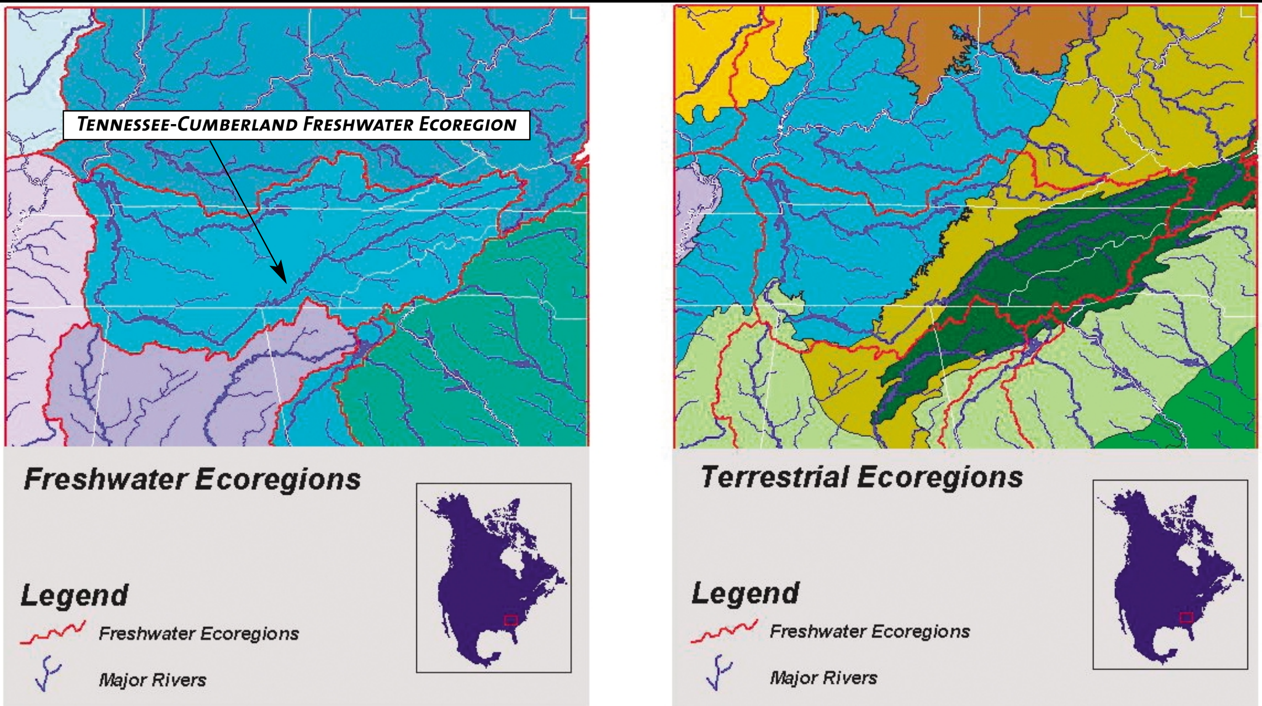
Most conservation biologists are still focused on the terrestrial realm, even though worldwide freshwater biodiversity is on average more imperiled than terrestrial. As an example, in 2000 The Nature Conservancy reported that in the United States two-thirds of freshwater mussel species, half of all crayfish species, more than 40% of stoneflies, and more than 35% of amphibian and freshwater fish species were at risk of extinction (Figure 2.4). These were the five most imperiled taxonomic groups. In contrast, mammals and birds, the groups that normally garner the most attention, were the least imperiled of those groups examined.

Although the world's conservationists are slowly becoming aware of the perilous state of freshwater biodiversity, we must continue to draw attention to the problem whenever we have the opportunity. We need to work to educate managers, policy makers, and ordinary citizens about the biodiversity hidden in streams, lakes, and springs and explain why protecting it is as important as protecting the more visible and familiar species inhabiting the terrestrial realm. Embarking on conservation planning in ecoregions selected primarily for their freshwater biodiversity is one way of achieving this. Although it is tempting to focus on the needs of well-studied animals such as waterbirds and aquatic mammals, it is critical that we not turn our attention away from lesser-known taxa and their habitats. While conducting freshwater ecoregion conservation, we should emphasize the intimate connection between the freshwater and terrestrial realms and stress that protection of one depends on conservation within both (see Table 2.1).

Does a freshwater ecoregion project focus exclusively on freshwater biodiversity and habitats? Where does the larger catchment fit in?

All projects differ, but the biological assessment of a freshwater ecoregion should be structured primarily around the freshwater species, assemblages, and habitats that have identified the ecoregion as a priority —

[11] Channelization is the process of straightening a stream, which usually involves lining it with concrete or rock. Channelization is generally undertaken to control flooding and/or to divert water (Doppelt et al. 1993).



Figures 2.3a-b. The Tennessee-Cumberland freshwater ecoregion. Figure 2.3a (left): the Tennessee-Cumberland freshwater ecoregion, defined by the catchments of the Tennessee River to the south and the Cumberland River to the north. Figure 2.3b (right): the Tennessee-Cumberland freshwater ecoregion, overlain by terrestrial ecoregions (shaded areas).

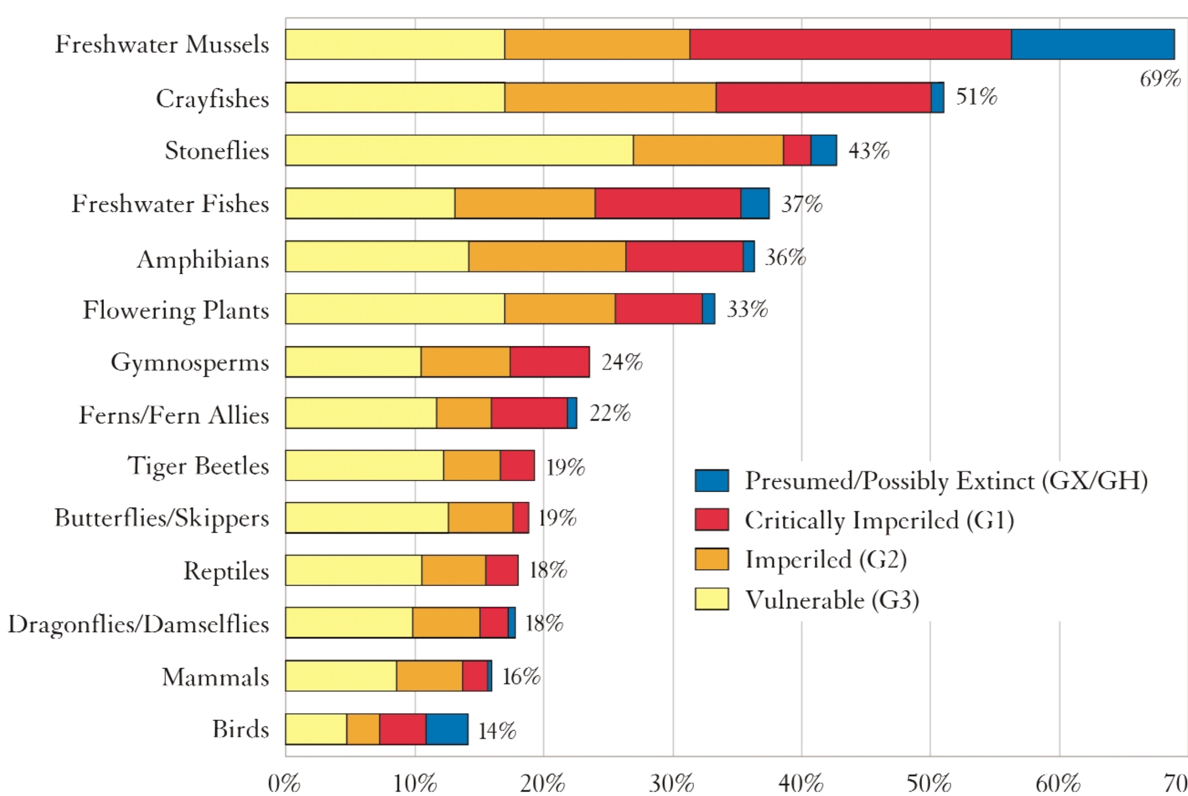


Figure 2.4. Proportion of species at risk in the United States as of 2000. (Taken from: Stein et al. 2000. © The Nature Conservancy and Association for Biodiversity Information. Reproduced with permission.)

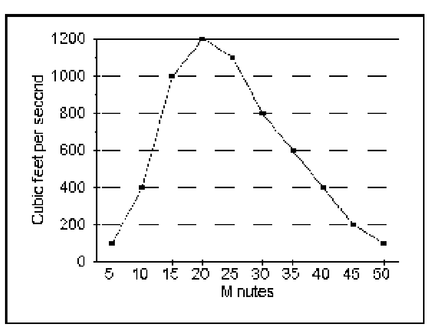
Table 2.1. Examples illustrating the interrelationship between riverine and terrestrial ecosystems. (Adapted from: Healey 1998.)

Impact of land on river ecosystem	*Impact of river on terrestrial ecosystem*
Local relief determines river gradient	Carries surplus water away from the terrestrial ecosystem
Local geology influences water chemistry, sediment load	Carries sediment and organic debris from upstream to downstream locations
Local groundwater regime determines base flow (portion of discharge whose source is not runoff)	Contributes to groundwater recharge in certain locations
Catchment vegetation influences water supply, storm hydrographs[12]	Transports sediment and nutrients out of the channel and onto the floodplain
Riparian vegetation influences channel form, evolution, and migration	Creates intermittent disturbance regime in floodplain, which affects vegetational succession
Riparian vegetation influences stream temperature, light available for photosynthesis	Contributes to the creation of new land in lacustrine (lake) and estuarine deltas
Riparian vegetation provides organic carbon to the river ecosystem	Creates new habitat for colonization by riparian species
Riparian vegetation provides insect food to stream fishes	Provides food and water sources for numerous species that are primarily terrestrial

even if the ecoregion also contains exceptional terrestrial biodiversity features. We describe the approach to conducting a biological assessment in more detail in subsequent chapters, but in general it entails identifying the key habitats and processes that sustain important elements of freshwater biodiversity. The identification of habitat types and an analysis to ensure that those habitats were adequately represented within a portfolio of priorities would focus on aquatic habitats. *Priority areas are those identified as requiring some form of conservation management, which could be anything from strict, year-round protection to selective sustainable resource use.*

The identification of priority aquatic areas is only a portion of a biological assessment and biodiversity vision. Many of the critical processes that maintain freshwater biodiversity are linked to protection of the larger catchment, and many of the threats to this biodiversity originate on higher ground as well. For example, maintenance of water levels and flows, which is critical for most freshwater organisms, depends in large part on surface and subsurface flows across the catchment, and these in turn are affected heavily by land use. Maintaining natural flows may involve the protection of headwater catchments or, at a more local scale, it may require the restoration of riparian vegetation. Those actions required to protect freshwater biodiver-

[12] A hydrograph is a graphic representation showing changes in the flow of water or in the elevation of water level, plotted against time.



sity will vary from ecoregion to ecoregion, but we would expect that any biodiversity vision would identify actions that must be undertaken in the terrestrial as well as in the freshwater realm.

What is the assessment approach when priority freshwater and terrestrial ecoregions overlap? Are there inherent conflicts?

Priority freshwater and terrestrial ecoregions often overlap. Where ecoregions overlap it is highly recommended that the biological assessments and vision development are combined in some manner. This is important to maximize the synergies between WWF's forest and freshwater conservation objectives. While costly, jointly developing the vision(s) is important to ensure that WWF's freshwater priorities are not inadvertently overlooked, yet it does not require that implementation of the two visions be funded concorrently.

The degree to which the two ecoregions match each other both geographically and ecologically will largely determine how the visioning processes are combined. Additionally, if the biological experts are one and the same for terrestrial and freshwater ecoregions, resource and time constraints would likely favor combining the efforts. An example of a combined effort comes from the Chihuahuan Desert, where high-priority freshwater ecoregions are largely contained within the terrestrial ecoregion complex, and scarce freshwater resources are critical to the maintenance of biodiversity in both realms. Terrestrial and freshwater ecoregions were considered within the same assessment, but separate freshwater and terrestrial analyses of species and habitats were retained.

If a single biological assessment for both freshwater and terrestrial biodiversity elements is conducted, the problems posed may be more logistical than substantive. The first challenge will be delineating the geographic area of the assessment, because the boundaries of the two ecoregions will differ. Since all ecoregion projects must begin with a reevaluation of the ecoregion's geographic extent to determine if it captures the target species and processes, this does not constitute an extra step. If one ecoregion completely subsumes the other, the larger ecoregion can define the area of concern. If the two ecoregions only overlap in part, the decision is a bit more complex and should be based on biological reasoning. Both ecoregions may be taken in their entirety, or the boundaries may be modified to make the process more feasible.

From a freshwater perspective, we should attempt to retain within the region of analysis complete catchments, or at a minimum all upstream areas. In the Chihuahuan Desert, portions of 14 freshwater ecoregions fall within the terrestrial ecoregion complex, although they are not all closely related biogeographically. Four of the 14 have been identified as highest priority for all of North America, and these 4 ecoregions are all part of the larger Rio Grande freshwater complex, which covers much of the Chihuahuan Desert and extends well outside it. Including the entire Rio Grande complex in the ecoregional effort would have unnecessarily enlarged the area of analysis, because much of the complex is not considered high priority. Restricting the analysis to the terrestrial complex, however, would have eliminated important headwater areas of several of the priority freshwater ecoregions. For this reason, the analysis included all areas draining into the terrestrial complex, but not low-priority downstream areas outside of it.

Once the region of analysis is determined, the next decision concerns which elements of the biological assessment will be conducted separately for the freshwater and terrestrial realms, and which elements will be combined. If the freshwater and terrestrial analyses are kept largely separate, important exchanges of information may not occur during an expert workshop; individuals with expertise in both realms will be forced to choose between groups or divide their time; and artificial distinctions between freshwater and terrestrial habitats may be created.

If the freshwater and terrestrial efforts are combined, there is the chance that the freshwater effort will be diluted unless similar resources are devoted to both. In most cases there will be more data available for assessing terrestrial biodiversity and ecological integrity, so an assessment will include more terrestrial than freshwater experts and it will evaluate more terrestrial than freshwater taxonomic groups. If freshwater and terrestrial biodiversity are evaluated together, terrestrial elements may overshadow the freshwater ones and consequently receive greater weight in the selection of priorities. Most important, there is a tendency to employ similar or identical approaches for the two realms, even when a less site-focused approach would be appropriate for freshwater ecoregions. Even if conservation of the freshwater ecoregion lent itself to the identification of small priority areas, it would be important to generate different decision rules for their selection (described in further detail in Chapter 7).

If freshwater and terrestrial priority areas are selected separately, a process for choosing the final, combined portfolio of areas is required. One option is simply to select the highest priority areas from each group. Another option is to overlay the freshwater and terrestrial priorities and to select those places where there is substantial or complete overlap (taking the union of the two areas, rather than only the area of overlap).

There are two caveats regarding the latter process of combining priorities. First, terrestrial experts may avoid including freshwater habitats in their priorities if they think that a separate freshwater subgroup will cover these habitats, and in this case there will be little or no overlap. Second, freshwater priorities may take a very different form from terrestrial ones. It may be hard to reconcile long linear rivers with polygonal terrestrial priorities, or freshwater priorities in the form of entire catchments may seem to overwhelm smaller terrestrial areas. Finally, to reiterate, some freshwater priorities may not take the form of mappable areas at all, and it is important to keep these priorities from slipping through the cracks when formatting a biodiversity vision.

Whatever the approach, ecoregion coordinators should take every opportunity to foster discussion and analysis of conservation needs between the two realms. During workshops in particular, facilitators should encourage individuals to communicate across disciplines. Effective, on-the-ground conservation in the ecoregion requires the cooperation and collaboration of these experts, and many freshwater and terrestrial experts will not have interacted before.

We should note that invariably one of the main threats to coastal marine ecoregions are land-based sources of pollution, where coastal rivers and streams are the vector. In these situations conservation activities in the coastal ecoregion should be planned using this freshwater methodology to maximize conservation of both freshwater and marine biodiversity.

What is the approach for those "terrestrial" ecoregions that are defined largely by wetlands (e.g., flooded forests, flooded savannas)?

Institutionally, WWF has made a decision to classify ecoregions as either "terrestrial," "freshwater," or "marine." These distinctions are fuzzy, and arguments could be made for inclusion of certain ecoregions in multiple categories. Ecoregions defined by wetlands pose the biggest challenge for the terrestrial-freshwater distinction (similar problems involve the marine realm for deltas and mangroves). Multiple possible categorizations should pose no real problem for conducting ecoregion conservation, which is driven by the target species, assemblages, habitats, and processes that are unique to each ecoregion. For example, a flooded savanna ecoregion may be identified as a priority because of its vegetation and associated "terrestrial" wildlife, but conservation of the floral elements would most likely require maintenance of the flood regime, which in turn might be dependent on river flow. The ecological integrity of such "terrestrial" ecoregions is directly tied to the extent to which the hydrological regime functions within its natural range of variation. For such ecoregions, the biodiversity vision would recognize the importance of the river's flow regime and consequently of catchment-scale conservation. A less-intensive analysis of aquatic biodiversity could augment the larger terrestrial assessment. In some cases, wetland habitat is not linked to a river system, and then a more traditional terrestrial approach might be sufficient, though wetlands would certainly figure as important habitat types to be represented. In summary, the category to which an ecoregion has been assigned is less important than the biodiversity features that distinguish it as a priority and the insight employed during the planning process.

Should freshwater biodiversity be assessed in a terrestrial ecoregion project and, if so, how?

Many ecoregions selected as priorities because of their terrestrial biodiversity features may also contain important freshwater elements. Of course, the opposite could also be said for freshwater priorities. In either case, it is normally too resource- and time-intensive to conduct an assessment of every biodiversity element in both the freshwater and terrestrial realms within a given ecoregion. Common sense dictates that, if important freshwater elements are known from a terrestrially defined ecoregion, an attempt to gather information on them and include it in the analysis is warranted, even if the information is incorporated in a less systematic fashion. As discussed earlier, the lack of resources historically devoted to the conservation of freshwater biodiversity means that we have an obligation to draw attention to important freshwater elements where they occur if information is readily available. Highlighting the benefits to freshwater biodiversity that would be derived from conserving priority terrestrial areas should add an extra incentive for taking action.

Will two sets of ecoregions confuse policy makers and make conservation more difficult?

The concepts of ecoregions and ecoregion conservation can be difficult to understand, and introducing two sets of ecoregions or two sets of priority areas would doubtless be confusing to many people, including policy makers. For this reason, it makes sense to combine priority areas where possible, to present a unified vision to the public, and to emphasize the links between the freshwater and terrestrial realms. Even if separate freshwater and terrestrial analyses produce different strategies, a single biodiversity vision can encompass both. Theoretically, it should be easier to persuade a policy maker to commit to an action that conserves both terrestrial and freshwater biodiversity features simultaneously. The process by which WWF chooses its priorities should be transparent and carefully documented, but in most cases the public and policy makers will be less concerned with how priorities are chosen than why they are chosen.

Box 2.1. On catchments, landscapes, and issues of scale. (Taken from: The Federal Interagency Stream Restoration Working Group 1998. Reproduced with permission.)

A landscape is a geographic area distinguished by a repeated pattern of components, which include both natural communities like forest patches and wetlands, and human-altered areas like croplands and villages. Landscapes can vary in size from a few to several thousand square miles. Landscapes differ from one another based on the consistent pattern formed by their structural elements, and the predominant land cover that comprises their patches, corridors, and matrices....

At the landscape scale it is easy to perceive the stream corridor as an ecosystem with an internal environment and external environment (its surrounding landscape). Corridors play an important role at the landscape scale and at other scales.... Much of the movement of material, energy, and organisms between the stream corridor and its external environments is dependent on the movement of water. Consequently, the watershed* concept is a key factor for planning and designing stream corridor restoration. The term "scale," however, is incorrectly applied to watersheds.

A watershed is defined as an area of land that drains water, sediment, and dissolved materials to a common outlet at some point along a stream channel (Dunne and Leopold 1978). Watersheds, therefore, occur at multiple scales. They range from the largest river basins...to the watersheds of very small streams that measure only a few acres in size.... The term "watershed scale" (singular) is a misnomer because watersheds occur at a very wide range of scales.... (see Figure 2.1).

Ecological structure within watersheds can still be described in matrix, patch, corridor, and mosaic terms, but a discussion of watershed structure is more meaningful if it also focuses on elements such as upper, middle, and lower watershed zones; drainage divides; upper and lower hillslopes; terraces, floodplains, and deltas; and features within the channel....

In short, watersheds and landscapes overlap in size range and are defined by different environmental processes. Whereas the landscape is defined primarily by terrestrial patterns of land cover that may continue across drainage divides to where the consistent pattern ends, the watershed's boundaries are based on the drainage divides themselves. Moreover, the ecological processes occurring in watersheds are more closely linked to the presence and movement of water; therefore, as functioning ecosystems, watersheds also differ from landscapes.

The difference between landscape scale and "watershed scale" is precisely why practitioners should consider both when planning and designing stream corridor restoration. For decades the watershed has served as the geographic unit of choice because it requires consideration of hydrologic and geomorphic processes associated with the movement of materials, energy, and organisms into, out of, and through the stream corridor.

The exclusive use of watersheds for the broad-scale perspective of stream corridors, however, ignores the materials, energy, and organisms that move across and through landscapes independent of water drainage. Therefore, a more complete broad-scale perspective of the stream corridor is achieved when watershed science is combined with landscape ecology.

* "Watersheds" are equivalent to "catchments"

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The Biodiversity Vision for Freshwater Ecoregions: What is it, How do we get there?

3

Introduction

The goal of ecoregion conservation is to conserve the full range of species, natural communities, habitats, and ecological processes characteristic of an ecoregion. The purpose of this chapter is to explain (a) the value of the biodiversity vision, (b) the process for creating a draft vision, and (c) key elements of the vision. A portion of this chapter is taken from *Volume I: Terrestrial Ecoregions*.

What is a biodiversity vision?

The key feature of ecoregion conservation is the clear articulation of a biodiversity vision that incorporates the full range of biological features, how they are currently distributed, how they may need to be restored, and how to safeguard them over the long term. A biodiversity vision is essential because it helps us to move beyond a business-as-usual approach to conservation. It serves as a touchstone to ensure that the biologically and ecologically important features remain the core conservation targets throughout the ecoregion conservation process. Even when we respond to local emergencies in the course of developing an ecoregion program, a biodiversity vision provides a useful framework for interpreting threats to the integrity of the entire ecoregion rather than to individual sites. Without a vision, we lose sight of the overarching conservation targets, we have difficulty establishing priorities, and we waste scarce resources.

To be successful at ecoregion conservation, we need a vision of what we want the ecoregion to look like 50 years hence. If ecoregion conservation in general forces us to consider larger spatial scales than before, it is the biodiversity vision in particular that requires us to consider much longer temporal scales. Getting the biodiversity vision right is a critical step in the process and makes the considerable investment in ecoregion conservation worthwhile.

Securing active support for the vision is critical to the next steps in the ecoregion conservation process. Obtaining this support is challenging and ecoregion-specific. When relevant government scientists or other influential experts are involved from the early stages of the process, endorsement or ownership of the vision may be more likely.

Setting our sights high: the value of a biodiversity vision

To illustrate the visioning process, we can categorize approaches to conserving biodiversity under four main headings: do nothing, business-as-usual, visionary, and idealistic.

The first approach is to do nothing. If we do nothing in the face of threats to species, habitats, communities, and ecosystems, we know the result: extirpation of populations, extinction of species, and loss of habitats and natural processes. In short, doing nothing will, with rare exceptions, allow current trends to lead to extensive losses of biodiversity. For conservationists, that option is clearly untenable.

The second approach, business-as-usual, describes conservation interventions that rarely stray beyond treating isolated symptoms, even if these interventions do little to stem the overall decline of populations, species, and habitats. For instance, there is a long history of river restoration efforts that work at the local scale, treating only the results of larger, basin-wide problems. Frissell (1997) gives two examples of this from the United States. First, "most current management plans for national forests assume — with little or no scientific support — that increased fish production from new artificial structure projects will more than compensate for the logging of critical ecosystems in sensitive watersheds." Second, "in arid ecosystems, federal agencies commonly install artificial structures in streams that have been damaged for decades by livestock grazing, [even though] the primary process causing the damage — grazing — is not controlled." In these examples, engineering solutions implemented at discrete sites are substituted for basin-wide shifts in land use, because they are more politically expedient.

Strategies or actions that are truly visionary change the course of conservation with a bold move that often requires strong political will and courage, as well as a willingness to take some risks. These strategies also require thinking on larger spatial and temporal scales than communities, sites, or next year's work plan. The planned restoration of the Everglades ecosystem in the United States, which will attempt over the next 20 years to create a hydrological regime resembling historic conditions, is an example of a visionary step (Figures 3.1-3.3).

At the far end of the continuum are actions that are often viewed today as idealistic or idiotic — ideas or recommendations that are so far removed from the current reality that they seem too foolish to be taken seriously. And yet, simply introducing such ideas — such as restoring the Everglades — can lead to the eventual acceptance of that idea over time. In another example, 20 years ago the idea of removing dams from rivers to allow fish passage was considered outside the realm of possibility, but today more than 470 dams in the United States have been removed, and many more are targeted (American Rivers 1999).

We offer these examples to highlight three points that are applicable to any ecoregion. First, if we continue with business-as-usual in our approach to conserve biological diversity — planning mostly at the scale of isolated sites or communities — we will win battles here and there, but we are likely to lose the war (as is the case now).

Second, ecoregion conservation offers an approach to biodiversity conservation that allows us to be visionary in the creation of conservation plans with a view to long-term biodiversity conservation. We are forced to think of the big picture and not to accept what exists on the current map as the limit to what can happen in an ecoregion.

Third, ideas or initiatives that were once considered visionary but unachievable, or even idealistic, can soon become business-as-usual. Conservationists should never be satisfied with the status quo simply because we think it is all we can achieve. What may seem hopeless now may become possible in a few years' time. For example, in the United States, more than 2,400 privately owned hydropower dams have operating licenses that expire every 30 to 50 years. For relicensing, dam owners must justify that operation of the dam is in the best public interest, both in terms of power and non-power benefits (e.g., fisheries, recreation, species protection). A large number of these dams' licenses will expire over the next five years, presenting an important (and once-in-a-half-century) opportunity for removing dams that no longer provide benefits to society. Conservation groups are working quickly to identify those dams whose removal or modification would lead to substantial gains for biodiversity. A biodiversity vision that identified priority rivers

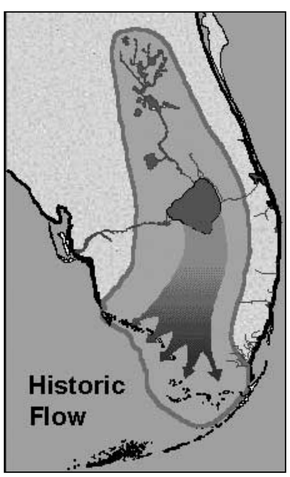

Figure 3.1. Historic water flow in the Everglades.

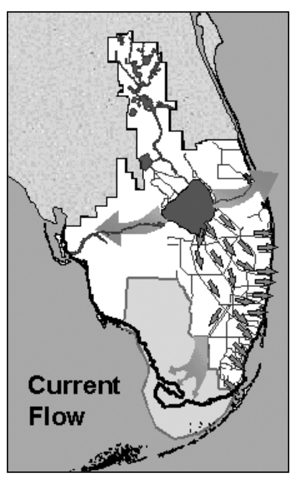

Figure 3.2. Water flow in the Everglades today, resulting from massive diversions, channelizations, and withdrawals.

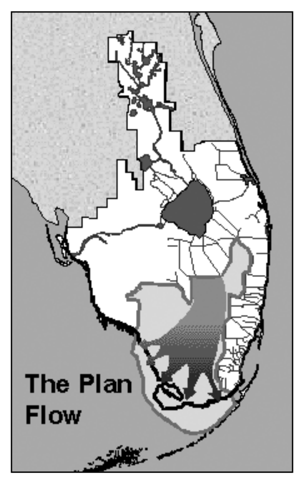

Figure 3.3. Projected water flow in the Everglades as a result of restoration efforts implemented over the next 20 years.

Figures 3.1-3.3. Restoration of water flows in the Everglades, USA. (Taken from: U.S. Army Corps of Engineers 2001. Reproduced with permission.)

would aid in that identification and give scientific grounding to conservationists' recommendations. Similarly, the recently released World Commission on Dams report, *Dams and Development*, is a respected, impartial assessment of large dams that provides recommendations for their construction and operation to minimize environmental impacts (World Commission on Dams 2000). Establishment of the Dams and Development Project to facilitate implementation of those recommendations presents a strong opportunity to institute best practices around the world.

Other examples of potential opportunities for achieving freshwater biodiversity protection include:

- A moratorium on logging of native forests across China. This act was partly in response to disastrous floods in the summer of 1998 and will provide broad protection of headwaters.
- The President of Brazil's declaration to conserve 10% of the Brazilian Amazon in a network of protected areas representative of the basin's forest ecoregions. There may be opportunities to offer recommendations that will confer protection to flooded forests and to important headwaters.
- The commitment to conserve 20% of the land area of Mongolia under formal protection by the year 2000. As with Brazil, this provides an opportunity for achieving protection of precious freshwater habitats.

Doing your biological homework

Biodiversity visions for freshwater and terrestrial ecoregions have the same goal — defining what will be required to maintain biodiversity over the long term — but some of the steps for developing them may differ. For *terrestrial* ecoregions, a list of those basic biological features that the ecoregion team should understand before developing a draft vision includes:

- the outstanding biological features of the ecoregion — distribution, relative abundance, or area of influence (for processes), all developed into a conservation targets chart (see Chapter 5 for more detail),
- the original distribution of the native plant communities of the ecoregion,
- the dynamics that influence habitat composition, the prominent disturbance regimes, and the processes that sustain biodiversity,
- distribution patterns of species that, although limited today, may have previously been more extensive,
- the demography (the size of populations and their trajectory) of important species (focal species) found within the ecoregion,
- the presence of any important phenomena that formerly occurred, such as long-distance animal migrations or large concentrations of breeding individuals, and
- concentrations of species with localized ranges.

For many *freshwater* ecoregions, we need to modify this list. First, knowing the original distribution of native vegetation communities in an ecoregion is not as critical as knowing about the distribution of aquatic habitats. In some cases, aquatic or riparian vegetation may be primary determinants of these habitats, but this is not always the situation (see Chapter 2). The physical characteristics of aquatic systems (e.g., substrate, water chemistry, flow regime, temperature) are always important determinants of aquatic habitats, whereas the role of associated vegetation varies. If the outstanding biological features of a given freshwater ecoregion are related to vegetation (e.g., for a flooded forest ecoregion), it makes sense to map the distribution of vegetation communities to the best extent possible. For instance, the floodplain forests along the major rivers of the Amazon Basin define the Amazon River and Flooded Forests ecoregion; the extent of these forests has been mapped, even though there is little information about how the vegetation varies at fine scales within the ecoregion (Figure 3.4). In other cases, it may be more important to try to map the distribution of aquatic habitat types, or to go directly to mapping areas that are known to be critical for maintaining identified conservation targets.

Second, in many freshwater ecoregions only anecdotal information exists on the demography of potential focal species (those whose habitat needs can be used to set minimum targets for the vision; see Chapter 7 for more detail). Aquatic mammals such as river dolphins, large reptiles such as crocodiles, breeding or wintering waterbirds, and some exploited fish species may have been studied, but the demography of the vast majority of target species is likely to be virtually unknown. Do not assume that data are lacking, but do not be discouraged to find that this is the case — the ecoregion conservation effort can proceed without it. However, one task of the ecoregion team will be to identify critical research gaps and fund targeted research to address them, where possible.

Demographic information (related to growth rates and age structures of populations) is used to determine the minimum area required for a viable population of a given species. Combining area requirements with species or habitat distribution data can identify potential areas for

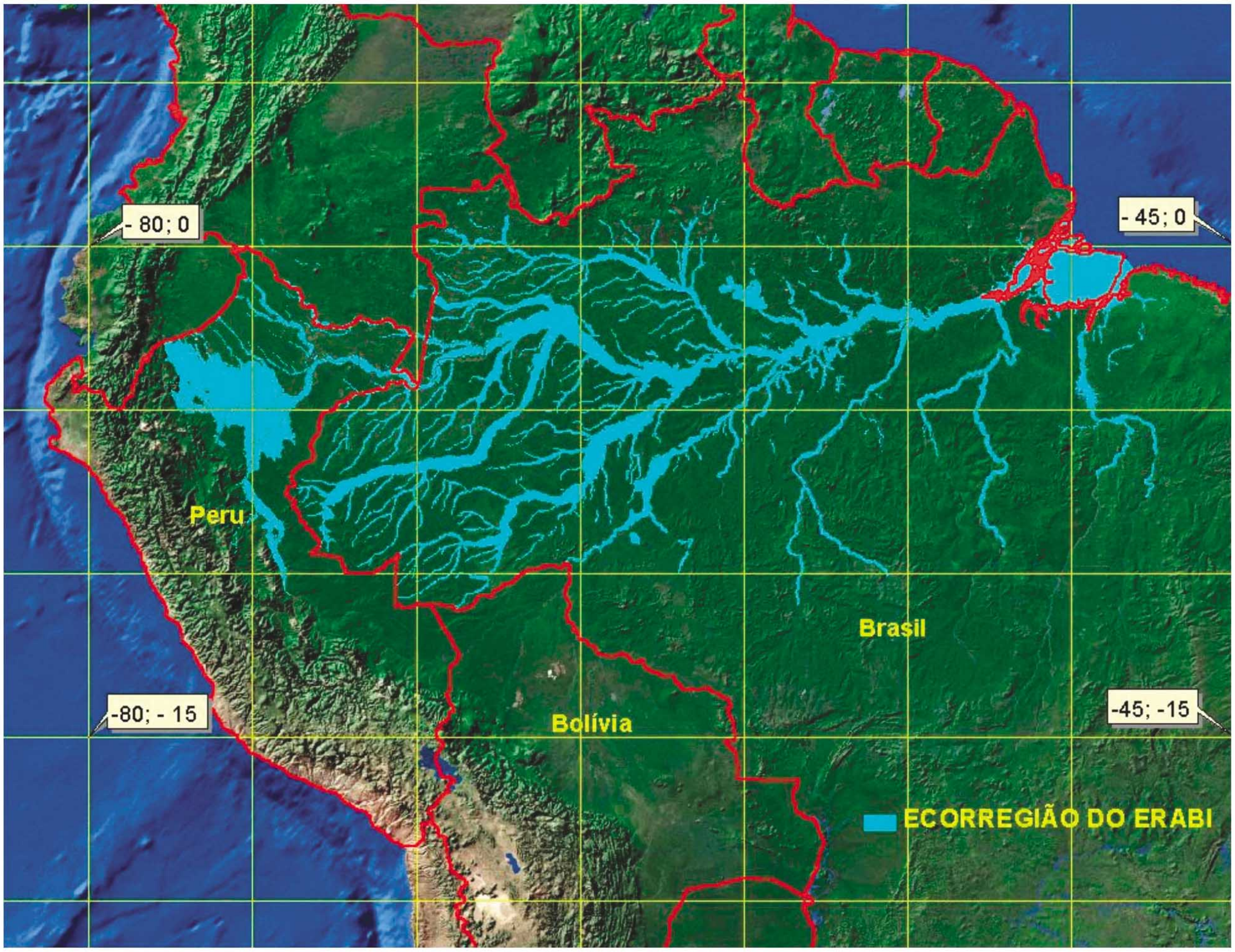

Figure 3.4. Flooded forests defining the Amazon River and Flooded Forests ecoregion.

protection. Even if we had demographic and distribution data for aquatic species and habitats, however, calculating the minimum area that must be placed under protection would be difficult. Because a freshwater habitat is affected to a greater or lesser extent by activities within its catchment, protection of that aquatic habitat will require some degree of protection in the catchment upstream and possibly downstream. Not all land uses produce equal disturbances, and some disturbances attenuate with distance (Stanford et al. 1996). Research into the scale over which different disturbances operate in freshwater systems provides some basic rules of thumb (Allan et al. 1997), but in general it suggests that catchment-wide protection is the best solution, and that protection should perhaps be focused on those catchments that remain relatively undisturbed. Chapter 5 discusses approaches to developing a freshwater conservation strategy in greater detail.

In many cases, understanding the life histories of focal species is more important than charting the demographics of their populations. Although many aquatic taxa are poorly studied, research suggests that lotic (flowing water) species often require very specific habitats for the completion of critical life history stages, such as spawning and juvenile rearing (Sedell et al. 1990; see Box 3.1 at the end of this chapter). The same is true for at least some lake species, particularly those that migrate up rivers to spawn (a kind of *potamodromous* species). Identifying those habitats that are critical to the survival of key species, and determining the minimum quality (including size, if necessary) of those habitats where possible, may be an essential line of investigation. Again, where this information is lacking for focal species, you might consider identifying these information gaps as priorities for research funding.

Finally, we cannot overstate the importance of considering physical processes, and particularly the natural hydrologic regime. It is critical to understand, to the best extent possible, what constitutes the natural hydrologic regime (including the geographic and temporal scales over which it operates), how it maintains different aquatic habitats, how freshwater taxa are adapted to that regime, and what the main threats are to its maintenance. You should also consider identifying minimum targets (e.g., minimum flow levels, minimum number of days of flooding, minimum lake levels) and approaches for achieving them. It may be far easier to develop a plan for meeting such targets in impounded or otherwise engineered systems than in those without flow-regulating structures. For any freshwater project, *we strongly suggest inclusion of hydrologists or, more specifically, biohydrologists,*[13] *in the ecoregion conservation process as early as possible.*

There is no simple way to determine the most appropriate historic baseline against which to develop a biological vision for an ecoregion and to judge what success should look like. Our goal is to identify a time when anthropogenic influences had not yet caused widespread land-use changes, and to estimate the ranges of variation within which populations and processes fluctuated at that time. In some ecoregions this time may have occurred recently, in others it may have occurred many hundreds of years ago, and in remote ecoregions widespread land-use changes may not have yet occurred.

As an example, in North America the state of an ecoregion when Europeans first arrived is likely to be a useful baseline even though Amerindians had already altered ecosystems substantially. Widespread introductions of aquatic species from across the Atlantic Ocean, the construction of power-generating dams on rivers, the draining of wetlands for settlement and agriculture, and the extirpation of keystone species such as beavers all followed European settlement. Luckily, European explorers and settlers also documented the location, condition, and biota of many North American freshwater systems as they encountered them, so there is some record of what existed prior to the systems' large-scale modification.

In contrast, it will be far more difficult to establish a baseline for those ecoregions that have had a much longer history of intense modification. In Europe, for instance, it may be impossible to establish if an aquatic species is native or exotic to a river system within a particular ecoregion, given the extent of introductions over time and the sometimes confused distinction between "naturalized" and "native" species. In many ecoregions, it may be sufficient to use pre-industrial conditions as the baseline (Angermeier 1997).

Numerous sources contain historical information. These sources can include old biological surveys, museum samples, field stations, university archives, diaries of amateur and professional naturalists, non-peer-reviewed literature (agency reports, environmental impact statements), and scientific journals (Wissmar 1997). Because reconstructing a picture of the historical condition is an arduous process, we recommend carefully identifying the specific questions that you need to answer first, then perhaps commissioning a desk study[14] to address those questions as efficiently as possible (Wissmar 1997).

For freshwater systems with altered hydrologic regimes, it may make sense to engage hydrologists to attempt a reconstruction of the historic regime. Such reconstructions may be achieved through analyses of long-term gauging data (where they exist), simple water budget models, or other means (Richter et al. 1997; The Nature Conservancy 1999).

In general, when trying to reconstruct a historic baseline and set targets, it may help to think about the natural range of variation of the elements of interest.[15] Under natural conditions, what were the ranges within which populations, communities, environmental regimes, or natural disturbances generally fluctuated? You may not have good enough data to evaluate the ranges of variation with precision, but you may be able to estimate these ranges using pieces of historical evidence (The Nature Conservancy 1999).

An overview of the vision-building process

Contributors to the ecoregion planning process will be able to contribute most effectively if they understand

[13] A biohydrologist is someone who studies the interactions between the water cycle and plants and animals.

[14] A desk study is, in essence, a synthesis of existing literature on a given topic.

[15] The Nature Conservancy (1999) provides a good explanation of natural ranges of variation: "All natural systems and their internal components are variable, and perturbations and changes occur over some particular range of variation. When an ecological system is subjected to fluctuations outside the natural range of variability associated with that system — including too little, too much, or novel disturbances — the system and its components are likely to experience fundamental changes in structure, composition, and function. Once a critical ecological threshold has been crossed, a system may not be capable of reverting back to a former state...This is particularly important for freshwater systems, where hydrologic, chemistry, and temperature regimes are principle ecosystem drivers and determinants of habitat features and target viability (Angermeier 1997; Richter et al. 1997)."

how their work fits into the larger vision-building process. *Volume 1: Terrestrial Ecoregions* presents a flowchart of the steps involved in defining a portfolio of priority areas and developing a biodiversity vision for a terrestrial ecoregion. These basic steps hold true for freshwater ecoregions, but our experiences suggest that for freshwater projects there is room for greater flexibility in the sequence of steps, the process of carrying them out, and their outputs.

Here we represent the process of developing a freshwater vision as a set of boxes with component steps (Figure 3.5). *This is a suggested framework only, not a prescription.* Within a given box, you may decide to shift the order of some of the steps. Within the larger vision-building process, you may decide to shift the order of some of the boxes. In the case of some freshwater ecoregions, certain boxes or steps may be eliminated altogether, with new ones added. Past experience suggests that too rigid an adherence to the original flowchart of steps can result in a less-than-visionary vision.

This flowchart is detailed, emphasizing the steps required to develop the methodology prior to generating the vision. Each ecoregion will require a somewhat different approach, based on the types and sizes of habitats, the kinds and quality of available information, and the current and future threats. All participants should understand and agree on the approach before they begin their work, or the results will lack standardization. The second box in the flowchart covers the methodological issues that the ecoregion team should agree upon prior to embarking on the assessment.

The flowchart deals with developing a vision for a freshwater ecoregion on its own. Combining freshwater and terrestrial assessments into a single vision poses an additional set of challenges (see Chapter 2). Merging freshwater and terrestrial priorities could theoretically occur at any point in the process. Decide how and when to merge the two vision processes before you begin the assessment (preferably no later than at the orientation meeting; see Chapter 5), because you will need to modify one or both processes in advance to make them fit together.

This sourcebook describes each of the flowchart boxes in the order in which they are shown. Terms shown in the flowchart are defined in the text and also in the glossary. Part II of this sourcebook covers all the recommended steps for conducting an assessment and developing a biodiversity vision. In Chapter 5, *Getting Oriented*, we discuss the steps that we suggest might be covered during an orientation meeting. In Chapters 6-8, we recommend various steps for preparing for an assessment. Chapters 9-10 discuss conducting the assessment, and Chapters 11-12 cover the integration of the assessment results into a biodiversity vision. Before we delve into the biological assessment, however, we use the following chapter (Chapter 4) to describe key ecological principles for freshwater conservation.

Box 3.1. Associations of fish with different habitat types. (Taken from: Schlosser 1991.)

Numerous studies of fish in headwater streams and large rivers reveal associations between structural characteristics of the environment and the occurrence of fish species or size classes. Studies of fish communities conducted on large spatial scales along longitudinal and lateral dimensions indicate many fish species exhibit well-defined zonation, suggesting adaptation to habitat conditions associated with upstream versus downstream (Huet 1959) or floodplain versus midchannel habitats (Welcomme 1985). The distribution of stream fish along both axes is highly dynamic, however, with much of the movement involving reproductive activities during which adult fish move into shallow, upstream, or floodplain habitats to spawn, and juvenile fish move out of these areas once a sufficient size is reached (Northcote 1978; Lowe-McConnell 1987; Schlosser 1987; Copp 1989). In conjunction with these spawning migrations, considerable complementarity occurs in the distribution of large and small fish along longitudinal and lateral axes, with small fish being found predominantly in shallow upstream or lateral habitats (Welcomme 1985; Power 1987; Schlosser 1987; Moore and Gregory 1988) and large fish being more abundant in deeper downstream or midchannel habitats (Welcomme 1985; Schlosser 1987).

Studies on small spatial scales, within stream reaches or within specific types of habitat, also reveal differences in habitat use by various species and life-history stages of fish. In either upstream reaches or large rivers, spawning habitats normally differ from juvenile-rearing habitats, juvenile habitats differ from adult habitats, and habitat use by adults and juveniles varies among species. Furthermore, as on large spatial scales, habitat use on small spatial scales is dynamic and strongly influenced by the sequence of events in the life cycle of the fish (Lowe-McConnell 1987).

Figure 3.5. Suggested flowchart of steps for conducting a biological assessment and developing a biodiversity vision for a freshwater ecoregion.

Laying the Groundwork — **Chapter 5**

Getting oriented

Step 1. Identify target ecoregion
Step 2. Identify broad conservation targets for ecoregion
Step 3. Identify major processes required to maintain conservation targets
Step 4. Identify major threats to the maintenance of conservation targets and major processes
Step 5. Refine ecoregion boundaries using biogeographical and hydrological information
Step 6. Define biogeographic subregions
Step 7. Identify habitat types for representation analysis
Step 8. Identify types of information required to evaluate patterns of biodiversity, processes, ecological integrity, and threats
Step 9. Identify the type of biological assessment that is appropriate to the ecoregion
Step 10. Discuss what form the biodiversity vision should take

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Preparing for the Assessment

Data collection and synthesis — **Chapter 6**

Step 1. Begin to collect necessary information and to identify data gaps
Step 2. Identify key experts and stakeholders in the ecoregion
Step 3. Identify key desk studies and contract with experts to write them
Step 4. Begin preparing for ecoregion workshop or other assessment venue

Methodology for biological importance — **Chapter 7**

Step 1. Agree upon level and types of representation to be achieved, and algorithm for representation analysis
Step 2. Identify focal species, habitats, and processes, and determine minimum requirements
Step 3. Agree upon criteria for identifying candidate priority areas
Step 4. Agree upon methods for representing candidate priority areas on maps
Step 5. If multiple types or layers of candidate priority areas will be generated, agree upon method of synthesis
Step 6. Agree upon method for evaluating biological importance of candidate priority areas

Methodology for ecological integrity and integration — **Chapter 8**

Step 1. Agree upon method for evaluating ecological integrity of candidate priority areas
Step 2. Agree upon method for integrating ecological integrity with biological importance

Conducting the Assessment

Biological importance — **Chapter 9**

Step 1. Revisit ecoregion boundaries, using collected information and expertise
Step 2. Refine biogeographical subregions
Step 3. Revisit habitat types, focal elements, and minimum requirements
Step 4. Select candidate priority areas
Step 5. If multiple types or layers of candidate priority areas are identified, synthesize if appropriate
Step 6. Conduct representation analysis
Step 7. Analyze set of candidate priority areas to determine if all focal elements, and the minimum requirements for maintaining them, have been addressed
Step 8. Assess biological importance of candidate priority areas

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Ecological integrity — **Chapter 10**

Step 1. Evaluate habitat intactness of candidate priority areas
Step 2. Evaluate population/species viability of areas, add or change boundaries if necessary
Step 3. Assess ecological integrity of candidate priority areas

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Prioritizing areas at the ecoregion scale — **Chapter 11**

Step 1. Assign priority levels to candidate areas using integration matrix/algorithm
Step 2. Conduct representation analysis again, and elevate the priority level of one or more areas if necessary
Step 3. Analyze portfolio of priority areas to determine if conservation targets have been addressed, and elevate the priority level of one or more areas if necessary
Step 4. Analyze overlap of priority areas with protected areas, and with results of other priority-setting exercises

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Pulling It All Together

Identifying specific and overarching future threats — **Chapter 12**

Step 1. Identify future threats specific to priority areas, and the intensity of those threats
Step 2. Identify overarching threats to the region, ecoregion, and subregions, and their intensity
Step 3. Identify specific actions or kinds of conservation required for each priority area, subregion, or larger areas, and the urgency of action

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Developing a biodiversity vision — **Chapter 13**

Step 1. Evaluate if priority areas and actions, taken together, would result in the long-term maintenance of ecoregion's conservation targets, and add new priorities if necessary
Step 2. Synthesize key information gaps and research priorities
Step 3. Combine priority areas map and priority actions into comprehensive vision
Step 4. Draft a vision statement
Step 5. Identify next steps

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PART II:

Conducting a Biological Assessment and Developing a Biodiversity Vision for a Freshwater Ecoregion

Ecological Principles for Freshwater Conservation

4

Introduction

In Part I of this sourcebook we outlined the basic framework for a biological assessment and biodiversity vision. Part II focuses on the particular details of freshwater conservation planning at the ecoregion scale and discusses each step in the process. The framework that we recommend differs somewhat from that for a terrestrial assessment, because freshwater ecology is in many ways fundamentally different. Before launching into the assessment process, we offer this chapter, which summarizes some key ecological concepts that will shape most freshwater planning exercises.

The particular nature of freshwater conservation planning

Whereas terrestrial ecoregion conservation focuses largely on size requirements for protected-area networks and conserving beta diversity, freshwater ecoregion conservation must tackle a somewhat different set of complex questions. Not only must it answer the question of how much area within a catchment must be protected (and if the location/configuration of such protected areas is important), but it must also try to determine how much aquatic habitat is required to sustain viable populations of species. Unlike in the terrestrial realm, where the extraction of trees from one patch of forest may not substantially affect a forest in another location, the extraction of water from a headwater stream *will* have downstream impacts. To complicate matters, the extraction of *trees* from a headwater catchment may have downstream impacts as well. In the freshwater realm, the effects of disturbances propagate downstream, so a protected lake or river reach is only as secure from threats as are the lands and aquatic habitats in its catchment upstream (Sedell et al. 1994; Frissell 1997). Catchment management is required to protect both water quality and quantity.

A second, and related, major theme of freshwater conservation planning is the importance of maintaining connectivity. In all realms, corridors are essential for the exchange of individuals between populations and the recolonization of patches following disturbance — both of which serve to maintain viable metapopulations. The corridors are also essential for the movement of individuals between habitats over the course of their life cycles. But whereas in the terrestrial realm a species might dare to cross a road even it preferred not to, many species in the freshwater realm do not have the option of crossing land or skirting a dam. For obligate aquatic species, dispersal routes are highly constrained, often linear, and easily obstructed (Schlosser and Angermeier 1995), and there is evidence that this is the case for other freshwater species as well. This lack of dispersal routes has implications for the persistence of biodiversity; studies of recovery of stream biodiversity following disturbances have found strong correlations between the time to recovery and the existence of recolonization routes (Niemi et al. 1990). In short, it is critical to incorporate connectivity among aquatic habitats into the design of a freshwater conservation strategy. This includes maintaining riparian connectivity as well.

This sourcebook focuses most on lotic (flowing water) ecosystems, and some ideas are less applicable to lentic (standing water) systems. For example, cosmopolitan aquatic species (e.g., freshwater algae, zooplankton, planarians, some molluscs and crustaceans) sometimes colonize new lake habitats where no dispersal routes appear to exist (Reynolds 1989; see Box 4.1 at the end of this chapter). These colonization events may be a result of underground aquatic connections, dispersal by other species moving between habitats, or other mechanisms. Nonetheless, we cannot assume that obligate freshwater species will be able to cross terrestrial or even aquatic barriers. This is particularly true if we are most concerned with the protection of distinct biodiversity elements such as endemic taxa, which tend to have highly different requirements from cosmopolitan species.

Understanding biodiversity patterns

In a typical biological assessment, one of the first steps is mapping areas that are important for maintaining the ecoregion's conservation targets. Recall the five broad categories of conservation targets that we offered in Chapter 1:

- distinct communities, habitats, and species assemblages (distinct units of biodiversity),
- large expanses of intact habitat, and intact native biotas,
- keystone habitats, species, and processes,
- large-scale ecological phenomena, and
- species of special concern.

In most ecoregions identifying areas supporting these features will be a challenge because of a lack of data. In particular, there are often little or no data for taxonomic groups other than fish, and even for fish the data can be sparse; this lack of distribution data will primarily hinder identification of areas supporting distinct units of biodiversity (the first category). Where good data exist, it is possible to identify areas harboring large numbers of species (high species richness), one or more endemic species,[16] an endemic genus, or relict taxa. Land-use data and remotely sensed images may aid in the identification of rare habitats, areas containing large expanses of intact habitat, and keystone habitats. The locations of some keystone species may be inferable from other data. Experts may be most familiar with those areas supporting large-scale ecological phenomena and species of special concern, because these elements tend to garner the most research attention. The best information on where biotas remain free of established exotics may also reside with experts.

Even in the best-studied ecoregions an element of educated guesswork is required in identifying areas of biodiversity importance, especially because the life histories of most freshwater species are poorly known (Power et al. 1988; Sedell et al. 1994; Schlosser and Angermeier 1995). With the exception of local-scale species (those inhabiting small habitat patches; see Box 5.3, next chapter), freshwater animals often use a variety of habitats over the course of a year and/or their life cycles.[17] This life history feature means that protecting an area known to support high biodiversity may not confer absolute protection to those species, and protecting connections to other habitats will be critical.

With insufficient data, proxies can provide guidance for which areas may be the most important for biodiversity. Some examples for freshwater ecoregions are:

- Older habitats — those that have not been "re-set" by glaciation or tectonic events in the recent past — *may* contain endemic species, though some species radiations occur in "new" habitats. Isolated habitats may also have a higher degree of endemism, although they may have fewer species because of fewer opportunities for colonization.
- Areas characterized by sinkholes, caves, and underground drainage may contain rare *troglobites* (obligatory cave species), *troglophiles* (facultative cave species), or species adapted to spring outflows (Hobbs 1992). These species can include fish, amphibians, and a wide range of invertebrates, which often have highly restricted ranges (Samways 1994).
- Waterfalls often serve as effective barriers in lotic systems, with different biotas found above and below them. Large rivers may also serve as barriers to tributary biotas.
- Temperature is one of the primary factors determining the distribution of freshwater fish in the temperate zone. Although water temperature is strongly influenced by shade, groundwater inputs, flow, and water transparency, climate will be the main determinant of water temperature at the ecoregion scale. For ecoregions spanning large latitudinal or altitudinal ranges, climatic isotherms may give general information on fish species distributions.
- High levels of habitat heterogeneity (complexity) are associated with hotspots of freshwater biodiversity, particularly in river systems (Stanford et al. 1996). Dynamic areas where habitats are created and destroyed may be important as priorities.
- Habitats subject to different flooding regimes (timing, duration, and levels) are likely to harbor different biotas. Some information on flooding may be derived from remotely sensed images.

[16] In the context of ecoregion conservation, we can identify endemic species at various spatial scales. A species may be endemic to the ecoregion, endemic to a subregion, endemic to a subcatchment, or endemic to an area within a subcatchment (such as a lake or tributary stream). In general, we recommend focusing on species that are endemic to a subregion or smaller area, because species endemic to an ecoregion and distributed widely within it offer little discrimination among areas. An exception would be species restricted to specialized or patchy habitat types.

[17] For lotic fish, recent evidence suggests that many species originally considered "resident" may actually move often and over substantial distances (Fausch and Young 1995).

At the coarsest scale, you can assume that within a biogeographic subregion[18] (see Chapter 5) species and habitats are broadly similar. You can select representative areas within those subregions without much additional information about patterns of biodiversity, although certainly the more information that you can bring to bear on the process, the better. The same information (geology, soils, topography, etc.) that you use to inform your delineation of subregions can also aid in the identification of broad habitat types, and you can assume (if there is no evidence to the contrary) that these habitat types support different species assemblages.

If you truly have no way of identifying important areas for biodiversity, you can consider the following basic rules. First, all else being equal, larger catchments will probably contain more species than smaller catchments, because they will contain more available habitat and potentially more habitat types (Rieman and McIntyre 1995). The same is true for lakes and wetlands — more available habitat generally correlates with more species (Samways 1994). Habitat heterogeneity is highly correlated with species richness, so catchments draining a range of soil types, geologies, elevations, or vegetation types will likely have greater species richness than those that do not.

Conserving patterns of beta diversity

Terrestrial assessments have typically emphasized patterns of beta diversity, particularly where species distribution data are sparse. Understanding patterns of diversity is no less important for freshwater systems, but application of the concepts may be somewhat different. For example, we define beta diversity ("differentiation diversity") as the change of species along an environmental gradient or among the different communities of a landscape (see Chapter 1). All lotic systems, by definition, traverse an elevational gradient. This gradient can be steep or relatively flat, but nonetheless all river systems begin with headwaters and terminate at the ocean, an inland sea or lake, or the confluence with another river. To measure beta diversity in a stream, then, we could look at how species changed as we moved up or downstream — and we would certainly find turnover in species, since we know that habitats and species change with stream size and elevation. If we found, however, that a stream exhibited unusually high beta diversity — and this could be difficult to measure, because studies of beta diversity in freshwater systems are rare — what would that mean for developing a conservation strategy? Since we probably cannot develop an effective conservation strategy for a portion of a stream reach, an inventory of the entire stream's richness might be equally useful information for our scale of analysis.

It might be more informative to compare the species richness and/or composition of similar habitats in different subcatchments. For example, we could compare fourth-order streams in neighboring subcatchments, which would control for the effects of stream size and to some extent for elevation. Or, we could compare the aquatic species richness and composition of entire fourth-order subcatchments. Differences in species composition in these cases could be due to the effects of allopatric speciation (speciation of geographically isolated populations).

In short, we are interested in "differentiation diversity" in whatever form it takes. If high levels of beta diversity characterize your ecoregion, it will require much greater effort — more protected or managed areas distributed over the landscape — to conserve the full expression of biodiversity. A good example of high beta diversity in the freshwater realm is Cuatro Ciénegas, a basin in the Chihuahuan Desert characterized by hundreds of isolated spring-fed pools, many of which contain their own endemic biotas. A similar example would be karstic areas within the Balkans region, where subterranean habitats support high numbers of restricted-area hydrobiid snail species. These examples of beta diversity within freshwater systems are straightforward because the freshwater habitats in question are more isolated than connected. As such, they resemble terrestrial habitats, and in particular terrestrial islands. Lake Tanganyika provides a different example, with species turnover along environmental gradients and between habitats. The lake exhibits species turnover both along the main axis of the lake with change in bottom slope and thickness of the oxygenated water layer, as well as across littoral, pelagic, and benthic zones (Coulter 1991). In all three examples, species turnover from one freshwater habitat to another is high, and a fine-scale approach will likely be necessary to protect the ecoregions' distinctive biodiversity features.

[18] The term "subregion" refers to a biogeographically distinct subdivision within an ecoregion. The term "subecoregion" has been used instead in some ecoregions.

To summarize, we are aiming to identify and protect distinct species assemblages, which we can quantify as the percent dissimilarity of species between catchments, habitats, or reaches. Because of the interconnected nature of most freshwater systems, protecting areas of high beta diversity will necessarily require conserving flow patterns and water levels beyond the site scale. The best way to do this is by targeting entire catchments, especially where fine-scale species distribution data are unavailable to discriminate among areas within catchments.

For ecoregions where species are more widespread or where there are no data to judge if high beta diversity characterizes the ecoregion, focusing on high habitat diversity may be a good alternative. For instance, in the Amazon River and Flooded Forests ecoregion, the ecoregion team mapped all flooded habitats and generated a habitat diversity index for each large catchment using the digitized data. Those catchments with the highest habitat diversity were considered to have high biological importance. Particularly for enormous ecoregions where fine-scale data will not exist, such a tactic — analyzing habitat diversity within large catchments — may be the most practical option to assessing biological importance.

Protecting catchments

No matter what quality of data are available, we recommend considering the selection of entire catchments[19] as priority areas. If these catchments are in different physiographic areas, the freshwater habitats in them are likely to vary and consequently support different species assemblages (Angermeier and Winston 1999). Overlaying terrestrial ecoregions with catchments may help to identify these physiographic areas. Obvious differences in water chemistry, such as between black and whitewater systems, or barriers to dispersal such as rapids, would be possible indicators of where differences in species assemblages might occur within catchments.

Because few catchments of substantial size remain intact except in remote places, those intact catchments that do occur should be highlighted. "Intactness" is relative and difficult to quantify, but a simple measure might be the degree to which the original land cover in the catchment has been converted. An alternative criterion for intactness is an absence of river impoundments and flow regulation structures; again, such cases are so rare in many ecoregions that they should be emphasized. You could apply numerous other criteria as well; we discuss these in detail in Chapter 8 and list relevant data types in Chapter 6.

Upstream catchments (those draining low-order streams) are more likely to be intact and easier to protect from future disturbance. Protection of headwater catchments is critical for the maintenance of downstream flow regimes and water quality. Headwater habitats also support species not found downstream and are the destinations of many migrating fish and other taxa. For these reasons, we argue for including headwater catchments in any conservation portfolio. But, downstream areas must be included as well to capture the full complement of an ecoregion's freshwater species and to maintain linked upstream-downstream processes (Frissell et al. 1993; Peres and Terborgh 1995). Downstream areas are generally more accessible, have more abundant water resources, are more productive, have greater species richness, and tend to be subject to a greater intensity of human use. Conservation of downstream freshwater habitats may require more creative approaches, including a greater emphasis on restoration (see Box 4.2 and Chapter 14 for discussion of restoration principles). Conservation of intact upstream catchments should be balanced by efforts to conserve more disturbed and biologically rich lowland freshwater habitats.

In many arid ecoregions, deforestation or poor irrigation practices can cause saline water tables to surface. Because salinization may be virtually impossible to reverse once it has commenced, except via massive reafforestation campaigns, it may be an important factor in selecting priority areas for conservation work. Heavily disturbed catchments where salinization has commenced may be considered a low priority.

Focal habitats

If you choose to identify biologically important areas within catchments, either as an alternative method to identifying entire catchments or as a next step in the development of a conservation strategy, you may want to consider certain broad habitat types that

[19] Recall that catchments are hierarchical, nested units, and the term catchment is size-independent. We sometimes use the term subcatchment to distinguish a small catchment embedded in a larger one. All catchments, except for those draining to the sea/ocean or with no external drainage, are also subcatchments.

tend to serve critical biodiversity functions. These focal habitats may also be the target of ecoregion-wide priority actions in your vision — for example, a priority to secure the protection of riparian buffer zones across the ecoregion. We briefly describe several potential focal habitats below, but this list is not inclusive.

- *Large, alluvial river reaches:* Expansive alluvial river[20] reaches and floodplains often provide high-quality habitat that supports core populations of fishes. Stanford et al. (1996) write: "These productive populations can serve as stable sources of dispersers that can recolonize peripheral habitats where less productive satellite populations have undergone local extinctions; or, core populations may 'rescue' from extinction satellite populations whose abundance has been severely reduced. Thus, core populations can buffer metapopulations against environmental change and contribute to resiliency of regional fish production. Certain riparian plant species also appear to exist in metapopulations with cores on alluvial floodplains. Therefore, we propose that alluvial reaches should... be foci for large river conservation and restoration."
- *Riparian zones:* Naiman and Décamps (1997) write that, "as corridors within catchments, riparian zones have a unique longitudinal pattern that exerts substantial controls on the movements of water, nutrients, sediments, and species." Riparian zones exert controls on the mass movement of materials and consequently on channel morphology, on wood input to streams, and on microclimate. In some regions, riparian vegetation provides an estimated 99% of the instream nutrients in the aquatic food web (Doppelt et al. 1993). Riparian zones serve as nutrient filters and ecological corridors, provide refuges for regional diversity during dry periods, and provide diverse habitats for terrestrial and aquatic species. Wetlands associated with riparian zones provide many of the same functions. Within the terrestrial portion of a catchment, the riparian zone is likely to have the strongest influence on the river ecosystem's functioning, and as such is a prime focal habitat (Schlosser 1991; Doppelt et al. 1993).
- *Headwaters:* Doppelt et al. (1993) write that small headwater streams "are the most vulnerable to human disturbance (especially timber harvesting, road building, grazing, and related activities) because they respond dramatically and rapidly to disturbances to their riparian areas and are most sensitive to changes in riparian vegetation in the surrounding watershed. Even where inaccessible to fish, these small streams provide high levels of water quality and quantity, sediment control, nutrients, and woody debris for downstream reaches of the watershed. Intermittent and ephemeral headwater streams are, therefore, important contributors to the riverine-riparian ecosystem. Thus, especially in the highly degraded systems, headwater streams serve as critical ecological anchors for riverine systems and important refuges for biodiversity." Headwaters are also the destinations of spawning fish, many of which exhibit strong site fidelity, and they may harbor populations of localized species of aquatic insects and amphibians (Samways 1994).

Lakes

Ecoregions defined by lakes, particularly large lakes with little or no external drainage, may require a somewhat different approach to identifying priority areas. While hotspots of biodiversity may exist within such lakes, protection of these areas without considering their catchments may be virtually impossible. As with lotic systems, catchment activities such as logging, agriculture, industry, and human settlement pose threats to lakes, primarily in the form of pollution (including nutrients, sediments, heavy metals, agricultural chemicals, and other toxins, as well as acid deposition). Overexploitation of fisheries is also a serious threat, perhaps on average more than in river systems. Introduced species tend to play one of the largest roles in the decline of native lake species and, once established, they are virtually impossible to eliminate. For lakes, then, we recommend considering the following areas as important for protection and/or restoration:

- Steep areas (preferably entire tributary catchments) draining to the lake, where forestry or agriculture would lead to high rates of sedimentation. Where these areas have already been converted,

[20] "Stream channel form is generally categorized as being either alluvium or bedrock. Bedrock channels are predominantly controlled by geology; alluvial channels by streamflow. In bedrock channels, streamflow is confined by rock outcrops, and changes in channel morphology generally occur slowly over a long time period. In comparison, alluvial channels are characterized by channel beds and banks composed of materials transported by the river under current flow conditions. Alluvial channels are therefore free to adjust their gradient, dimensions, and shape." Taken from: Briggs (1996).

consider reforestation or implementation of more sustainable agriculture practices.

- Near-shore areas known to be important nursery or feeding areas. Underwater sanctuaries could be established there.
- Riparian areas around the lake and along rivers draining to it.
- Lacustrine wetlands, particularly those known to provide important ecosystem services.
- Rivers draining to the lake that are known to provide important habitat for lake species, particularly endemics; these rivers could serve as potential refugia if protected.

Wetlands

Where they occur, wetlands help to maintain water flow regimes (Mitsch and Gosselink 1986). Riverine wetlands in particular are important for downstream flood mitigation, because they intercept storm runoff and store storm waters. Ogawa and Male (1983) have found that the flood-reducing capacity of wetlands increases with (1) an increase in wetland area, (2) the distance the wetland is downstream, (3) the size of the flood, (4) the closeness to the upstream wetland, and (5) the lack of other upstream storage areas such as reservoirs (Mitsch and Gosselink 1986). Wetlands are also important for groundwater recharge and for removing organic and inorganic nutrients and toxic materials from water flowing across them (Mitsch and Gosselink 1986). Additionally, they provide habitat for many aquatic and non-aquatic species, including critical breeding habitat for waterbirds, amphibians, and aquatic insects. While waterbirds tend to be more wide-ranging, amphibian and aquatic insect species may be restricted to particular wetlands or wetland complexes (Samways 1994). All of these functions are impaired when wetlands are lost, which argues for maximizing their protection. Hydrological requirements for maintaining wetlands can also help set the limits of acceptable change and consequently benefit a range of biota.

The strategy for identifying the most important wetlands may, however, depend on the target. If wetlands serve critical hydrologic or other physical functions, protecting the largest wetlands may be the best approach. But protecting small, scattered wetlands may be a more appropriate strategy if the wetlands provide key habitats for certain species. Some waterbird experts argue that protection of wetland complexes may be more important for certain highly mobile bird species than the protection of a single large wetland (Haig et al. 1998). And for aquatic-breeding amphibians, research suggests that small, scattered wetlands may be equally critical (Semlitsch 2000; see Box 4.3 at the end of this chapter). Semlitsch and Bodie (1998) provide evidence that the majority of natural wetlands are small and tend to have high amphibian species richness. The authors state that the loss of these wetlands will "cause a direct reduction in the connectance among remaining species populations" because individuals will be unable to traverse the increased distance between wetlands. In fact, they argue that large wetlands tend to be more permanent and therefore more likely to support predatory fish and invertebrates, which exclude amphibian larvae (Semlitsch and Bodie 1998). For semi-aquatic organisms such as amphibians that depend on terrestrial environments as well as aquatic ones, protection of habitat surrounding the wetlands will be equally important (Semlitsch 1998).[21]

Protecting and/or restoring key processes

Perhaps the way in which freshwater ecoregion conservation departs most from terrestrial ecoregion conservation is through its focus on protecting and restoring physical processes. Physical processes are those that structure habitats, and for freshwater systems these are largely related to the movement and storage of water and the materials that water transports. For terrestrial ecoregions a guiding principle for developing a biodiversity vision is to focus on patterns of beta diversity and large landscapes. This advice will also work well for many freshwater ecoregions, but it may not be the best guiding principle for freshwater ecoregions in general. Instead, we offer the following principle: *Conserving flow patterns, water levels, and water quality will go far to protecting freshwater biodiversity.* This principle focuses less on *what* to protect and more on *how* to protect it. That is, getting flow patterns and water quality "right" will assist many biodiversity conservation objectives.

It is clear that biotic processes (e.g., competition, predation) also affect the structure of communities, particularly in more stable, isolated, or small habitats. In some cases a biota-focused strategy may be most appropriate, such as where exotic species are replac-

[21] Semlitsch (1998) summarized data from the literature on terrestrial habitat use by one group of pond-breeding salamanders and calculated that a buffer zone extending 164.3 m from a wetland's edge would encompass the habitat used by 95% of individuals in the populations studied.

ing natives (Johnson et al. 1995). Even in these situations it is often habitat modification (normally homogenization) that has allowed the success of exotics, so a conservation strategy would need to focus to some extent on habitat restoration, and this in turn requires considering physical processes.

In the case of rivers whose flows have been altered, there is a degree of consensus among scientists that rivers "can do most of the work" of habitat restoration with the reestablishment of a more natural hydrologic regime (Stanford et al. 1996). For rivers where impoundments have seriously altered the flow regime, restoration of more natural flows may be possible through changing the duration and timing of flow releases to mimic the natural hydrograph (termed *re-regulation* or *re-operation*). This, coupled with the installation of well-designed fish passage structures, appears to be the most likely solution for impoundments whose removal is not a possibility (Stanford et al. 1996) (see Chapter 14; Box 14.1). Pilot studies are being conducted to test if ecological connectivity, habitat complexity, and biodiversity are in fact restored when water releases are modified to produce more natural river flows.

Preventing the construction of impoundments will be essential to protecting the physical processes of rivers that remain free flowing. More insidious changes to river channels and the catchment can be just as disruptive to natural processes, however, and these may pose even greater conservation challenges. For example, regarding the Amazonian várzea (whitewater flooded forests), Henderson and Robertson (1999) write:

> In terms of fish species diversity, probably the most damaging changes man undertakes within floodplains is the simplification of the structural complexity. This may take many forms, from the dredging of strength-sided canals to land reclamation to the removal of fallen trees that obstruct boat movements. Successful conservation may require a much-improved knowledge of the types and amounts of change that are acceptable. However, it seems clear that conservation will require the maintenance of three things: (1) structural complexity over a wide range of spatial scales, (2) spatial dynamics (i.e., lakes and channels must be created and destroyed), and (3) connectivity between headwater, ria lake, main stream, and várzea lake. This will require the establishment of conservation plans covering areas of forest greater than those thus far achieved.

The authors' approach provides a good example for ecoregion conservation:

- First, identify the biodiversity features of interest (fish species diversity).
- Second, identify the conditions required to maintain these features (structural habitat complexity within floodplains, and connectivity between habitats).
- Third, identify any processes that are critical to maintaining these conditions (the creation and destruction of habitats as a result of flooding).
- Fourth, identify threats to the maintenance of those processes (floodplain simplification).
- Finally, identify actions required to prevent or mitigate the threats (protection of large expanses of floodplain forests from alteration).

A biodiversity vision might go one step further, identifying which floodplain forests should be targeted for protection. This identification could be accomplished by selecting those areas with the largest expanses of intact floodplain, those with the lowest threat of encroachment by logging or other industry, those fringing waters known to harbor high numbers of fish species, or all of the above.

To repeat from Chapter 3, working with hydrologists or biohydrologists will be essential to understanding how to define, measure, and conserve the physical processes that operate to maintain biodiversity in your ecoregion. These topics are too complex and location-specific to summarize here, and we lack strong examples from past freshwater ecoregional projects to share. This will be an important frontier as ecoregional planning for freshwater biodiversity evolves.

Resilience, refugia, and connectivity

Resilience refers to the speed at which a habitat, population, or community is able to return to equilibrium following a perturbation (Pimm 1986). Resilience enables biota to persist in the face of stochastic (random) events and adapt to habitat changes associated with those events (Ebersole et al. 1997). Freshwater biologists have been particularly interested in issues of resilience because freshwater habitats, and especially headwater streams, tend to face high frequencies of natural disturbances (e.g., floods, droughts, landslides) (Grossman et al. 1995). Given these disturbances, how have freshwater biota persisted over time?

Studies suggest that a key element in the persistence of freshwater biota, at least for riverine systems, is the presence of *refugia*. Refugia are defined as "habitats or environmental factors that convey spatial and temporal resistance and/or resilience to biotic communities impacted by biophysical disturbances" (Sedell et al. 1990). Ebersole et al. (1997) explain that "the occurrence of habitat patches of sufficient quality and connectivity may allow populations to successfully reproduce and persist within an otherwise hostile matrix." Refugia are particularly important for today's freshwater systems, since in many ecoregions human activity has created a matrix dominated by disturbed habitats.

Refugia, then, appear to be critical for the persistence of metapopulations. Studies of the recovery of riverine populations following disturbance strongly suggest that many aquatic species have maintained their historical distributions through the process of recolonization following local extinction (Frissell 1997) (see Box 4.4 at the end of this chapter). Human activities not only create disturbances (and local population extinctions), but also serve to destroy both refugia and connections among habitats that would otherwise permit recolonization (Rieman and McIntyre 1993; Frissell and Bayles 1996; Frissell 1997).

At the level of the individual organism, refugia can also be critically important. Habitats may serve as temporal refugia from floods, droughts, temperature extremes, or other natural conditions. These habitats can range from large floodplain lakes to tiny crevices; for example, in a drying pool of a stream in western Ecuador, 192 animals comprising 8 families, 12 genera, and 13 species were recovered from a single subterranean burrow of a catfish (Power et al. 1988). Although it may be difficult to protect such refuge habitats in a large-scale plan, it is important to understand what those habitats are and how individuals reach them. For example, the normal life cycle of stream fish often incorporate movements to and from a variety of habitats, and connections among those habitats are critical (Figure 4.1).

Lake ecosystems function in distinct ways from lotic systems, which translates into somewhat different resilience mechanisms. Nutrient inputs are one of the primary disturbances to lakes, but resilient systems contain natural buffers to such inputs. Carpenter and Cottingham (1997) describe how lakes with functional food webs are able to assimilate low to moderate nutrient inputs, but how high inputs can disrupt normal resilience mechanisms by setting off a chain reac-

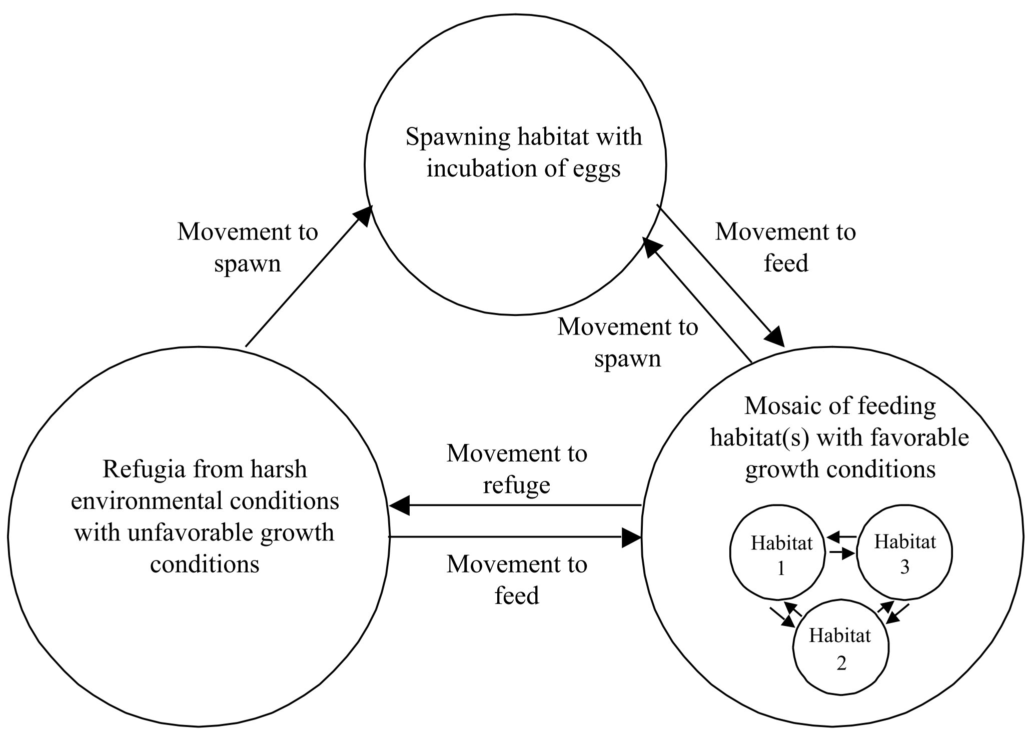

Figure 4.1. Basic life cycle of stream fish, with emphasis on patterns of habitat use and movement. (Modified from: Schlosser and Angermeier 1995.)

tion that leads to eutrophication (see Box 4.5 at the end of this chapter).

The process by which intact freshwater systems bounce back from natural disturbances is poorly understood because so few intact systems remain (Sedell et al. 1990). Still, understanding some of the basic theory behind resilience and refugia may help when designing a conservation plan. Expert opinion will be required for estimating the minimum conditions needed to confer resilience. It is important to set "goalposts," even if they are inexact, so that the vision does more than simply identify isolated hotspots that cannot be sustained over the long term.

Strategies for the identification of important areas for biodiversity

Conservation planning with the explicit goal of protecting freshwater biodiversity is a relatively new idea. A small number of freshwater biologists have been working over the past 15 years or so to synthesize relevant principles from freshwater ecology, biology, hydrology, and landscape planning into strategies for freshwater conservation planning at large scales. The work of Frissell et al. (1993) is one example that has focused on the restoration of degraded habitats in streams of western North America (see Box 4.2 at the end of this chapter). This strategy recognizes the contributions of different habitat types, both in terms of supporting species and maintaining physical processes.

Here we note two additional strategies, also developed primarily for western North America. One, that of Moyle and Yoshiyama (1994) and Moyle and Sato (1991), defines essential characteristics for the identification of "Aquatic Diversity Management Areas" (ADMAs), which are intermediate targets in the protection of entire catchments. The selection process for ADMAs incorporates virtually all of the key conservation principles covered in this sourcebook: representation; focal species and habitats; habitat connectivity; minimum requirements; protection of physical processes; and conservation of entire catchments (see Box 4.6 for details). The ADMA strategy is important to ecoregion conservation for two reasons. First, it attempts to set minimum targets in terms of size and number of protected areas, despite having a dearth of information on physical and biological dynamics. Second, the strategy is ambitious in its recognition that protection of entire catchments is an essential long-term goal, but in the immediate term it focuses on protection of smaller ADMAs.

The second strategy, developed by the Oregon Chapter of the American Fisheries Society, identifies key catchments termed "Aquatic Diversity Areas" (ADAs) (Li et al. 1995). The ADA strategy is built on similar principles as the ADMA approach, but it is focused more strictly on fish species and is more concerned with evolutionarily distinct biodiversity units.[22] The strategy is based on the assumption that "preserving representative watershed basins [subcatchments] in every ecoregion and in each zoogeographic province might preserve the evolutionary capacity of the fauna"(Li et al. 1995). As with the ADMA strategy, this one targets catchments with the highest ecological integrity, hoping that these could serve as "seed sources" for natural gene flow and for recolonization of disturbed catchments (see Box 4.6 for details). This strategy is particularly relevant to ecoregion conservation because it underscores the importance of zoogeographic units in conservation planning. Preserving representative subcatchments within a given zoogeographic unit (ecoregion) should lead to the protection of distinct faunas and their evolutionary capacity.

Conclusion

We have offered this discussion of ecological, biological, and physical processes and approaches to conserving them because it is important to have some basic principles in mind before designing a biological assessment. To summarize, conducting a biological assessment for freshwater systems is not necessarily as simple as drawing polygons around sites that are known for their high species richness or endemism. Identifying areas that support exceptional levels of biodiversity is certainly important, but in many cases the data required for that identification are lacking. Most of the approaches that we have drawn from the literature put more emphasis on identifying important *types* of habitats than on particular places, and we believe that this approach has merit, particularly when distribution data are poor. The approach that you develop, however, will most likely be unique to your ecoregion.

[22] This is a variation of the term evolutionarily significant unit, defined in the U.S. as a population that 1) is substantially reproductively isolated from other conspecific population units, and 2) represents an important component in the evolutionary legacy of the species.

Box 4.1. Lake biodiversity.

Lake conservation is based on many of the same principles as river conservation because most lakes are connected to river systems, and even isolated water bodies are connected to the surrounding landscape (Noss and Cooperidder 1994). On the other hand, certain biotic features distinguish lakes from other freshwater systems, and these differences will affect conservation planning for ecoregions containing natural lakes.

The majority of lakes lack endemic species because most lakes are relatively young topographic features. All lakes undergo the process of "terrestrialization," whereby they fill in with sediments and eventually become land. The largest, most ancient lakes, such as lakes Baikal, Biwa, and Ohrid in the temperate zone, and the East African rift lakes in the tropics, are also filling in, but this process may take hundreds of thousands of years. The life spans of these ancient lakes have stretched over evolutionary time, and therefore they tend to harbor endemic species in many taxonomic groups. Smaller lakes, and lakes occurring in recently glaciated landscapes (e.g., the northern portion of the temperate zone, glaciated as recently as 10-15,000 years ago), are less likely to contain endemics. When they do, however, it is highly unusual and they will be prime candidates to be chosen as priority areas.

Whether or not they contain endemics, lakes are distinct habitat types that should be represented in conservation plans for those ecoregions where they occur naturally. Because lakes gradually fill in, preserving individual lakes in a given state (e.g., preventing the natural transition from oligotrophy to eutrophy) may not be a suitable goal. Instead, protecting the conditions that allow for the existence of a mosaic of lakes in different successional stages may be appropriate. This would include maintaining the hydrological processes necessary for the creation of new lakes.

Lakes are islands in a sea of land. The numbers and kinds of species found in a given lake are a function of species' dispersal abilities, the size and age of the lake, the proximity of the lake to others, and the lake's habitat type(s) (Reynolds 1989). There is evidence that some lake-inhabiting species are less limited by dispersal ability than by their association with a particular habitat type (Reynolds 1989). This association argues for characterizing lake habitat types to the best extent possible in a biological assessment and ensuring that different habitats are well represented in an ecoregion conservation plan.

Lakes suffer from the same categories of threats as other freshwater habitats, but to a greater degree for particular threats. Because lakes are semi- or entirely closed systems, foreign materials are flushed out more slowly than in lotic systems. Nutrients such as nitrogen and phosphorus, derived most often from agriculture, grazing, and human settlements, can lead to anthropogenic eutrophication of lake systems when the nutrients were naturally limiting. Lowland lakes are particularly susceptible to nutrients in runoff, and highland lakes are vulnerable to atmospheric inputs of nitrogen and sulfur. Pesticides and other toxic chemicals entering lakes can become assimilated into the bodies of freshwater organisms and biomagnified up the food chain, or they can be trapped in sediments and resuspended in the future. Exotic species introduced into lakes, either accidentally or intentionally, can wreak havoc on natives, which have no real refuge in many lake habitats. Overfishing can also decimate populations when there is not continual recruitment from populations outside the lake.

All lakes are susceptible to threats related to changes in the water balance, and saline lakes may be particularly at risk. According to Comín et al. (1999), "Major water inflows take place in most saline lakes via groundwater discharges. This is the reason why environmental impact on the groundwater of the catchment area is greater in saline lakes than in freshwater lakes, where major inflows are, in general, surface runoff." The authors believe that careful management of groundwater and surface water extraction in the catchments of saline lakes is the best strategy for the lakes' conservation, rather than focusing exclusively on the protection of waterbirds, as is usually the case. Additionally, a strong correlation between climatic fluctuations and water levels suggests that climate change may pose a particularly serious threat to saline lakes in the future.

The degree to which lakes are susceptible to certain threats, and the best approaches for lake conservation within the context of ecoregion conservation, depend on the particular ecoregion, the types of lakes, and the species inhabiting them. Large, ancient lakes with endemics differ from small, ephemeral lakes supporting populations of widespread species. In Lake Tanganyika, for example, there has been some success in implementing no-fishing underwater reserves in critical spawning locations. In an ecoregion characterized by a series of small lakes rather than a single large one, designating entire lakes as no-take zones, while allowing fishing in others, might be an option. The way in which species are distributed within and among lakes, and the way in which lake habitats are formed and maintained, should drive the recommendations of the biodiversity vision.

Box 4.2. Identifying priority areas within a restoration framework.

Biologists approach conservation planning from many angles. Where freshwater habitats are largely degraded, restoration will be an important conservation tool. One approach for restoration is to focus first on securing biologically important areas that remain intact, and then to restore adjacent, more degraded habitats. Frissell et al. (1993) and Frissell (1997) propose constructing a multi-pronged restoration strategy around habitat types that have inherently different natural diversity and that also differ in the urgency of intervention required. The goal is "to secure and maximize opportunities for near-term recovery of natural populations and processes, while simultaneously building toward their long-term recovery as self-sustaining systems" (Frissell et al. 1993). This framework combines biological importance and ecological integrity to identify priorities, just as ecoregion conservation does (we discuss biological importance and ecological integrity in Chapters 7-10).

Although the details of this strategy are particular to North American riverine systems, we offer this framework because we believe it has broad applicability to identifying priority areas in the context of ecoregion conservation. The approach considers habitats from both a biological and physical perspective, and it stresses the importance of connectivity for permitting the recolonization of disturbed habitats. Five types of habitat are identified. The first two, "focal habitats" and "nodal habitats," are considered the most immediate targets for protection because they remain the most intact and contain important biodiversity elements. The last type, "grubstake habitats," are low-elevation, heavily disturbed habitats whose restoration would require extensive planning, experimental work, and high investment, but whose recovery would yield large benefits for biodiversity. The table that follows is adapted from Frissell et al. (1993) and Frissell (1997).

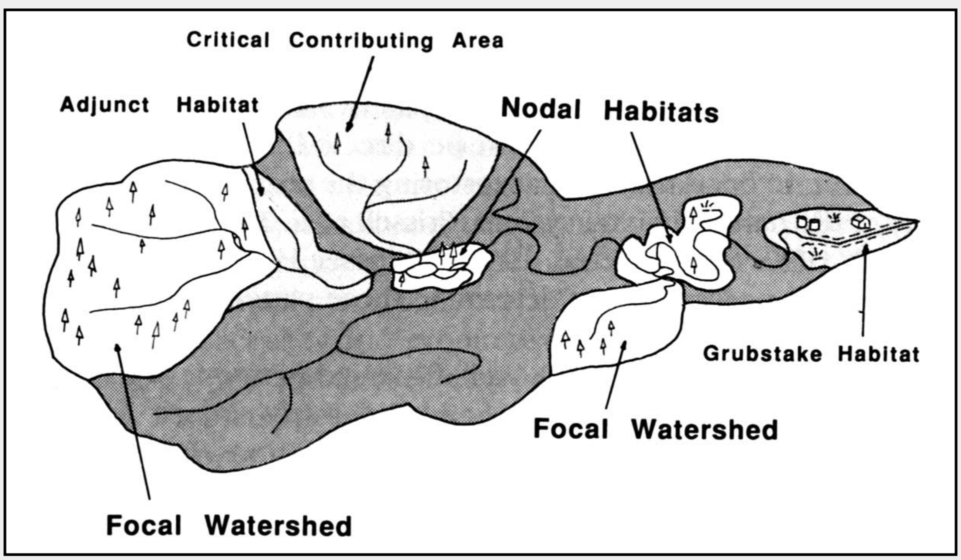

Figure 4.2. Conceptual diagram depicting functional habitat types in a restoration strategy. (Taken from: Frissell 1997. Reproduced with permission by the American Fisheries Society.)

Box 4.2 continued

Habitat Type	*Examples*	*Biodiversity Importance*	*Connectivity (for recolonization)*	*Biotic Objectives*	*Restoration Tactics*
Nodal	Forested alluvial valley flats; floodplain ponds; woody debris complexes; groundwater-fed deltas; coastal estuaries	Serve critical life history functions for individual organisms originating from populations in refuge habitats throughout the basin. Especially important for migratory and low-elevation taxa.	High connectivity; accessible to organisms moving upstream or downstream	Maintain integrity and existing connections to focal habitats	Secure basin and riparian corridors; maintain depth and tidal flow
Adjunct	Degraded reaches directly downstream of focal watershed or adjacent to nodal segment	Restoration can improve the productivity and viability of existing populations centered in focal or nodal habitats	Adjacent to focal or nodal habitat so appropriately adapted colonists close at hand	Restore integrity so adjacent populations can colonize effectively	Restore riparian and floodplain processes once headwaters secured
Critical contributing areas	Tributary basins contributing high-quality water downstream; wetland complexes or alluvial aquifers maintaining water quality and habitat integrity	Do not contain habitat for important biodiversity features, but are important sources of high-quality water and stable watershed conditions for downstream focal or nodal habitats	Not directly applicable	Not directly applicable	Secure intact areas and restore unstable "time bombs"
Grubstake	Diked estuarine marshes; drained floodplain-wetland complexes; heavily disturbed mainstem habitats of lowland rivers	Historically most richly productive habitats for anadromous fish and many other organisms, and they remain the largest single reservoir for potential increase in populations of some species of special concern (e.g., salmon)	If restored, can be highly connected to stream system and could be accessible to organisms from other parts of the basin	Remove artificial barriers to colonization; reduce non-natives; allow time for colonization	Reconnect to river channel; restore hydrologic regime and vegetation; alleviate offending land uses

Box 4.3. Management for aquatic-breeding amphibians. (Excerpted from: Semlitsch 2000. ©The Wildlife Society. Reproduced with permission.)

Local population dynamics

The majority of amphibian species use aquatic habitats for some portion of their life cycle. Species with a complex life cycle (i.e., having both larval and adult stages) use aquatic habitats, such as bogs, vernal pools, temporary ponds, and even streams for mating, oviposition, and larval growth. It is important to understand that such aquatic habitats are dynamic, often filling and drying on an annual basis, and that amphibians are specifically adapted to such processes.

Most pond-breeding amphibians live in the surrounding terrestrial habitat (usually within 200 m; Madison 1997; Semlitsch 1998) during the non-breeding season. Breeding adults typically migrate to the aquatic habitat during favorable weather conditions for mating and oviposition, and adults subsequently return to terrestrial habitats (Semlitsch and Ryan 1999).... Aquatic larvae feed, grow, and develop in the pond until metamorphosis, after which they immigrate as juveniles to terrestrial habitats....

Community dynamics in relation to pond hydroperiod

Spatial and temporal variation in the physio-chemical and hydrological characteristics of ponds due to climatic conditions, habitat succession, and anthropogenic disturbance usually produce a mosaic of habitats available to amphibians (Semlitsch et al. 1996; Skelly et al. 1999; Werner and Glennemeier 1999). Pond hydroperiods vary tremendously, even in undisturbed regions (Schalles et al. 1989).... An effective management plan must maintain or restore an array of natural ponds that vary in hydroperiod from perhaps 30 days to 1-2 years to insure that all local species have sites where the probability of reproductive success is high, even in extremely dry or wet years.

Metapopulation dynamics

Alteration and loss of wetlands reduces the total number or density of ponds where amphibians can reproduce and successfully recruit juveniles into the breeding population. Ultimately, a reduction in the number of wetlands reduces the total number of individual amphibians available to found new populations or colonize habitats where populations have become extinct. Because small seasonal pools and temporary ponds (<4.0 ha) are the most numerous type of wetlands in many natural landscapes (Gibbs 1993; Semlitsch and Bodie 1998), their loss especially reduces the number of source populations. Such small, temporary wetlands are often used by more species and produce more metamorphs for recruitment than either ephemeral pools or permanent ponds (Pechmann et al. 1989; Semlitsch et al. 1996)....

Reduced pond density increases the distance between neighboring ponds, thereby affecting critical source-sink processes (Brown and Kodric-Brown 1977; Gill 1978; Pulliam 1988; Gibbs 1993; Semlitsch and Bodie 1998). Wetland loss causes an exponential increase in inter-pond distance or isolation (Gibbs 1993, Semlitsch and Bodie 1998). Inter-pond distances directly affect the probability of recolonization, and consequently, the chance of rescuing amphibian populations from extinction (Sjogren 1991; Skelly et al. 1999). This is critical because most individual amphibians cannot migrate long distances due to physiological limitations, and adults return to home ponds, usually after migrating no more than 200-300 m (Semlitsch 1998)....

Finally, because the maintenance of terrestrial habitat between ponds may be critical for successful survival and dispersal (an issue of much debate; Saunders and Hobbs 1991), it is likely necessary to provide migration corridors or buffer zones of natural vegetation between adjacent ponds (Semlitsch 1998)....Thus, management plans that maintain continuous natural habitat (forested or grasslands depending on the region) adjacent to ponds or between neighboring ponds would help maintain source-sink dynamics of amphibians.

Critical elements of effective and biologically based management plans:

- Maintenance or restoration of temporary wetlands with a diverse array of hydroperiods
- Protection of terrestrial buffer zones of natural vegetation and associated habitats to protect core breeding sites (wetlands and streams)
- Protection of amphibian communities from invasion by fish predators (native and exotic)
- Protection of the integrity of ecological connectivity (i.e., stepping stone ponds with corridors of natural vegetation) among wetlands in the landscape
- Restriction of chemical use (salt, oil, fire retardants, vegetation growth retardants, herbicides, pesticides) on site, but especially near ditches, streams, or wetlands
- Prohibition of release of any captive-raised or maintained amphibians, native or exotic

Box 4.4. Role of refugia in river systems. (Excerpted from: Sedell et al. 1990. © Springer-Verlag. Reproduced with permission by Springer-Verlag and the author. Explanations of technical terms given in brackets.)

Rivers must be viewed from four dimensions: (1) longitudinally from upstream reaches to downstream segments; (2) transversely away from the river channel through the floodplain to the valley walls; (3) vertically through interstices in the river bottom and into adjacent groundwater systems, especially in porous, gravel-bottom rivers; and, (4) temporally, such as seasonal, annual, and long-term (Ward 1989)... (see Figure 4.3)

Upstream-downstream linkages are important in streams, whether viewed as gradients or zones. For example, thermal loading [heating of water], nutrient transport, and toxic dispersion are all strongly longitudinal. The quality and quantity of detritus in a given reach of stream is influenced by the allochthonous inputs [materials coming from outside the channel, such as leaves and twigs], primary production, organizational processing [breakdown of materials by organisms], and retention characteristics of upstream areas. In this sense the upstream-downstream linkage is a type of refugium in that disturbed areas downstream may be rehabilitated by the simple process of materials being transported downstream into the disturbed zone. Pristine tributaries or side-flows from groundwater sources may function similarly.

The lateral dimension includes the form and dynamics of the channel itself, interactions between the channel and riparian vegetation, and the associated floodplain systems. Complex channel patterns provide numerous and important refugia for plants, invertebrates, fish, birds, and mammals (Welcomme 1979). Side arms provide thermal refugia. Backwater and side channels are often important nursery and spawning areas and provide corridors to floodplain refugia (Bouvert et al. 1985). Studies conducted on small streams have demonstrated that vigorous and diverse riparian vegetation is required to maintain the integrity of land-water interactions (Karr and Schlosser 1978; Cummins et al. 1984).

As streams go through the annual hydrologic cycle, there is an expansion and contraction of wetted area as well as periodic incorporation of active floodplains. Large floods and other high-magnitude, low-frequency events (e.g., volcanic eruptions) have shaped rivers and floodplains and created a vast array of side channels, oxbow lakes, side arms, and floodplain terrace streams that are connected to the main channel at different flow regimes. The greatest diversity and aerial extent of riverine refugia occur where there is a maximum interaction between floodplain and aquatic systems. In the great floodplain rivers of the world, the lateral interactions are highly developed in reaches that have predictable annual flooding and extensive floodplains (Welcomme 1979)...

The major vertical dimension is the contiguous groundwater level and a lateral hypogean [below-surface] component present on many streams and rivers (Stanford and Ward 1988). Alluvial aquifers are important in terms of the vegetation that can grow on the floodplain and the hydrologic connectedness of fluvial features in the floodplain (Amoros et al. 1987)....

Recovery of aquatic biota from large-scale natural disturbance at the basin scale is dependent, at least in part, on the presence and juxtaposition of unimpacted reaches of stream. In the longitudinal dimension, streamside forests cannot directly impact flooding and water quality upstream of their occurrence, and their influence will diminish gradually in a downstream direction. Thus, streamside forests and wetlands in the lower reaches of river ecosystems or directly upstream of critical habitat are more advantageous than similar size riparian forest or wetland elsewhere in the watershed.

In the transverse dimension, riparian forests adjacent to the riverbank or in areas of high probability of flooding will have the greatest impact on habitat structural diversity, water quality, and flooding, with a diminishing marginal return as the width of the forested corridor is increased beyond some measurable distance. Thus the placement of streamside forests is often dictated by areas humans want to maintain for critical habitats, recreation, or water-quality and sediment modification.

From a fish distribution and conservation view point, the geometry and geomorphology of rivers further complicates maintaining adequate refugia (Moyle et al. 1982; Sheldon 1988). Rivers are open, directional systems, so protection of any segment requires control over the entire upstream network and surrounding landscape. There is little likelihood that such protection can be given to very many large streams, yet it is these streams that support the greatest diversity of fishes. It is hoped that strategically placed riparian controls and prevention of agricultural and industrial pollution, channelization, and impoundments may be sufficient to maintain diverse fish assemblages and maintain a diverse connected mosaic of habitats within a basin. Thus a whole-basin perspective is necessary for identifying, conserving, or restoring refugia within a basin.

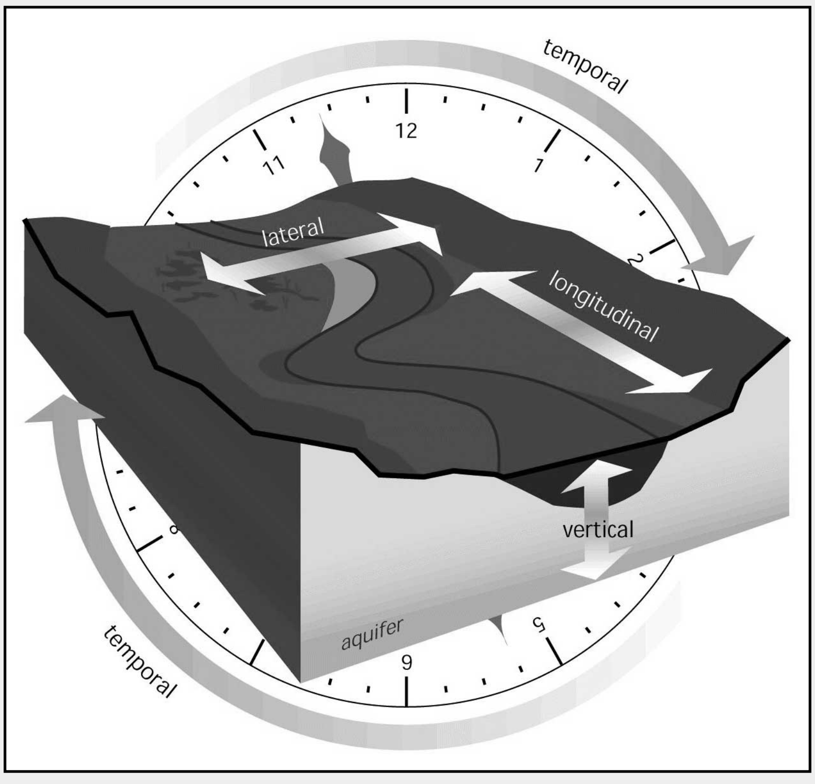

Figure 4.3. The four dimensions of the stream corridor. (Taken from: The Federal Interagency Stream Restoration Working Group 1998. Reproduced with permission.)

Box 4.5. Resilience mechanisms in lakes. (Taken from: Carpenter and Cottingham 1997. Reproduced with permission.)

In the normal dynamics of lakes, ecosystem processes are maintained despite moderate and continuous disturbances originating in the lake, its watershed, and its airshed. This resilience involves several mechanisms, which have different ecosystem components and distinctive spatial locations, spatial extents, and return times.

Riparian forests and grasslands delay or prevent nutrient transport from uplands to streams and lakes (Osborne and Kovacic 1993). Riparian forests are a source of fallen trees that can provide important fish habitat for decades (Maser and Sedell 1994; Christensen et al. 1996)....Wetlands function as vast sponges that delay the transport of water to downstream ecosystems and, thereby, reduce the risk of flooding (National Research Council 1992). Wetlands also modulate nutrient transport from uplands to streams and lakes (Johnston 1991). Wetlands are a major source of humic substances for lakes (Hemond 1990; Wetzel 1992)...[and] humic staining suppresses the response of phytoplankton to pulses of nutrient input (Vollenweider 1976). This resilience mechanism involves shading, effects of humics on thermal structure of lakes, and changes in lake metabolism (Carpenter and Pace 1997).

Although phosphorus inputs and recycling establish the potential productivity of lakes (Schindler 1977), predation controls the allocation of phosphorus for production of fish, algal blooms, or other components of the pelagic food web (Carpenter and Kitchell 1993). In the normal dynamics of many lakes, large piscivorous game fishes are keystone predators that structure the food web below them (Kitchell and Carpenter 1993). Such lakes have large-bodied zooplankton grazers that effectively control phytoplankton (Carpenter et al. 1991). When pulses of phosphorus enter these lakes, the nutrient is transferred effectively to higher trophic levels and does not accumulate as algal biomass (Carpenter et al. 1996; Schindler et al. 1996).

Low or moderate rates of phosphorus input promote low rates of phosphorus recycling, through effects on the oxygen content of the water. Conditions of low-to-moderate productivity constrain respiration by bacteria, so that oxygen is not depleted from deeper waters during summer (Cornett and Rigler 1979). Oxygenated conditions decrease the rate of phosphorus recycling from sediments in many lakes (Caraco 1993). If production of the overlying water increases, deep waters can be deoxygenated and phosphorus recycling can increase, thereby further increasing production. Oxygenation of bottom waters prevents this positive feedback and confers resilience in moderately productive and unproductive lakes.

Submersed macrophytes of the littoral zone provide crucial habitat for attached algae, invertebrates, and fishes (Heck and Crowder 1991; Moss 1995). They also modify inputs to lakes from riparian or upstream ecosystems, store substantial amounts of nutrients, and are a source of dissolved organic compounds (Wetzel 1992). Oxygen production by macrophytes and attached algae can decrease the rate of phosphorus release from sediments, and high denitrification rates in littoral vegetation can decrease nitrogen availability (Wetzel 1992).

Collectively, these resilience mechanisms, operating at diverse scales, buffer lake ecosystems against fluctuating inputs. They maintain water quality, fish productivity, and the reliability of other ecosystem services provided to humans....In the normal dynamics of lakes, perturbations are relatively brief in duration, but may be extensive in space. Examples are chemical or hydrologic fluctuations driven by weather, routine fluctuations of interacting populations, or fires that sweep through the watershed vegetation. Resilience mechanisms that tend to restore the normal dynamics involve longer or larger scales. Examples are food web dynamics that absorb nutrient pulses, wetlands that retain nutrients and release humic substances, or secondary succession of upland forests that stabilizes soils and retains nutrients. These resilience mechanisms can be destroyed by more extreme perturbations. Destruction of the normal resilience mechanisms is accompanied by the rise of new resilience mechanisms and qualitative changes in the ecosystem.

Box 4.6. Examples of freshwater priority setting: Aquatic Diversity Management Areas (ADMAs) and Aquatic Diversity Areas (ADAs).

The Aquatic Diversity Management Area (ADMA) and Aquatic Diversity Area (ADA) are strategies for choosing priority freshwater areas and constructing a conservation strategy around them. They have both been developed for the Pacific Northwest, USA, but the principles underlying the approaches have broad applicability, even for larger areas with lower-quality species data.

The ADMA strategy has both short- and long-term goals. The long-term goal is the protection of "representative watersheds (catchments) more than 50 km^2 (20 mi^2) in area that are still dominated by native organisms and natural processes or that have high potential to be restored to such a condition. The management goal for these watersheds is to ensure that natural processes are allowed to continue with minimal human interference" (Moyle and Yoshiyama 1994). Catchments selected for protection would need to contain a minimum amount of high-quality water and fish habitat — at least 6 mi^2 (about 16 km^2) for a catchment in the Pacific Northwest, based on the requirements of focal anadromous fish species (Johnson et al. 1991; Moyle and Yoshiyama 1994).

The strategy's short-term, intermediate goal is the establishment of ADMAs. Moyle and Yoshiyama expect that most of these would be small (<50 km^2) areas rather than large catchments. The following six rules, taken directly from Moyle and Yoshiyama (1994),[23] do an excellent job of summarizing many of the principles that might drive the identification of priority areas in a biological assessment. Note that the rules integrate biological importance and ecological integrity (we discuss ecological integrity in Chapter 8). We have italicized certain passages for emphasis.

1) **An ADMA must contain the resources and habitats necessary for the persistence of the species and communities it is designed to protect.** This criterion assumes all life history stages of all organisms (not just fish) are known, a degree of knowledge that is simply not available. Therefore, *design of an ADMA should be based on the largest and most mobile species on the assumption that their habitat needs will also encompass those of lesser known species*. This means ADMAs will largely be based on the needs of fish, amphibians, and macroinvertebrates, including migratory species present for only part of their life cycles, and on the needs of conspicuous riparian organisms (trees, birds, mammals).
2) **An ADMA must be large enough to contain the range and variability of environmental conditions necessary to maintain natural species diversity.** An ADMA that is too small will ultimately fail in its purpose even if all the correct environmental conditions are present. Small ADMAs are extremely vulnerable to natural and human-created disasters, but *the actual size of an ADMA will depend on the biota being protected*. A spring biota may require only a few hundred square meters, whereas a riverine biota may require several thousand square kilometers, encompassing much of a drainage. *ADMAs should also have their water sources protected, including aquifers, stream headwaters, or lake tributaries*. Streams and their associated riparian corridors are particularly difficult to include in ADMAs because of their unidirectional flows, dendritic drainages, and variable nature (Naiman et al. 1993). *Stream ADMAs thus need to include tiny, intermittent headwaters as well as changing conditions downstream that permit the existence of longitudinal faunal zones* (which often shift in location from year to year).
3) **ADMA integrity must be protected from edge and external threats.** Reducing edge and external threats are continual challenges to designers of natural areas. Edge threats result from the gradient of habitat quality between the ADMA interior and the unprotected regions outside. The sharper the gradient, the more likely the ADMA will suffer from habitat degradation and invasions of unwanted species....External threats do not recognize boundary lines, and they include such factors as pollutants, diseases, and introduced species. External threats pose a particularly severe problem for ADMAs because agents that affect the biota in any part of a drainage may eventually be carried by the water throughout its entirety (Moyle and Sato 1991). A particularly insidious external threat to aquatic systems is the pumping of groundwater from aquifers distant from the springs and streams that the aquifers feed....*Edge and external threats will always be problems for ADMA management and can be reduced by creating wide terrestrial buffer zones around each ADMA, protecting water sources and upstream portions of the watershed containing an ADMA, and con-*

[23] Reproduced with permission by the American Fisheries Society.

structing barriers to prevent invasions of unwanted species. Ideally, barriers should block entry of non-native species but not of native migrants....often the best barrier to invasion is a natural flow regime, because native species are generally well adapted to living under the fluctuating conditions (Baltz and Moyle 1993).

4) **An ADMA should have interior redundancy [replication] of habitats to reduce the effects of localized species extinctions due to natural processes.** This somewhat reiterates criterion 2, but the need for local redundancy [replication] cannot be overemphasized. Aquatic species frequently occur as small populations in narrow habitat types where populations come and go in relation to natural events and demographic processes. Adequate local redundancy [replication] therefore will allow recolonization to occur quickly and naturally. *For lakes and springs, this means the entire body of water will need protection. For streams, a network of two or more tributaries of each order should be included in the ADMA.*[24]
5) **Each ADMA should be paired with at least one other ADMA that contains most of the same species but is far enough distant that both are unlikely to be affected by a regional disaster.** Large disasters — volcanic eruptions, earthquakes, pesticide spills, forest fires — can fundamentally alter much of the integrity of an ADMA. Therefore, sources of species must exist for the biotic reconstruction of affected ADMAs, if necessary. *For streams, this means creating ADMAs in separate drainages with similar characteristics and biotas. For species inhabiting temporary ponds, this may mean protecting ponds at widely separated localities*...Greater replication of ADMA types increases the chances for long-term survival of the native organisms. However, *some ADMAs will not be replicable if they contain highly localized endemics*...
6) **An ADMA should support populations of organisms large enough to have a low probability of extinction due to random demographic and genetic events.** Small populations of organisms can become extinct as the result of natural fluctuations. Small populations also can experience "genetic bottlenecks" that greatly reduce genetic variability and, consequently, their ability to adapt to local environmental changes. This is particularly a problem in setting up stream ADMAs, where fish and invertebrate populations may frequently be driven to low levels by extreme floods or droughts. *Under natural conditions, populations from different streams eventually mix again — something that is not possible in an isolated ADMA unless enough of a drainage is included to permit natural recolonization events* (Zwick 1992).

The ADA strategy of the American Fisheries Society Oregon Chapter is built on similar principles as the ADMA approach, but it is focused more strictly on fish species and is more concerned with evolutionarily distinct biodiversity units. The criteria for choosing potential refuges or preserves are:

1. Supports a listed species or population sensitive to disturbance
2. Supports an endemic fish
3. Supports a rich, indigenous ichthyofauna, ideally without exotic fishes
4. Serves a critical ecological function such as providing a dispersal corridor, conveying spawning gravels, or supplying high-quality water
5. Associated with a long-term data set

The Chapter developed the ADA strategy with the goal of identifying potential refuges as quickly as possible, despite data gaps. The method for identifying areas resembled the approach used in many ecoregional assessments. The Chapter sent maps of ecoregions and watersheds, questionnaires, and sets of criteria to various biologists who were familiar with fishes and watershed conditions of ecoregions and zoogeographical provinces. The experts were asked to identify watersheds meeting the criteria listed above, and to fill out the questionnaires to explain their choices. Outside reviewers then examined the choices (Li et al. 1995), and the organizers conducted a representation analysis to find any omissions in habitat types. The Chapter's approach emphasizes that even in a data-rich area, one of the most efficient methods of identifying priorities is through expert assessment.

After identifying ADAs, the Chapter intended to evaluate the habitat integrity of each and identify potential habitats for rehabilitation and protection. Concurrently, the Chapter intended to identify the evolutionary relationships among fish populations in ADAs and those in unprotected areas, to ensure that metapopulations were protected.

[24] For bull trout (*Salvelinus confluentus*), Rieman and McIntyre (1993) recommend that in the absence of other information, core areas (roughly equivalent to ADMAs) should incorporate "no fewer than 5 to 10 subpopulations and conservatively many more."

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Getting Oriented

5

Introduction

In Chapter 3 we presented a suggested flowchart of steps to conduct a biological assessment and develop a biodiversity vision. In this chapter we focus on the first box of that flowchart, entitled "Getting Oriented." The 10 recommended steps are intended to help you refine your thinking and identify important information needs prior to embarking on the biological assessment. You may choose to cover these steps either before or during an orientation meeting (described below), but we recommend that you work through them by the completion of the orientation. You may find that you can go even further during the meeting, possibly identifying key experts, stakeholders, and desk study authors, and deciding upon some fundamental elements of the methodology to be used for the assessment. Look at the suggested steps in the second flowchart box, "Preparing for the assessment," for any that will require the assistance of experts to complete, then incorporate these steps into your orientation meeting agenda.

Laying the groundwork for developing a biodiversity vision

Preparing for an expert workshop or other assessment forum entails more than simply collecting data and producing maps. It requires first that the ecoregion team understands what characterizes the ecoregion biologically and what the vision will be designed to conserve. Everyone may not have the same understanding, even about such apparently straightforward matters as what defines the region of analysis. Everyone involved in preparing for the assessment, including experts contracted to write desk studies, must agree about what they are working to achieve before beginning an assessment and engaging additional experts.

Although it is theoretically possible to create a vision without the participation of regional biodiversity experts, their support and promotion of the ecoregion process and product are needed to achieve buy-in from the conservation community and governmental organizations ultimately responsible for implementation of the plan. You will want to engage key experts in the planning process as early as possible.

If you are already knowledgeable about the ecoregion and its principal biological experts, it will be relatively easy for you to begin contacting those people and discussing with them the goals of ecoregion conservation and its methodology. If you are not already familiar with the ecoregion and do not know who the experts are, you will need to identify them and initiate the process of cultivating their interest in ecoregion conservation. Once they are actively involved in the process, the assembled experts can help to identify the activities that will be necessary to prepare for a full-scale expert workshop (if necessary) and to secure the buy-in of other experts to the process.

Convening an orientation meeting

To initiate the process of developing a biodiversity vision, we recommend convening an orientation meeting. The purpose of the meeting is to:

- provide you with a quick analysis of the level of biogeographic knowledge of the ecoregion,
- identify the outstanding and distinctive biodiversity features for the ecoregion that will be the primary targets for conservation action,
- determine the most appropriate type of biological assessment for the quality and quantity of biological data available for your ecoregion, and
- serve as a mechanism for educating the participants about the concepts and procedures of ecoregion conservation.

The meeting should also strive to:

- provide recommendations for preliminary analyses and products (for example, desk studies for particular taxa) that will be used to assist the biological assessment and accelerate the ecoregion conservation process,
- identify a few overarching threats or pressures that need to be addressed immediately to create an entry point for targeted socioeconomic and political responses, and

- identify a few important conservation targets (areas or activities) where there is consensus on the need for immediate action.

Particularly in ecoregions where WWF has been active for a while, the orientation meeting can comprise a large part of the reconnaissance.[25] By identifying overarching threats at the orientation meeting, the linkages between the biological and socioeconomic analyses begin to be elucidated. If socioeconomic information and perspectives are introduced into the process at the outset, social scientists can begin collecting relevant data and conducting analyses based on identified conservation targets. If, by consensus, the meeting participants identify a few obvious conservation targets, then they create a small portfolio of activities to pursue immediately.

We suggest that the orientation meeting participants include 5 to 10 biologists (depending on the size and complexity of the ecoregion) who together offer a broad, if not encyclopedic, knowledge of the biodiversity of the ecoregion. Critical to freshwater ecoregions is the inclusion of several additional people who understand the hydrologic processes that operate in the ecoregion; individuals who understand how these processes maintain biodiversity features are particularly valuable participants. There should also be a few key sociologists, economists, and political scientists knowledgeable about the ecoregion. If a major river basin authority exists in the ecoregion, consider including a top scientist from the authority's advisory group, if one exists (see Box 5.1).

Where relevant, consider including representatives of indigenous communities. Indigenous peoples are often the best archivists of what the ecoregion was like when wildlife populations and processes fluctuated within their natural ranges of variation. For example, during an informal visioning exercise for the Bering Sea ecoregion, a Native American spoke of a time 40 years ago. "My grandparents took me to the fall duck hunting grounds as a child. When we arrived, clouds of eider ducks erupted from the marshes, darkening the sky." Is an important element of the vision, or even part of the benchmark for the Bering Sea ecoregion, to return waterfowl populations to the sizes observed four decades ago?

Another important aspect of including a diverse group of knowledgeable participants at the orientation meeting is to answer the question, Whose vision is it? Although WWF may be spearheading the effort to develop the vision, we believe that the vision should belong to the larger conservation community working in the ecoregion. This community will be more likely to endorse the vision if it has been involved in the process and if the most respected scientists working in the region have backed the effort. However, with a variety of participants the orientation meeting can easily get off track. The meeting facilitators should guard against allowing the meeting to devolve into a discussion about management plans and instead keep it focused on the future of biodiversity conservation.

Step 1. Identify target ecoregion

The target ecoregion for the assessment may or may not correspond to an ecoregion delineated in a continental-scale assessment or in the Global 200. A number of Global 200 ecoregions are in fact ecoregion complexes — groups of related ecoregions. Some ecoregion projects have adopted an ecoregion complex as their region of analysis. This may be an efficient use of resources, particularly when the same individuals are experts for the entire area. However, it may be possible to achieve only a coarse vision for an ecoregion complex, necessitating a subsequent refinement. Freshwater ecoregions delineated in continental-scale assessments are at the scale originally intended for ecoregion conservation. Continental assessments have not covered all regions, but a global map of freshwater ecoregions is in progress.

In some cases, the region of analysis may extend well beyond the target freshwater ecoregion. The Amazon River and Flooded Forests ecoregion provides a good example of this situation. The ecoregion is defined as "all permanently or periodically flooded areas hydrologically related to the Amazon River system." These areas are shown in Figure 3.4. WWF staff and consulting experts agreed, however, that conservation of these flooded areas must be linked to activities within the entire Amazon River Basin, and for that reason the basin became the region of analysis for the assessments of ecological integrity and future threats, and for the identification of priorities. For freshwater ecoregions, it is likely that you will focus only on aquatic habitats when assessing biological importance, but that an evaluation of ecological integrity and future

[25] A reconnaissance is a multidisciplinary rapid assessment to determine if WWF and partners should initiate an ecoregional conservation program, to frame the development of an ecoregional plan, and to identify any urgent needs that require immediate action.

Box 5.1. The importance of river basin authorities for implementing a vision.

By Jamie Pittock, Director, WWF Living Waters Programme

This sourcebook focuses on identifying freshwater biodiversity priorities at an ecoregional scale. Yet in most freshwater ecoregions, a river basin authority or authorities will be critical to implementing the conservation strategies derived from the vision. It is vital to bring together upstream and downstream stakeholders into an organization that facilitates understanding, commitments, and the transfer of funds and other resources to mitigate threats.

Developing a functional river basin authority can take many years. For this reason, early in the ecoregional visioning process it is important to consider what type of river basin authority will be required, who will be the main players, and how to engage them in helping to develop the vision so that they will own and implement it. In the case where an authority already exists, the task will be evaluating whether it is adequate or requires reform.

Most freshwater ecoregions (including river basins) will cross national and provincial boundaries. A major challenge is convincing governments that are often in dispute to work together for sustainable freshwater ecoregional management. Government engagement is critical as river basin management inevitably involves regulatory and financial measures that non-governmental organizations cannot undertake alone.

The management of freshwater resources almost always involves disputes between different interest groups. Water allocation among competing uses is a prime example of an issue that is increasingly affecting even well-watered regions. A biodiversity vision can serve to ensure that the requirements for maintaining aquatic biodiversity are represented among these uses. To address different interests, a river basin authority should be structured in such a way as to:

- Engage all key interest groups in a transparent process,
- Help these groups understand each others' perspectives and consider different options,
- Draw on authoritative data concerning the environmental, social, and economic situation,
- Seek consensus whenever possible,
- Have an expert, independent 'umpire' to provide advice where consensus is not possible to help political decision makers take tough decisions.

River basin authorities can be comprised of a number of different elements:

1. *Heads of government*. A heads of government council can provide a forum to get a common political commitment on important measures needed to conserve a river basin. However, without other structures to follow up these commitments, these types of agreements often falter in the implementation.
2. *Government ministers*. Ministers can meet more regularly than heads of government and can take high level decisions, with the same limitations related to implementation. It is important to ensure that such a ministerial council includes nature conservation ministers.
3. *Heads of government agencies*. Agencies can meet more regularly than ministers and process basin management issues in greater technical detail. However these bodies' effectiveness can be reduced by interagency rivalries and by a cautious 'second guessing' of ministers' political interests. It is important to ensure that such a council of agencies includes nature conservation departmental heads.
4. *Expert committees*. A committee of experts can meet regularly and process basin management issues in great technical detail. It is important to ensure that the recommendations from such bodies are politically and financially feasible (as well as being ambitious for biodiversity conservation!) rather than representing a 'wish list' that is easily dismissed by political decision makers.
5. *Stakeholder committee*. A stakeholder committee can meet regularly and engage, inform, and bring together the key sectors of society who will need to implement sustainability measures. The same recommendations apply to a stakeholder committee as to an expert committee, though there is an increased risk that the body can become deadlocked in conflict.
6. *Authority secretariat*. For an authority secretariat, it is important that each authority has staff to facilitate its work and to provide technical support with a 'whole basin' perspective, independent of any one member government.

7. *Independent chair.* For each of these bodies described above, a well respected person with excellent facilitation skills is need as an independent chair to ensure that the authority's work advances and to mediate disputes between participants where possible.

In general we recommend:

- Having a high level political body that can make hard political decisions and give a mandate to agencies of different governments to work together for sustainability,
- Having a respected, independent chair who can unofficially mediate between participants in conflict,
- Ensuring that in each basin authority government agencies representing both nature conservation and resource use participate,
- Having separate or combined expert and stakeholder advisory bodies that can be seen as an independent umpire or umpires to provide advice to political decision makers on tough decisions,
- Keeping membership of these advisory bodies to a small, workable number, and
- Having an authority secretariat independent of any one member government and with technical staff that can assess and provide 'whole ecoregion/basin' advice.

In developing your ecoregional vision and translating it into a conservation strategy you should seek to identify and involve members of basin authorities. Further, at the earliest opportunity you should consider how to establish or reform the basin authority or authorities needed to implement the ecoregional vision. For ecoregions within which numerous small basin authorities operate, it may be best to identify priority areas through the visioning process before strongly engaging all such authorities.

There are a number of examples of river basin authorities around the world whose work has experienced both successes and failures. These include the Rhine River Commission, Murray-Darling Basin Commission, Mekong River Commission, Lake Chad Basin Commission, and Niger River Basin Authority.

threats will consider both those aquatic habitats and the terrestrial landscape draining to them.

Meeting products

We recommend that the orientation meeting generate the following products:

- a preliminary resolution of boundary issues (ecoregion and biogeographic subregions),
- consensus on the outstanding processes and characteristics of the ecoregion around which conservation goals will be built and success measured,
- a list of habitat types to be considered in subregional representation analyses,
- general agreement on the geographic scale of areas to be identified in the biological assessment,
- a short list of specific threats or pressures and areas that should be top conservation priorities in the ecoregion,
- preliminary identification of stakeholder groups that should be engaged in dialogue and information-sharing prior to the biological assessment, and
- a list of data layers required for the assessment, and steps for obtaining or producing them.

An additional output of the orientation meeting may be a list of tasks to complete in preparation for the biological assessment (for example, compilation of biodiversity data, preliminary agenda, identification of specialists, analysis of focal species data, preparation of maps, etc.). Generation of such a list may or may not be an appropriate meeting activity, depending on the participants and their enthusiasm for being included in the "next steps" planning. In any case, schedule a wrap-up session with WWF staff directly following the orientation meeting to chart out next steps and assignments.

The orientation meeting should also serve as a forum for evaluating any previous biological assessments that have been completed in the ecoregion (Box 5.2). You will want to determine to what degree the biodiversity vision can be constructed from existing reports and how much additional material will need to be generated through the synthesis of existing sources and field analyses. Review, where appropriate, Biodiversity Action Plans, National Conservation Strategies, river basin management plans, and other NGO-generated strategies to determine how they compare to a biodiversity vision. If they are not ambitious enough, you will need to think about how to garner support for a new biodiversity vision without diminishing the importance of work that has gone before. Another component will be to evaluate

Box 5.2. What if another group has already undertaken a priority-setting effort?

Some ecoregions have already been the subject of priority-setting exercises. Is it necessary to repeat the process? To decide, review the methods, assumptions, and outputs of the previous exercise and consider the following questions:

- How thorough were the organizers of the previous exercise in addressing the conservation targets described in this sourcebook?
- Did the exercise address the protection of hydrologic and other physical processes? Did it focus on aquatic taxa and habitats? Did it address issues of connectivity? Did it include land use in its threat analysis?
- Did the exercise evaluate representation of all major habitat types?
- Did the exercise focus primarily on biological features when setting priorities (as opposed to giving greater weight to nonbiological criteria, such as human utility)?

If the effort addressed these features reasonably well, you can incorporate the findings into your biological assessment. Then consider:

- Did the exercise create a biodiversity vision that incorporates the consideration of minimum requirements for focal species and processes?
- Is the vision comprehensive and ambitious?
- Are the priorities based on a detailed biological assessment?
- Do you need to invest in additional activities to fill in critical information gaps?

Where appropriate, try to incorporate the findings of other priority-setting exercises into a preliminary biodiversity vision to use for the ecoregion planning process.

The following steps describe in detail those items that we recommend covering, either before or during the orientation meeting, prior to beginning an assessment.

previous priority-setting exercises for the country or countries included in the ecoregion.

If you are conducting a freshwater assessment in conjunction with a terrestrial ecoregion project, you will need to make an overlay of terrestrial and freshwater ecoregions. You may find that more than one high priority freshwater ecoregion overlaps with the terrestrial region of analysis, or that the freshwater and terrestrial ecoregions have very different boundaries. Chapter 2 discusses this situation and offers recommendations for resolving this problem.

Step 2. Identify broad conservation targets for the ecoregion

It might seem logical to refine the boundaries of the region of analysis next, but the conservation targets of the vision will drive these boundaries (this is an iterative process, and you may choose to revisit the targets once you have refined the boundaries). The five broad categories of conservation targets are:

- *Distinct communities, habitats, and species assemblages (distinct units of biodiversity)*
  Representative examples of all distinct habitat types and species assemblages — ideally, over their full natural ranges of variation — are important conservation targets. Distinctive units include areas of extraordinary richness, endemism, and higher taxonomic uniqueness. For example, a particular waterfall may support large numbers of fish and mollusc species that are found nowhere else. Distinct types of habitat that are important might be peat swamps, which often support specialized assemblages of aquatic species. The particular combination of units to be represented in an ecoregion strategy will vary depending on (a) the distinguishing features of each ecoregion, and (b) the availability and quality of information on patterns of biodiversity. There is no single scale at which distinct units occur; be sure to consider units occurring over small, intermediate, and large scales (see Box 5.3).

- *Large expanses of intact habitats and intact native biotas*
  This target was developed for the terrestrial realm, but it is equally relevant to freshwater systems. Large expanses of intact natural habitat are best for conserving the full range of species, habitats, and natural processes. In the freshwater realm, these expanses may be linear (e.g., long reaches of intact rivers, intact lake perimeters) or areal (e.g., intact catchments or portions thereof, intact wetlands). In particular, we know that hydrologic processes are tied both to aquatic and upland habitats, and that all things being equal larger intact areas are associated with a more normal hydrologic regime. The same is basically true for water quality.

  Intact natural ecosystems and biotas are increasingly rare around the world, particularly in the freshwater realm. Top predators and larger vertebrates (e.g., aquatic mammals and long-distance migrating fish) are disappearing rapidly in most ecoregions as human activities convert and fragment natural habitats and exterminate populations of vulnerable species through overexploitation. Exotic species have taken hold in so many freshwater systems and caused such profound change that habitats without established exotics should be vigilantly protected against them.

- *Keystone habitats, species, or processes*
  At ecoregional scales, certain kinds of habitats, species, and processes may exert a powerful influence on the composition, structure, and function of ecosystems and consequently on biodiversity. These keystone elements may or may not be "aquatic" by definition. For example, cloud forests may be essential for their role in capturing and regulating water for aquatic ecosystems. Floodplain forests play a critical role in supplying food and habitat to riverine fish, in addition to providing other services. In some marshes and lakes, reed beds provide nesting sites for birds and spawning areas for fish, plus they trap silt, remove nitrogen, and protect shores from erosion (Graveland and Hosper 1999). A classic example of a keystone species is the beaver (*Castor canadensis*), which dramatically modifies the riverine environment with its dam building. Research shows that anadromous salmon are keystone species, annually resupplying headwater areas with nutrients through their upstream migration and subsequent death (this would also be considered a large-scale ecological phenomenon, described below). Keystone species are not necessarily large-bodied animals, though. In lakes, for instance, algae and plankton may be critical for maintaining ecosystem functions. The most obvious keystone processes in freshwater systems are related to hydrologic regimes; these are addressed in the following step ("Identify major processes required to maintain conservation targets").

- *Large-scale ecological phenomena*
  The conservation of large-scale ecological processes, such as hemispheric-scale animal migrations, requires a combination of site-specific, regional, and policy-level efforts to be applied over vast continental areas or widely disjunct regions. Habitats or sites that are neither particularly distinctive (i.e., characterized by high richness or endemism) nor intact may still act as critical habitats for migratory species. In the freshwater realm, examples of such species would be diadromous fish (see salmon example above) or migratory waterbirds, which tend to favor lakes and wetlands. Conservation of such phenomena must be linked with ecoregion-level activities and potentially coordinated among different ecoregions.

- *Species of special concern*
  Some species that are heavily hunted, depleted in numbers, or highly specialized in their habitat requirements run the risk of falling through the cracks of ecoregion conservation, which tends to give greater weight to representation than to single-species conservation efforts. In many ecoregions, however, targeted efforts to restore populations of sensitive species and their habitats are central to ecoregion conservation because these taxa serve as focal species for planning. For example, in the lower Mekong River a few catfish species of the family Pangasiidae (including the giant Mekong catfish, *Pangasianodon gigas*) are species of special concern both because they are overfished and because their migratory routes will likely be blocked by planned dam projects.

Step 3. Identify major processes required to maintain conservation targets

In any ecosystem, physical processes create the habitats that support biodiversity. In lotic systems, the flow regime is the main determinant of habitat features such as water depth, current velocity, bottom type, channel shape, and the delivery of nutrients, sediment, and wood (Angermeier 1997) (see Box 5.4 at the end of this chapter for a discussion of wood). A flow regime comprises water quality, volume, duration, and seasonality; in many rivers, dry periods are equally important as wet ones. In lentic systems, the hydrologic regime, including inflow, outflow, and within-lake water dynamics, is equally important; other related processes include nutrient and oxygen fluxes, sedimentation, thermal stratification and mixing, and primary production. In some wetlands, as with floodplain systems, riverine flooding will be essential to maintaining habitats (Richter and Richter 2000).

When focusing on freshwater systems, understanding the abiotic and biotic processes (e.g., primary production in a lake or wetland) will be one of the most important steps in the ecoregional process. There may be a dearth of information on species distributions, but a vision built around the protection of key processes may be as or more effective as one built around species. At this stage in the process, having a detailed knowledge of hydrologic and other physical processes is not essential, but you should be able to identify the major processes that are essential to maintaining the ecoregion's conservation targets. Recall that just as targets occur at different scales, the processes that sustain them may operate over different scales as well. Thinking about processes will help you to revisit the list of targets that you have identified.

As an example, the freshwater component of the Cape Action Plan for the Environment identified broad categories of abiotic and biotic processes critical to maintaining biodiversity in South Africa's Cape Floristic Kingdom (van Nieuwenhuizen and Day 2000, Table 5.1). Abiotic processes for rivers were longitudinal flow, seasonal flow, nutrient dynamics, and sediment dynamics; biotic processes were life history processes (e.g., seasonal migration), population/genetic processes (e.g., interchange of individuals among populations), and community processes (e.g., predator-prey interactions).

Step 4. Identify major threats to the maintenance of conservation targets and major processes

A critical part of the biological assessment is assessing how current threats impinge upon the ecoregion's conservation targets and estimating the impact of future threats. Preparing for the assessment will entail assembling data that describe these threats, but to do this you first need to identify the threats. This may be less straightforward than it seems. Not all anthropogenic activities in an ecoregion will have an equal impact on the conservation targets, and they will almost certainly operate over various scales. Keep in mind that activities may affect terrestrial and aquatic targets quite differently. For example, a dam will have a much greater impact on aquatic and riparian species and habitats than on upland terrestrial elements; on the other hand, converting a natural forest to a plantation may have a much larger impact on terrestrial biodiversity than on aquatic species. If you are assessing freshwater systems within the context of a larger terrestrial ecoregion project, threat data collected for the terrestrial analysis may be insufficient for the aquatic assessment. In general, the following threat categories apply to freshwater systems, although additional major threats may be important for a given ecoregion:

Catchment-scale threats (land cover change)

- intensive logging and associated road building
- intensive grazing, particularly in riparian zone
- agricultural expansion and clearing for development
- urbanization and associated changes in runoff
- widespread mining or other resource extraction and associated road building

Habitat threats

- degraded water quality (e.g., point or nonpoint source pollution; changes in temperature, pH, dissolved oxygen (DO), other physical parameters; sedimentation and/or siltation; salinity)
- altered hydrographic integrity (flow regimes, water levels) resulting from dams, surface or groundwater withdrawals, channelization, etc.
- habitat fragmentation from dams or other barriers to dispersal
- reduced organic matter input
- additional habitat losses, such as siltation of spawning grounds
- excessive recreational impacts

Biota threats

- unsustainable fishing or hunting
- unsustainable extraction of wildlife or plants as commercial products
- competition, predation, infection, and genetic contamination by exotic species
- genetic effects of selective harvesting

Instead of considering the entire universe of possible threats, you can streamline your data collection by identifying the major threats impinging on the targets and processes that you identified in Steps 2 and 3. Returning to the previous example of the Cape Floristic Province, Table 5.1 shows the major threats to the abiotic and biotic processes identified in the Cape Action Plan (van Nieuwenhuizen and Day 2000).

In a second example, an assessment of the Klamath-Siskiyou ecoregion in the United States found that the major proximate factors limiting salmon (the primary conservation target) were high water temperatures, low flows in juvenile rearing areas, sedimentation, loss of instream structure, and channelization. These habitat alterations were, in turn, linked to loss of forest cover, roads, and dams (Conservation Biology Institute 2001).

Table 5.1. Threats to processes identified for Cape Floristic Kingdom freshwater systems. Threats in italics have a direct effect on a particular process; threats in normal font have an indirect effect because of the interaction between various ecosystem processes. For example, changes in flow regime because of dams will change the quantity and velocity of water, which alters the amount of sediment and nutrients and other aspects of water chemistry. This alters habitat and thus affects which organisms can survive, the movement of these organisms up and downstream, and ultimately affects the entire aquatic community. * IBTs = inter-basin water transfers. Taken from van Nieuwenhuizen and Day 2000.

To seasonal flow	***To longitudinal flow***	***To wetland hydrology***	***To nutrient dynamics***	***To sediment dynamics***	***To life history processes***	***To population processes***	***To community processes***
Dams	*Dams*	Dams	Dams	Dams	Dams	Dams	Dams
*IBTs**	*IBTs*	IBTs	IBTs	IBTs	IBTs	IBTs	IBTs
Water abstraction	*Water abstraction*	Water abstraction	Water abstraction	Water abstraction	Water abstraction	Water abstraction	Water abstraction
Afforestation/ alien vegetation	*Afforestation/ alien vegetation*	*Afforestation/ alien vegetation*	Afforestation/ alien vegetation	Afforestation/ alien vegetation	Afforestation/ alien vegetation	Afforestation/ alien vegetation	Afforestation/ alien vegetation
	Bridges	Bridges	Bridges	Bridges	Bridges	Bridges	Bridges
	Channel modification	Channel modification	Channel modification	Channel modification	Channel modification	Channel modification	Channel modification
Infilling/draining wetlands	*Infilling/draining wetlands*	*Infilling/draining wetlands*	Infilling/draining wetlands	Infilling/draining wetlands	Infilling/draining wetlands	Infilling/draining wetlands	Infilling/draining wetlands
			Cultivation: fertilizers	*Cultivation: increased erosion*	Cultivation	Cultivation	Cultivation
		Removal of natural vegetation	*Removal of natural vegetation*	*Removal of natural vegetation*	Removal of natural vegetation	Removal of natural vegetation	Removal of natural vegetation
			Industrial waste		Industrial waste	Industrial waste	Industrial waste
			Sewage inputs		Sewage inputs	Sewage inputs	Sewage inputs
			Diffuse organic pollution: informal settlements		Diffuse organic pollution: informal settlements	Diffuse organic pollution: informal settlements	Diffuse organic pollution: informal settlements
				Roads in catchment	Roads in catchment	Roads in catchment	Roads in catchment
				Overgrazing in catchment	Overgrazing in catchment	Overgrazing in catchment	Overgrazing in catchment
					Destruction of habitat	Destruction of habitat	Destruction of habitat
						Fragmentation of populations	Fragmentation of populations
							Alien species

You may find that certain threats are repeated multiple times; this situation may signal that desk studies on these threats would be appropriate, or that a strategy to address these threats should be drafted in the near term. This is also a good opportunity to begin a list of stakeholder groups that should be engaged in the ecoregional process prior to the biological assessment.

A simple table can help to organize the outputs from Steps 2-4 (Table 5.2); not all target types must be represented, and major processes and threats may be repeated. You may also want to add information about the scales at which targets, processes, and threats occur and operate. In effect, an expanded table can serve as a conservation targets chart — the cornerstone of your ecoregion's assessment and vision.

Step 5. Refine ecoregion boundaries using biogeographical and hydrological information

After thinking about conservation targets, processes, and threats, you can refine the boundaries of your ecoregion (and your region of analysis, if these are two different areas). You are not obligated to use the boundaries delineated in prior continental or global-scale maps; these maps provide only coarse resolution. Your ecoregional team has the best expertise to decide where the boundaries should be.

Consider those targets, processes, and threats that occur and operate most broadly, and refine your ecoregion boundaries to include these. To delineate the boundaries, start with the best possible map of catchments, overlain with surface water features (rivers, lakes, springs, and wetlands if appropriate). An overlay of terrestrial features may also aid the process, if catchments do not provide appropriate ecoregion boundaries. You can also look for obvious dispersal barriers such as waterfalls that mark where the ecoregion boundary could be drawn.

Document your decisions about the boundary delineation, because experts will want an explanation before embarking on an assessment. You can revisit and modify the boundaries later, but it is important to have a good idea of the ecoregion boundaries before beginning to collect various types of ecoregion-wide data.

Step 6. Define biogeographic subregions

Most ecoregions are sufficiently large and biologically complex to justify dividing them further, usually into fewer than 10 subregions. Subregional classifications are integral to a representation analysis, particularly where there are insufficient biogeographical data to accurately map distinct assemblages of species. If habitats in all subregions are adequately represented in a portfolio of priority areas, we assume that distinct species assemblages are captured as well.

You may not be able to delineate precise subregions at this stage, but the orientation meeting participants should be able to define broad biogeographic units that have roughly similar patterns of drainage density, gradient, hydrologic characteristics, connectivity, and zoogeography (Higgins et al. 1999). As an example, the freshwater component of the Cape Floral Action Plan (CAPE) defined six bioregions (the equivalent of subregions in ecoregional terminology): the Fynbos, Alkaline Interior, Southern Coastal, Southern Inland, Arid Interior, and Drought Corridor (van Nieuwenhuizen and Day 2000).

Table 5.2. Possible format for a conservation targets chart.

Target Type	*Target Name*	*Major Processes Maintaining Target*	*Major Current and Future Threats to Target and/or Process*
Distinct biodiversity unit	Target 1	Process 1	Threat 1
	Target 2	Process 2	Threat 2
	etc.	etc.	etc.
Intact habitat or biota			
Keystone element			
Large-scale phenomena			

We can use subcatchments to help define subregions if the subcatchments are characterized by different habitat types or species assemblages. For example, where a large river has served as a barrier to the movement of species from one major tributary to another, leading to isolation and speciation, the subcatchments defined by those tributaries would fall in different subregions. As with ecoregion delineations, other barriers to dispersal (e.g., waterfalls) may also be good indicators of where subregion lines could be drawn. Geologic history of the region might also indicate past connections between catchments that may have facilitated the exchange of species.

You could look at maps of physiographic, geologic, or other physical features if you knew that particular features strongly influenced aquatic habitat types. For example, if groundwater inputs were important to distinguishing habitats, a geologic map might help to indicate where those inputs were most likely to occur. Certainly you should also consider any relevant information on flow characteristics or water types.

This method assumes that different habitats support different assemblages of species, an assumption that must be made in the complete absence of species distribution data. However, if you have information on the biogeography of aquatic species, no matter how coarse, you should incorporate it into your subregional delineation.

An example of subregional delineation comes from the lower Mekong ecoregion. There, experts had evidence to suggest that zoogeographic subregions could be delineated within the aquatic region of analysis based on fish distributions. Four major subregions, and two additional regions that the group suspected should be separated, were defined (Figure 5.1). These were:

1 = Northern lower Mekong catchment
2 = Korat plateau and Laos lowlands
3 = East Mekong basin
4 = West Mekong basin
A = Cardamom and Elephant ranges
B = Mekong Delta

Small or homogeneous ecoregions, particularly those not characterized by high beta diversity, may not require delineation of subregions; in this case, it may be sufficient to conduct a representation analysis of habitats within the single ecoregion unit. As with the ecoregion delineation, document clear reasons for the decisions.

To summarize, biogeographic subregions may or may not correspond with major catchments. Subcatchments will be embedded within subregions, and subcatchments within a given subregion should share species and habitat types at a coarse level. Identifying a minimum number of subcatchments as priorities within each subregion should ensure representation of basic biodiversity features.

Step 7. Identify habitat types for representation analysis

One of the key steps in creating the biological vision is the representation analysis, which ensures that all habitat types are represented in the portfolio of priority areas. To do this, the habitat type(s) of those areas must first be identified. There are two general approaches to this identification. The first method classifies habitats across the entire region of analysis prior to the assessment; the second identifies habitat types within areas only after they have been identified as *candidate priority areas* — those areas that are important for the maintenance of one or more conservation targets, and that will be prioritized through the assessment process.[26] To reiterate from Chapter 2, priority areas may or may not require strict, year-round protection (equivalent to IUCN's Category I of a strict nature reserve; IUCN 1994); a priority area could conceivably receive a lower level of protection, or strict protection could be timed to correspond with critical life history stages of target species.

In the first approach, a single, coarse habitat classification is assigned to each unit of analysis. For instance, the freshwater component of the Cape Action Plan for the Environment (CAPE) identified five habitat types: mountain streams, foothill rivers, transitional rivers, lowland rivers, and wetlands (van Nieuwenhuizen and Day 2000). Each small subcatchment was then assigned one of these habitat types. Similarly, the aquatic assessment for the Klamath-Siskiyou ecoregion used cluster analysis (a statistical technique) to group subcatchments into 16 different classes, based on similarities in slope, elevation, aspect, and land cover (Figure 5.2) (Conservation Biology Institute 2001). In

[26] Most assessments have used the term *nominated priority area* to refer to an area identified as important for an individual taxon or an occurrence of a phenomenon, and the term *candidate priority area* has referred to the amalgamation of these areas. In this sourcebook we only use the term candidate priority area for the sake of simplicity, although you may choose to use both terms if your approach follows the terrestrial method.

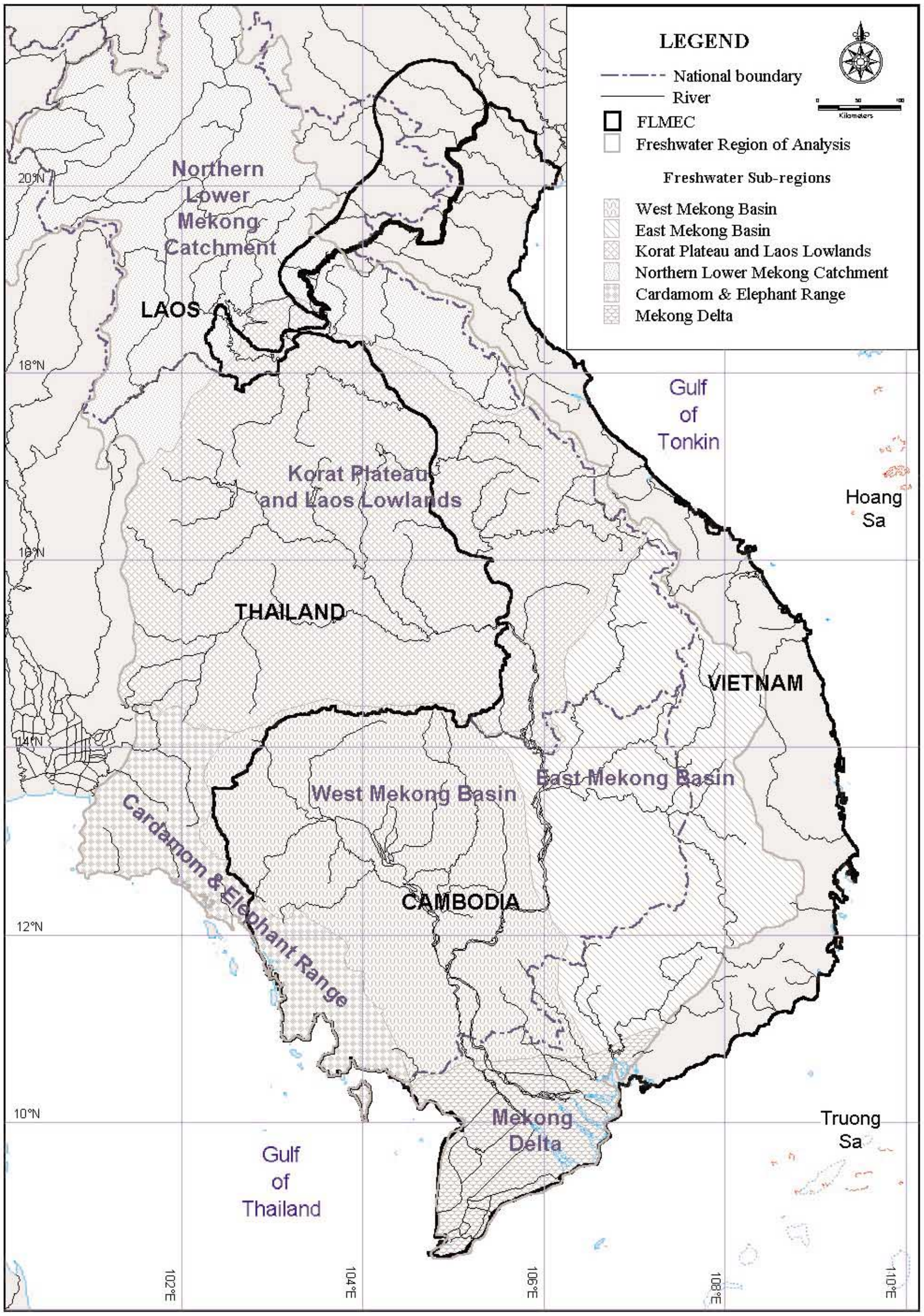


Figure 5.1. Subregions for the lower Mekong River Basin. In the legend, FLMEC = Forests of the Lower Mekong Ecoregion Complex, the terrestrial region of analysis

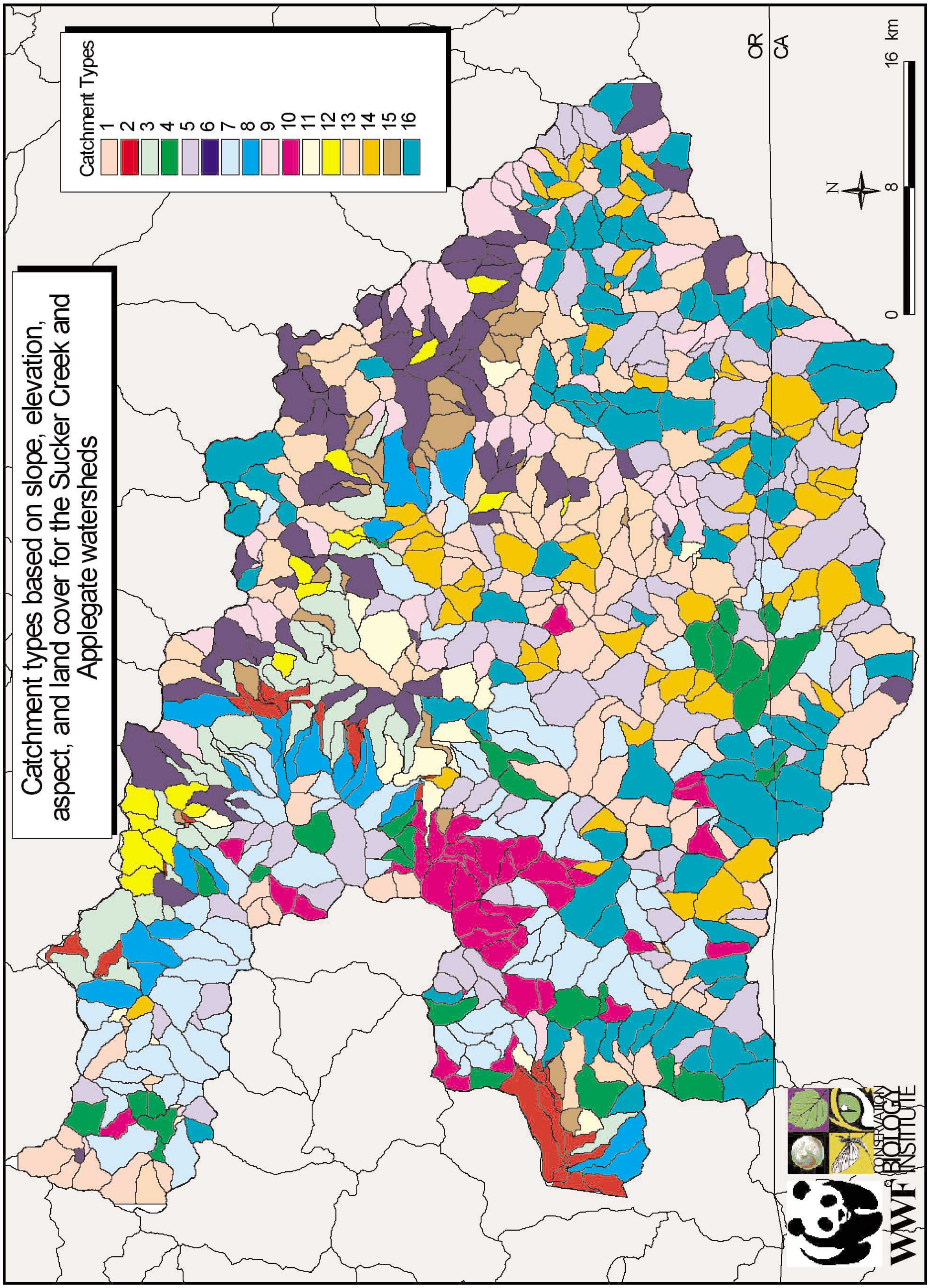


Figure 5.2. Catchment types for a portion of the Klamath-Siskiyou ecoregion, based on physical characteristics. (Taken from: Conservation Biology Institute 2001. Reproduced with permission.)

both of these examples, the classifications were derived for the entire region of analysis, primarily through the use of computer algorithms. Checking for adequate habitat representation then becomes a relatively simple exercise of tallying the habitat types captured within candidate priority areas. This technique requires a good map of small subcatchments as well as some physical data for a basic habitat classification.

A second approach, which is typically less data-intensive, is to identify all of the freshwater habitat types occurring within each candidate priority area after those areas have been selected. Multiple habitat types may be identified for each area. This approach requires developing a complete list of freshwater habitat types for the ecoregion, but there is no additional work required prior to an assessment. While it is possible to generate such a list during an expert assessment workshop, it is more efficient to construct a list beforehand and ask experts to modify it if necessary.

An example of such a list, which experts at the Chihuahuan Desert workshop generated, shows a high level of resolution (Table 5.3). As with the delineation of subregions, the finer the division of habitat types, the greater the number of priority areas that will be required to achieve representation and replication of habitats. In the Chihuahuan example, the experts omitted both hyporheic[27] habitats (for lack of information) and artificial habitats (because they are not part of the natural landscape) from the representation analysis. It should be noted that the Chihauhuan Desert represents one of the most well-studied ecoregions, and that this level of resolution in the identification of habitats may be unrealistic for less-known or larger ecoregions.

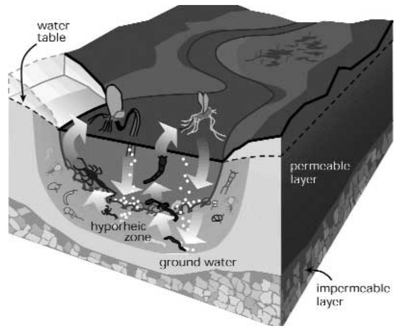
For ecoregions distinguished as much by riparian as by aquatic habitats, such as flooded forests and flooded grasslands, it may be appropriate to categorize freshwater habitats in part or wholly according to their associated riparian vegetation. There are no strict rules prescribing how to define habitat types, but the characterization should be based on those attributes (e.g., gradient, hydrologic regime) that are most important for structuring the distribution of aquatic communities in the given ecoregion (Higgins et al. 1999).

When constructing the list of habitat types, you do not need a priori knowledge of how those habitats are distributed. The list should be as comprehensive as possible, and should not exclude habitats with typically low biodiversity. For example, many lakes and ponds will have low endemism. Nevertheless, they still provide important habitat that should be represented in a biodiversity vision if they are characteristic components of the ecoregion's natural landscape.

Step 8. Identify types of information required to evaluate patterns of biodiversity, processes, ecological integrity, and threats

After identifying the main pieces of the conservation puzzle, namely the conservation targets, processes, and current and future threats, you can consider what kinds of information to collect to describe these pieces. The information in Chapter 6 and Chapter 15 (remote sensing) will help you to identify the kinds of data sources and data analyses you might employ. We suggest creating a new table that lists, for each analy-

[27] The hyporheic zone is the interstitial habitat below a river's alluvial substrate where groundwater interacts hydraulically with the river. It is important for riverine organisms, especially invertebrates, as a refuge during periods of disturbance. Fish spawning and rearing areas also may be associated with this zone (Doppelt et al. 1993). Because it occurs widely in association with alluvial rivers, the hyporheic zone may not qualify as a separate habitat type.



Taken from: The Federal Interagency Stream Restoration Working Group 1998. Reproduced with permission.

Table 5.3. Chihuahuan Desert complex freshwater habitat types.

I. Warm springs
   A. High salinity
   B. Low salinity

II. Cool springs
   A. High salinity
   B. Low salinity

III. Large rivers (and associated floodplain)

IV. Perennial streams
   A. High gradient
   B. Medium gradient
   C. Low gradient

V. Ephemeral streams
   A. High gradient
   B. Medium gradient
   C. Low gradient

VI. Lagunas
   A. Permanent terminal
   B. Temporary

VII. Ciénegas

VIII. Subterranean habitats

IX. Hyporheic habitats

X. Artificial habitats

sis you want to perform, the kinds of data you will require and the potential sources of that data. Analyses might include mapping the distributions of focal species, identifying the natural range of variation of flooding, identifying catchments with high habitat integrity, or mapping potential dam locations. This list can evolve as you begin preparing for the assessment. Do not restrict your list only to those data sources that you know are available.

Step 9. Identify the type of biological assessment that is appropriate to the ecoregion

Another major purpose of the orientation meeting is to assess the status of information in the ecoregion to determine the best methodology for the biological assessment. Past experience suggests that three basic tracks are available for the assessment process, depending on the state of available information (Figure 5.3). In the previous step we recommended identifying the kinds of information that you anticipate needing for an assessment; now you should do a rough evaluation of whether any of that information exists, and in what format. Participants at the orientation meeting should have an idea of the quality of information available across the ecoregion; if they do not, ask them for suggestions about whom to contact. This is a good opportunity to begin a list of the key experts who should be involved in the biological assessment (see Chapter 6 for more details).

For ecoregions that are rich in published data, an approach that draws heavily on computer synthesis of digitized data and requires detailed information on species distributions may be applicable (Option 1). An example of this approach is the freshwater component of the Cape Action Plan for the Environment (van Nieuwenhuizen and Day 2000). If you decide to take this track, the Conservation Science Program of WWF can help you identify literature and experts to guide you through the process.

Where data are not available in publications, but are partially available in unpublished formats housed with taxonomic experts, you should be able to use experts to identify conservation priorities (Option 2). This methodology of convening a workshop of experts and having them identify areas of high importance has been employed in a number of ecoregions around the world. Contracting with experts to conduct preliminary desk studies for particular taxa, subregions, or issues may be a useful way to gather information to focus discussions at workshops. The orientation meeting may provide a good opportunity to identify the most important desk study subjects and potential authors. We discuss desk studies in more detail in Chapter 6.

While these two tracks should cover the majority of ecoregions, there remains a final group of ecoregions where biodiversity information may be insufficient to identify specific conservation priorities, even among scientists who are experts in the ecoregion. Examples include the Amazon River and Flooded Forests and the ecoregions of the Congo River Basin. For ecoregions with an almost complete absence of information, there should be sufficient expertise to delineate biogeographic subregions that can then be used as the first cut for representation of biodiversity (Option 3).

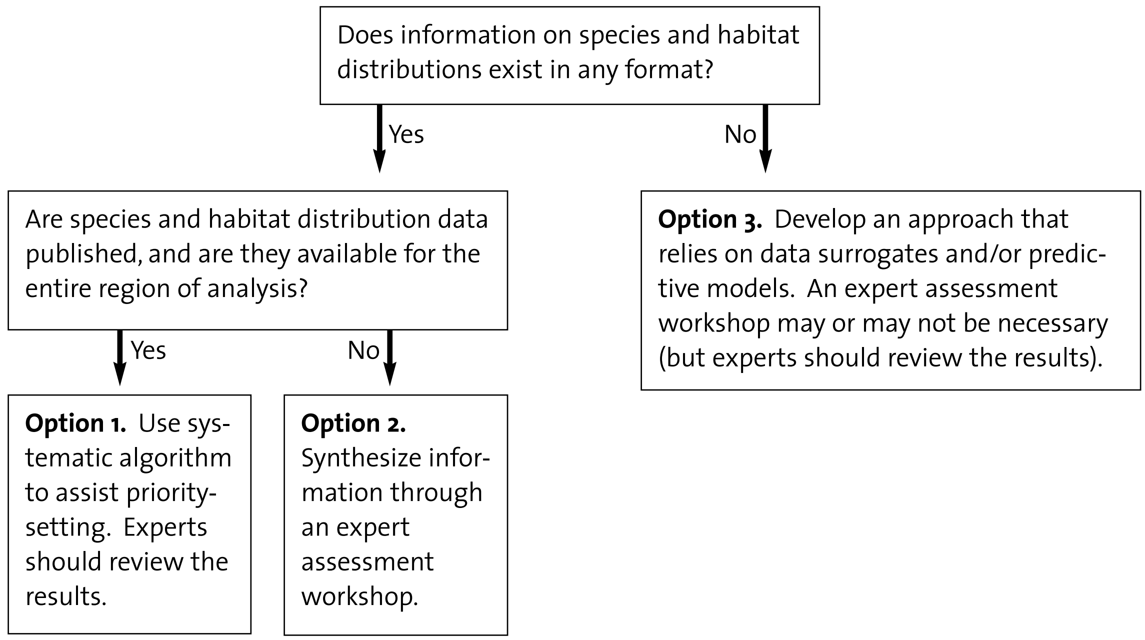


Figure 5.3. Possible approaches for conducting a biological assessment.

A method that involves focused sampling, followed by predictive modeling of biodiversity patterns, is being tested in some terrestrial ecoregions and may have applicability for freshwater systems as well.

A similar type of diagram might be appropriate when designing an implementation strategy. Strategies will likely be substantially different for freshwater ecoregions threatened by water abstraction versus diffuse sources of pollution, or for those that are largely intact versus heavily disturbed.

Step 10. Discuss what form the biodiversity vision should take

Relying on the terrestrial ecoregional model has at times hampered the development of a strong vision for freshwater systems. The terrestrial model focuses first on the identification of places with high species richness or endemism and then builds a network of protected areas around these hotspots. This approach has limits when applied to most freshwater systems, primarily because identifying discrete aquatic areas fails to address hydrologic processes or the effects of land-based activities in the catchment. In several instances, biological assessments have generated maps showing important river reaches, lakes, and wetlands, but there was no mechanism in place for translating those results into a viable vision.

The orientation meeting is a good time to discuss the basic form that you expect the vision to take. Will the vision be composed entirely of mapped priorities, or will priorities also take the form of legislative or other initiatives to be applied more broadly? Will a vision need to be catchment-based, or will it focus on priority units of different types (or multiple scales)? Will the vision be built more around species, habitats, processes, or a combination thereof? To answer these questions, you will need to revisit the question of what it will take to conserve the ecoregion's biodiversity over the next 50 years. Unless you have an idea of what the vision will look like *before* you design your biological assessment, you may find that the assessment yields information that is incomplete for developing a powerful vision. Chapters 7 and 8 offer recommendations for designing biological assessments; if time permits during the orientation meeting, take the opportunity to discuss possible frameworks for the assessment. If not, consider vetting the approach with individuals from the orientation team prior to conducting the assessment.

Additional steps

Before the orientation meeting adjourns, the group may want to consider the following questions:

1. What are your general conservation goals? For instance, are you trying to conserve the last remaining source pools of native species for future restoration, or is your goal to maintain the integrity of large landscapes/catchments?
2. What biological features that were abundant previously are missing in your ecoregion today?
3. Have many defining species populations for your ecoregion become endangered or extirpated from parts of their original range?
4. To what extent have the natural flow regime and/or water levels been modified? Are there freshwater habitats where physical processes still operate close to their original condition?
5. What additional ecological or physical processes are no longer operating within their natural range of variation?
6. Has most of the original natural habitat been converted and degraded, or do large areas remain intact?
7. Are intact areas located primarily in upper, middle, or lower reaches, or are they more widely distributed?
8. Do any entire subcatchments retain relatively intact habitats? To what extent does riparian vegetation remain? Are intact habitats isolated from each other, or can species move among them? Are lotic habitats fragmented by impoundments, or do long reaches of unimpounded river remain?
9. To what extent do protected areas confer protection to aquatic habitats? Are there any protected areas designed specifically to protect aquatic habitats and species, and do any include whole subcatchments? How well are protected areas connected from an aquatic perspective? Has a formal gap analysis been conducted for the ecoregion?
10. Do major gaps in information on patterns of biodiversity and processes require targeted surveys and analyses to move forward in ecoregional planning?
11. What portion of the outstanding biological features will require extensive restoration over the next 10 to 50 years?
12. What are the major barriers preventing conservation on an ecoregional scale? Are there any cracks developing in them? How can you or the international community proactively advance conservation to bring down these barriers?

In addition, consider creating a timeline in increments of five-year intervals. List your conservation goals. Discuss in a preliminary fashion what might be undertaken immediately and what will require long-term planning and investment. For ecoregions where conservation or restoration of ecological processes is more fundamental to ecoregion conservation than areas of high richness or endemism, you may need to address processes first. The purpose of the exercise is to conceptualize where you want to be in 50 years.

A final task is to identify top conservation priorities requiring immediate attention. The process of developing a final biodiversity vision will likely require a year or more to complete, and there will be additional time before a full conservation plan exists. Ecoregion coordinators recognize that they cannot put all conservation activities on hold during this period. So, the orientation meeting provides a good opportunity to identify urgent conservation actions that fit within the scope of the biodiversity vision.

Box 5.3. The spatial scales of conservation targets.

An ecoregion's conservation targets will occur at multiple scales, suggesting that "one size fits all" does not apply to identifying priorities. Although freshwater planning requires taking a catchment perspective, we need to understand the scales over which target species and habitats occur to develop the best strategies for conserving them. The Nature Conservancy has developed a framework for thinking about how biodiversity is related to spatial scale (Poiani et al. 2000). Species are characterized in terms of the geographic area over which they occur, and ecosystems are defined in terms of patch size. However, a particular species may use resources at different scales in different regions.

The following descriptions are adapted from Poiani et al. (2000). The "regional geographic scale" roughly corresponds to an ecoregion, and the "coarse" scale is basically equivalent to a conservation landscape or large subcatchment.

Local geographic scale (meters to thousands of hectares). At a local geographic scale, small-patch ecosystems and local-scale species exist. Local-scale species are restricted to a particular habitat and are generally immobile or poor dispersers. In the freshwater realm, examples would be restricted-distribution molluscs or wetland plants. Small-patch ecosystems tend to be relatively discrete, geomorphologically defined, and spatially fixed; they often occur because of distinct abiotic factors (e.g., geologic outcrops, unique soils, or hydrologic features, such as seeps). Freshwater examples are isolated spring or cave systems. Local-scale species are usually closely connected with specific small-patch ecosystems — for instance, a snail or amphipod restricted to a particular spring.

Intermediate geographic scale (hundreds to tens of thousands of hectares). At an intermediate geographic scale, we find large-patch ecosystems and intermediate-scale species. Like small-patch ecosystems, distinct physical factors and environmental regimes define large-patch ecosystems, and they are relatively discrete in distribution. However, they are significantly larger than small-patch ecosystems. Some large-patch ecosystems — such as bogs or coastal salt marshes — are defined by relatively stable physical factors and tend to be fairly uniform in internal composition and structure. Other large-patch types, such as riparian ecosystems in arid environments and aquatic macrohabitats in rivers, are defined by dynamic and more frequent disturbance regimes. These large-patch ecosystems are variable in structure and composition, with distinctly different internal habitat types and seral stages that shift and rearrange over time and space. Intermediate-scale species depend on large-patch ecosystems or on multiple habitats. For example, a floodplain-spawning fish uses the main channel, floodplain backwaters, and sloughs of aquatic ecosystems.

Coarse geographic scale (tens of thousands to millions of hectares). Matrix ecosystems and coarse-scale species occur at coarse geographic scales. Matrix ecosystems do not have discrete boundaries and are defined by general, widespread climatic and elevation gradients. Species at the coarse scale are habitat generalists, moving among and using ecosystems at multiple scales. Larger-bodied freshwater vertebrates, and some common aquatic insects, may be examples of coarse-scale species.

Regional geographic scale (millions of hectares or thousands of kilometers). Regional-scale species exist at the broadest geographic scale. They include wide-ranging animals, such as migratory fishes in big rivers and many species of migratory birds. These species use resources over millions of hectares or more, including natural to semi-natural matrix and embedded large- and small-patch ecosystems.

Box 5.4. Wood in world rivers. (Taken from: Petts 2000. Reproduced with permission by the Freshwater Biological Association.)

Forest biomes dominate much of our planet yet most research on river ecology has been undertaken on small streams in catchments across Europe and North America that have long been deforested. Pioneering research in the Pacific Northwest [of North America] inspired Chris Maser and Jim Sedell to write a book on the ecology of wood in streams, rivers, estuaries and oceans: From the Forest to the Sea. Published in 1994 by St. Lucie Press, they challenged scientists and managers to address not only the connectivity within catchment ecosystems, but also the connectivity between river catchments and oceans. They told the story of driftwood: the journey taken by water and wood from the mountains to the deep ocean basins. Their conclusion was clear: that driftwood makes a vital contribution to the health of streams, rivers, estuaries, and oceans. But their work raised a key question: what have been the consequences of the disappearance of driftwood from aquatic ecosystems? And what might be the benefits of restoring wood in streams and rivers?

Multi-disciplinary research

Research on wood in rivers is an excellent example of the need for multi-disciplinary studies involving a range of physical and biological sciences. Large wood is important in streams as both a physical structure and as a biological resource. Wood provides structural habitat for perching, hawking, and spawning; and shelter, cover and refuge (denning, nesting, and resting). Complex wood structures partition habitat and influence microclimate (provide shade and moderate temperatures and humidity) and microhydraulics (deep-water pools and fast-flowing chutes). Wood is an important element in the trophic structure of aquatic systems. Wood provides a food resource providing nutrients as well as particulate and dissolved organic matter. However, its indirect contribution may be more important, trapping litter, seeds, and providing a substratum for fungi, insects, biofilm, etc. The production and respiration of biofilm on large wood can contribute a significant proportion of stream metabolism during the summer low-flow periods.

Snags, pools, and islands

Wood in streams and rivers forms jams, snags, and trains. Large amounts of sediments are stored behind wood jams where also hyporheic flows and interactions between the channel and riparian wetlands are enhanced. Wood accumulations have a major impact upon channel form, creating stepped channel profiles characterised by deep pools below jams; and deep gravel bars, marginal sand berms, and a wide range of hydraulic habitats. At a larger scale, wood accumulations play an important role in island formation and channel dynamics. The size, number, and distribution of pools associated with wood accumulations may be particularly important in determining fish densities and biomass. The dispersal of a population between a large number of pools may also improve stock conditions. With regard to invertebrates, wood accumulations are often a hotspot of diversity and production. However, most animals simply occupy wood as habitat and many obtain their food from allochthonous resources that accumulate or are trapped by the wood surfaces. Although the nutrient content of wood is low relative to other types of organic matter, wood has a major impact upon the energy budget of streams by regulating the rate of transport of materials downstream. In the streams of the Pacific Northwest, the retention of salmon carcasses is an important component of the trophic dynamics.

Flow and nutrients

The roles of wood in the functioning of stream ecosystems vary along a river. In simple terms two primary zones can be described. First, in the headwaters of forested catchments, streams are structured by valley form and hillslope and tributary processes. Here, wood accumulations regulate flows (maintain dry-weather flows), regulate sediment and nutrient fluxes, and structure benthic (including gravel bars, sand bars, organic benches) and riparian habitats. Piedmont, lowland, and estuarine systems are structured by inputs from headwater catchments and lateral erosion of the valley floor contributing living wood, wood debris, and exhumed trees; and for estuaries, tides, and storm surges. Wind may be important in both estuarine and large, lowland rivers. In these reaches, driftwood again plays an important role in structuring channel habitats (islands, lateral trains, wood-cored sand levees, blocked channels), influencing channel migration and avulsion [cut-off], sustaining wetlands, and accelerating floodplain succession.

From a geomorphological perspective, recognition of the role of wood in rivers is leading to the development of new models of channel form and process. Hitherto, models have focused upon two primary variables (water discharge and sediment load) to explain the spatial and temporal patterns of river channel forms. New research on the role of wood indicates that this must be included in models of natural channel development. Wood is shown to be influential in all streams and rivers, but to have different effects according to the amount, size (length), and type of wood; the valley topography; the flow regime; and the sediment yield. To these are being added new biological models of trophic, population, and community dynamics in streams.

Dynamics of wood in rivers

One of the most interesting aspects of the role of wood in rivers is that both the physical and biological quality of dead wood in rivers changes over time, with variable rates of delivery, accumulation, decomposition, and breakdown.

Modeling wood delivery requires a knowledge of forest stand dynamics and an understanding of both biotic process such as species succession, growth rate, disease mortality (not forgetting the role of beaver), and abiotic processes and triggers including slope failure (landslides, avalanches), fluvial erosion (undercutting), drought, wind, and fire.

Wood can accumulate to form large jams. River systems as large as 8th order have been recorded as being obstructed by drift jams up to 1500 m long, but commonly channel obstructions are restricted to the headwaters where individual trees block a channel and then accumulate other pieces forming complex structures. These can be liable to catastrophic failure, leading to the episodic flushing of large volumes of wood and sediment during floods. However, the timing of jam breakup is not simply a function of the magnitude of the flood, but also relates to the decomposition and breakdown of the wood. This is related to wood type (size and heartwood ratio, sugar and starch content of the sapwood, nutrient content, etc.). Unlike wood decomposition in the terrestrial environment where fungi are the primary decomposers, bacteria dominate in streams and rivers, and this slow process means that some pieces of wood can survive for centuries or millennia. However, most jams include key pieces that experience alternating aquatic-terrestrial conditions. Certainly in some environments, including ephemeral tropical streams, terrestrial decomposition can be rapid.

Wood or shopping trolleys?

The major forest biomes include the northern coniferous forest, the temperate deciduous forest, and the tropical rainforest. But even within drier grasslands and desert biomes, river corridors are often characterised by riparian woods. In all these areas streamside forests provide inputs of large wood to streams and rivers and there is a growing body of evidence to suggest that woody debris was not only a common feature of natural rivers but also a dominant one. Yet it is likely that the clearance of driftwood was one of the first actions taken by early societies.

The history of human civilizations is founded upon the use of rivers and the use of wood. Across Europe, deforestation to provide fuel and timber as well as agricultural land has been well documented as has the use of rivers for irrigation, domestic water supply, water power and navigation. Channel clearance to relieve hazards associated with driftwood is likely to have been an early activity, not least to facilitate passage and to prevent damage to hydraulic structures.

Detailed analyses of the functions of wood in rivers suggest that at least some of the abiotic ones can be "engineered" and incorporated in stream restoration schemes. However, the neat designs of some restoration schemes, where a single tree is placed along the bank or across the channel, may be of less ecological value than a discarded shopping trolly [also known as a cart] that mimics the complex structure of a natural wood accumulation!

The restoration of wood in rivers involves the reversion of stream systems to a natural condition dominated by the creation and breakup of debris jams, that is to a more dynamic condition characterized by episodic (catastrophic) disturbance. In the developed world, the risks associated with large-scale wood-and-sediment pulses means that "wood in rivers" is incompatible with perceptions of a clean, safe, "civilized" environment unless confined to designated wilderness areas. Nevertheless, given the growing body of evidence to support the conservation value of wood in rivers, opportunities for the passive restoration of wood in rivers should be evaluated seriously. the scope of the biodiversity vision.

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Preparing for an Assessment I: Data Collection and Synthesis

6

Introduction

Ecoregion conservation challenges us to bring the best biology to the design of a credible conservation strategy. For ecoregion conservation to be successful, we need to use the most current information and enlist the assistance of the top experts. The purpose of this chapter is to give recommendations on three topics: (1) identifying data types and sources, (2) identifying experts, and (3) planning for an expert assessment workshop, if you choose that forum for a biological assessment. You could easily undertake the steps in a different order than that in which they are listed.

Forming the assessment team

WWF's experience with ecoregion conservation suggests that the success of a given ecoregion program will depend in large part on the strength of its leadership. The same can be said for a biological assessment. Although it takes a team of dedicated individuals to conduct an assessment, having a leader who is able to manage what is ultimately a complex process is essential. A biological assessment is composed of numerous steps and pieces, and the leader must be able to keep the process on track and moving forward. The leader will need to delegate many tasks and be comfortable putting pressure on team members and expert participants to obtain the necessary products. We recommend that the team leader be a biologist with some expertise in the ecoregion and a good understanding of the principles of freshwater conservation. While ecoregion coordinators are often fully qualified to serve as team leaders, it is rare that coordinators have the time to devote to leading the assessment. The ecoregion coordinator should consider contracting with a leader for no less than 18 months to see the process through.

The composition of the team that will run the assessment should roughly mirror the orientation meeting group. Because the assessment will evaluate species, habitats, processes, and threats, an ideal team would include individuals who could be responsible for each of these elements. If you decide to conduct a workshop, you may need additional people to help facilitate working groups; we describe workshop preparation later in this chapter. Strong GIS support is critical to any assessment, and the team should include enough GIS specialists to analyze data and produce mapped results before, during, and after the assessment. Recent experiences suggest that as many as a dozen GIS staff may be necessary to keep a large workshop running smoothly. Try to arrange for GIS support as early as possible in the assessment process (preferably even before the orientation meeting).

During the reconnaissance or orientation meeting, you may have identified other conservation groups doing complementary work in all or part of the ecoregion. Consider exploring the idea of partnering with these groups to harness additional resources and to produce a vision with greater buy-in. Even if a formal partnership is not possible, members of other organizations sharing a basic approach to large-scale planning can be team participants.

Whatever the composition of the team, the clear definition of roles is essential, particularly if members are working from different locations. We have found that verbal agreement about roles often leads to confusion. We suggest a clear written articulation and assignment of tasks and deadlines.

Step 1. Begin to collect necessary information and to identify data gaps

Once you have assembled your assessment team, you can begin preparing for the assessment. Most likely you will have already begun to collect the information that you identified as important to assessing conservation targets, processes, and threats.

Collecting information and identifying data gaps may be frustrating, because inevitably there will be problems with data acquisition and analysis. Start this task as soon as possible, because obtaining some datasets will take a long time, and you may find that some are insufficient and that you will need to identify new sources. Some data layers may be available or reliable for only a portion of your ecoregion, forcing decisions about how to deal with data inconsistencies. Even for the best-known ecoregions there are invariably inconsistencies, so you will likely be unable to limit your analyses only to complete datasets.

If you find that data simply do not exist, decide whether to skip the particular analysis you had intended or to find a surrogate measure instead. Ecoregion conservation, particularly in the freshwater realm, is an exercise in creativity.

GIS facilities

A fundamental requirement for researching and gathering data is access to proper GIS facilities. This access includes unrestricted use of computers with current GIS software, appropriate hardware for inputting acquired data (zip drive, CD-ROM drive), access to the Internet for data searches, and downloading capabilities. Specific hardware and software requirements are described in Appendix III.

Sources of data

The focus of gathering data at this stage is to provide fundamental baseline information for the preparation of assessment materials. In Chapter 5 (Step 8), we recommended that you identify the types of data that you would need for the assessment. If you have been unable to locate sources of those data, consider the following:

- commercially available CD-ROMs (e.g., ESRI's Digital Chart of the World),
- data from the Internet (see Appendix VI for examples),
- data from NGOs, government groups, and other organizations,
- hardcopy sources (e.g., maps), and
- information gathered from experts.

The cost of acquiring these data sources will vary. In the acquisition of data, be sure to keep all metadata. Metadata is the information on the source, date, projection[28] (if in map form), and format of the data.

Types of data

Data can be divided into primary (raw) data and secondary data (the results of analyses performed on primary data). Both data types are valuable. If using secondary data, keep the metadata detailing any analyses. Data can be in either digital or hardcopy (paper) format. For maps, digital data exist as raster (e.g., satellite imagery and aerial photos) or vector (e.g., roads and rivers) format. You will need to digitize hardcopy maps to allow integration of the information with other data layers.

Not all information that you collect will be geographic in nature, or even qualify as "data." Much of it may take the form of scientific findings or other information published in the literature. We recommend conducting a complete literature review covering key topics identified in the orientation meeting. A graduate student or other individual with access to library resources may be the best person to undertake this task and acquire key publications. Have an organization system in place to keep track of all incoming information and data as you receive and process it. For published and unpublished literature, you may want to store references and notes using any of several commercial software packages (e.g., ProCite).

Your biological assessment will probably rely heavily on mapped data. We can roughly group these data into biotic and abiotic categories, although maps will often display biotic and abiotic features together. You may want to consider obtaining, if appropriate to your ecoregion and available, the following data layers:

Biotic

- Historic and present species distributions, particularly for focal species
- Patterns of endemism
- Wetlands distributions (historic and present)
- Breeding areas for focal species
- Migration routes for focal species
- Known "strongholds" or refugia for populations of focal species
- Other key habitats for focal species
- Land cover
- Terrestrial ecoregions
- Vegetation (potential and remaining, riparian and upland)
- Riparian vegetation
- Rare or focal habitat types
- Indigenous areas
- Cattle/livestock densities
- Ranges of exotic species, or areas of known introductions
- Aquaculture operations
- Human population density
- Areas of deforestation

[28] Projection refers to a method of representing the earth's three-dimensional surface as a flat, two-dimensional surface. This normally involves a mathematical model that transforms the locations of features on the earth's surface to locations on a two-dimensional surface. There are a variety of different projections, such as the Transverse Mercator Projection (Association for Geographic Information 1999).

Abiotic

- Catchment boundaries
- Surface water (rivers, lakes, springs)
- River channel morphology (historic and present)
- Stream order
- Seasonally and permanently flooded areas (historic and present)
- Water level of flooded areas
- River or lake depth
- Water quality characteristics (various)
- Groundwater
- Karst areas or caves
- Soils
- Geology
- Rainfall
- Elevation
- Gradient
- Political, administrative boundaries
- Roads
- Towns and cities
- Land uses (current and historic)
- Erosion potential (by grid cell)
- Runoff (by grid cell)
- Areas of conflict
- Protected areas
- Fishing centers
- Impoundments and reservoirs (present and planned), plus additional barriers to passage
- Fish passage devices (working & failing)
- Inter-basin water transfers (present and planned)
- Water abstractions
- Logging activity and concessions
- Irrigated and nonirrigated croplands
- Pesticide application
- Pipelines (present and planned)
- Power generation plants
- Channelized or diked streams
- Canals
- Drainage projects
- Industrial sites
- Major ports
- Railroads
- Mining activity and concessions
- Toxic sites
- Sediment transfer (by grid cell)

Additionally, if flow hydrographs are available these would be useful.

For biotic data, think broadly about the taxonomic groups to include. You will probably have already narrowed down your list during the orientation meeting. For animals, consider invertebrates in addition to fish, aquatic mammals, waterbirds, aquatic and semi-aquatic reptiles, and amphibians with aquatic life stages. Depending on the ecoregion, invertebrate groups that you might consider include:

- Aquatic and/or wetland molluscs (snails and mussels)
- Crustaceans (crabs, lobsters, copepods, ostracods)
- Ephemeroptera (mayflies)
- Odonata (dragonflies and damselflies)
- Plecoptera (stoneflies)
- Hemiptera (backswimmers, water boatmen, diving bugs, water striders, water scorpions, etc.)
- Diptera (mosquitoes, black flies, midges, etc.)
- Neuroptera (hellgrammites, dobsonflies, alderflies, etc.)
- Coleoptera (diving beetles, riffle beetles, whirligig beetles, etc.)
- Trichoptera (caddisflies)

Molluscs and crustaceans often display high levels of richness and endemism; however, they are very large groups, and you may want to identify particular taxa within the groups (e.g., snails, crayfish) to focus on.

Use the list of information types that you generated during the orientation meeting to prioritize among the many possible data layers. *The layers that are absolutely essential to an assessment are catchment boundaries and surface water features*. If these data do not exist in digital format, we strongly urge you to find ways of generating the data yourself (e.g., produce catchment boundaries using standard models) or search out hardcopy maps to digitize.

For data-rich areas, or if you are employing an algorithm-based approach to priority setting (Figure 5.3), you may want to consider other data types. Some possibilities, taken from Pressey (2001), include:

- information on between-class similarity of habitat types (e.g., hierarchical information on the relatedness of abiotic types; environmental variation in ordination space),
- habitat types predicted across unmapped areas,
- models or predictions of species distributions,
- information on relatedness of species, or on populations, and
- data on inter-specific effects that influence density and distributions.

Temporal and spatial aspects of data

Not all data are created equal, so use discretion when deciding which to obtain and use. It is usually preferable to use the most recent data available, but new data may be prohibitively expensive. For some data themes (e.g., vegetation), satellite images or aerial photos from different points in time (e.g., every five years) allow the assessment of temporal change. But, particularly for large ecoregions, the cost of obtaining a series of images may be too high. Data at a coarser scale, or for a single point in time, may be an acceptable compromise. For example, for freshwater analyses you may only need fine-scale vegetation data for riparian areas, and coarser data may be suitable for upland areas in the ecoregion. Far fewer satellite images will be required to cover river corridors than an entire ecoregion.

For some data themes, such as land use, you may want to obtain historic as well as current data. Many land uses leave a strong imprint on freshwater habitats, long after the activities have ceased (Niemi et al. 1990; Frissell 1997; Harding et al. 1998; Findlay and Bourdages 2000).

Once you have obtained the available data, gauge their usefulness. Is the scale appropriate? Are the data recent enough to be relevant? After you complete this step, you can produce maps for the assessment.

Data analyses and map presentation

Most of the data layers that you obtain will have limited use if displayed alone. Instead, you can combine data layers to assist analyses that you intend to conduct. We urge that all maps produced for the assessment be generated at the same scale (covering either the entire ecoregion or individual subregions) and that at a minimum they all contain catchment boundaries and surface water features. They should also all extend beyond the ecoregion, because experts may decide to alter — and potentially enlarge — the ecoregion boundaries during the assessment. The particular maps that you decide to generate will depend on the assessment type (expert workshop or other approach), the available data, and the analyses that you choose to perform.

For a generic expert assessment workshop, the maps you bring will serve several purposes. They will:

- provide information upon which the experts can comment and improve,
- serve as a medium with which experts can work and to which they can add attributes (notes/comments that you can digitize or add to a database), and
- help to standardize experts' annotations and evaluations.

Not all relevant information that you bring to the assessment, or that experts add through the assessment, will be in map format. Think through how you will organize, present, and use this other information during the workshop and how you will incorporate any new information added during the workshop.

Basic maps to consider generating for a workshop or other assessment forum include, but are not limited to:

- Primary base map[29] with catchment boundaries, surface water features, major political boundaries (make certain that rivers, streams, and lakes are prominent and dark enough to be seen clearly through any overlays)
- Overlay of terrestrial ecoregions with base map[30]
- Biodiversity maps: base map with important areas for focal species, habitats, or areas of high species richness or endemism
- Habitat map: map showing habitat type classification of freshwater systems or subcatchments (see Figure 5.2). Note: this map would be used for the representation analysis.
- Wetland map: map showing important wetlands, many of which may be too small to appear on other maps
- Land-use maps: base map with current land uses (classified into broad categories)
- Water-use map: base map with water extractions and/or other hydrologic features
- Physical maps: base map with elevation, rainfall, and soils, etc.
- Human infrastructure maps: base map with administrative boundaries, roads, railroads, towns
- Protected areas maps: base map with protected areas, coded by level of protection
- Resource extraction maps: base map with oil wells, logging or mining concessions, etc.
- Potential toxic contamination maps: base map with refineries, pipelines, industrial areas

[29] A base map is a map containing geographic features used for locational reference (ESRI 1998). In the case of a biological assessment, a base map is typically the basic map on which other features are overlain for analyses.

[30] Geoclimatic features such as climate, soils, and topography largely determine the physical character of aquatic habitats, and these same features serve as the primary criteria for delineating terrestrial ecoregions. For this reason, an overlay of terrestrial ecoregions on top of a map of the ecoregion's surface hydrology (rivers, lakes, springs) could suggest regions where aquatic habitats might be different from each other.

- Habitat fragmentation maps: base map with impoundments, levees, water transfers, channelized reaches, etc.
- Exotic species maps: aquatic habitats with or without particular exotic species

Available mapping resources will determine the kinds of maps that you can produce. If you have the capacity to plot maps on mylar (transparent plastic material), you can then generate mylar data layers and overlay these on the base map(s). Depending on the degree of transparency of the mylar, you may be able to overlay only one or two mylar sheets at a time, so you will want to plot multiple data layers on each mylar sheet, if possible. Alternately, you might print your base map on mylar and overlay it on paper maps that display the other data layers. Or, if the proper computer technology is available and the assessment forum lends itself to this approach, you can conduct the entire assessment by generating maps on the computer screen and projecting them onto a vertical surface.

Because catchments are hierarchical units, displaying them on a map requires making choices. You will probably want to show the smallest level catchments for which you have boundaries (e.g., for fourth-order streams), but you will want to be able to see which larger catchments these smaller ones are nested within (Figure 6.1). Displaying different levels of catchments on a single map will limit the number and type of other features that you can display at the same time.

In Chapter 8 we suggest a number of possible map-based analyses that you could run to assess habitat intactness. Additional analyses can inform your choice and evaluation of biologically important areas. Some analyses that you might consider running prior to the assessment include:

- Subcatchment size
- Flow contribution, by subcatchment
- Taxonomic richness, by subcatchment
- Taxonomic endemism, by subcatchment
- Percentage of land-use classes, by subcatchment (e.g., 20% forest, 40% agriculture, 10% urban, etc.)
- Percentage of land-use classes within fixed-width buffer of streams or other water bodies, by subcatchment
- Road density or number of road-stream crossings, by subcatchment
- Sediment contribution or erosion potential, by subcatchment
- Average flow accumulation or runoff of grid cells, by subcatchment

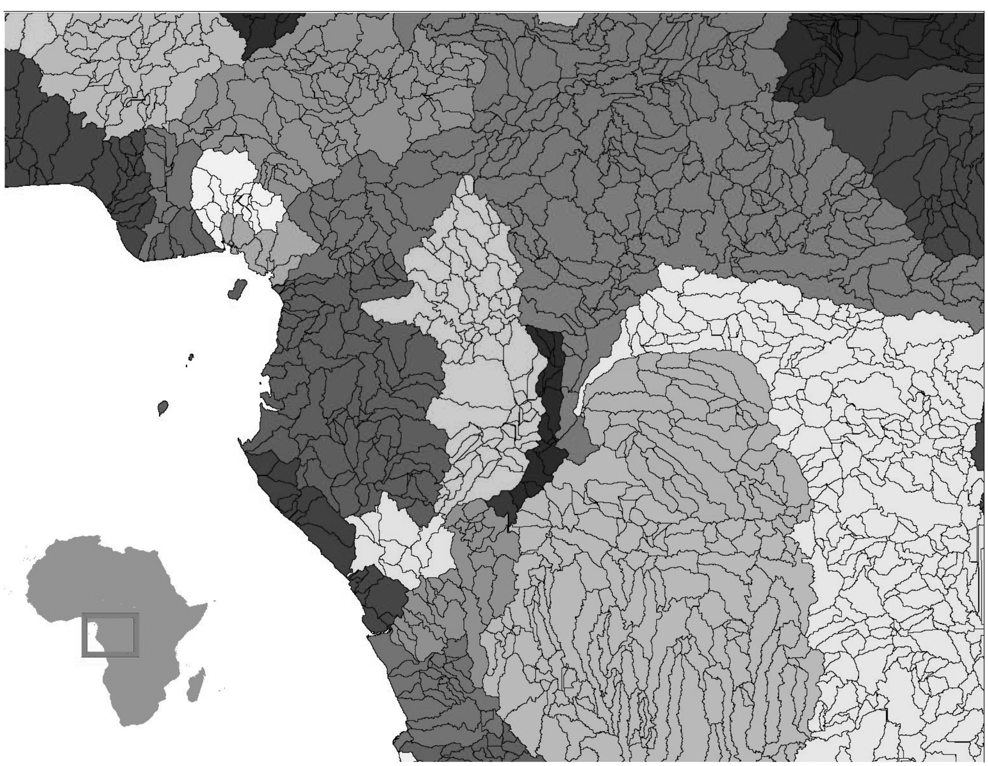

Figure 6.1. Two hierarchies of catchments for central West Africa. Shaded polygons are large river basins, and areas outlined in black are small catchments.

- Urban expansion or population growth, by subcatchment
- Percentage of area grazed, by subcatchment
- Length or percentage of streams with riparian vegetation cover, by subcatchment
- Percentage of headwaters (defined by elevation, gradient, stream order, etc.) with original land cover, by subcatchment
- Average population density, by subcatchment
- Degree of protected area coverage (all areas, or only aquatic habitats), by subcatchment
- Number or coverage of mining, logging, or other resource extraction operations, by subcatchment
- Number of pipeline-stream crossings, or length of pipeline, by subcatchment
- Number of impoundments per stream length, by subcatchment
- Length of stream flooded by impoundments, or length of stream above impoundments made inaccessible to migrating species, by subcatchment
- Number or length of free-flowing streams, divided by number or length of impounded streams, by subcatchment
- Length of stream habitat lost as a result of channelization (requires historic and current stream morphology maps)
- Length or area of floodplain habitat cut off from river

If you also have historic data for any features, you can calculate rates of change in these statistics over time, to help generate a picture of past activities and future threats. As you can see from the above list, there are far more opportunities to generate statistics for the evaluation of habitat intactness than for biological importance. Although we suggest here that you do analyses by subcatchment, you may choose to use different units altogether.

Give careful thought to your choice of statistical analyses and application of the results. Choose your analyses on the basis of the targets, processes, and threats that you identified during the orientation, and avoid generating statistics simply because you have the data to do so. We present additional ideas and suggestions on remote sensing for freshwater analyses in Chapter 15.

Step 2. Identify key experts and stakeholders in the ecoregion

During the orientation meeting you may have begun to identify key experts who should be included in the assessment process. The kind of assessment that you conduct, the types of analyses that you hope to perform, and the existing expertise for the ecoregion will determine the number and type of experts that you invite to participate in the assessment. In general, experts will be responsible for commenting on data you have already assembled and adding to it, interpreting the data, and making judgments based on their experience in the case of data gaps.

The composition of the group of experts will likely mirror your orientation meeting group, although it will probably be larger and include some individuals with more specialized expertise. Many experts will not have knowledge about the entire region of analysis, or about more than one small taxonomic group (for biologists). Strive to find more than one expert to cover a given area, taxonomic group, habitat type, or other feature, so that pieces of the assessment do not rest on the judgment of a single individual.

Let the outstanding features of the ecoregion guide your search for experts. It may be difficult to find experts in invertebrate groups, but if invertebrates are important elements of your ecoregion's biota, it will be important to locate specialists — especially if you have found little or no data describing invertebrate distributions or habitat requirements. The same is the case for narrow habitat types for which few individuals are experts. For example, subterranean habitats have their own specialized biota that only a handful of biologists know. Do not assume that biologists with more general training will be able to "cover" these habitats.

You may find that there are features for which no experts or data exist. In this case, you will need to identify these information gaps clearly in the assessment results, and you may choose to recommend these as research priorities.

Identifying stakeholders is perhaps more difficult than identifying experts, since a stakeholder is simply "any person, group, or institution that affects or is affected by, positively or negatively, a particular issue or outcome" (WWF definition). Obviously, you will not want to include representatives from all stakeholder groups in the biological assessment. But, it will be important to include stakeholder groups that can strongly influence the eventual implementation of a conservation plan, or that will be affected disproportionately by proposed strategies. The Conservation Strategies Unit can provide resources to help you identify stakeholders.

Step 3. Identify key desk studies and contract with experts to write them

During the orientation you may have begun a list of key desk studies and possible authors. Desk studies synthesize existing unpublished or published information into a product that is usable in an assessment, or they can produce new information as a result of analyses of existing information. Desk studies that include interpretation of results (e.g., identification of most important areas for a taxonomic group) are useful because experts can react to them, rather than beginning with their own interpretation. It may be expensive to contract with an expert to undertake a desk study, but if you define the subject and goal of the study carefully and select the right expert, the study will be extremely valuable to the assessment. Allow plenty of time (4-6 months) for the expert to complete the study in advance of the assessment. This means contacting potential authors as early in the process as possible.

Step 4. Prepare for an ecoregion workshop or other assessment venue

If you are unsure about whether or not to hold an expert assessment workshop, consider the following. An expert workshop provides an opportunity to gather a great deal of essential information relatively quickly. Even in the best-studied ecoregions, much of the data useful for biological assessments are seldom found in books or peer-reviewed journal articles. Rather, much of the data exists in the gray literature, buried in unpublished manuscripts, or "housed" in the heads of experts.

Consider holding an expert workshop when maps or other published sources of information required for your assessment are inadequate or nonexistent for the ecoregion. This decision will call for good judgment, because maps are generally available in some form.

An expert workshop is an expensive undertaking, but it has the added benefit of being an effective way of engaging the scientific community in the ecoregion conservation process. The larger scientific community will be more likely to support the conservation priorities that experts propose through the planning process. We have found that it is better to have a diverse group of scientists debate conservation priorities while they participate in a workshop than to have them launch harsh critiques of the conservation plan at a later stage.

Despite its benefits, a workshop is not appropriate for every ecoregion. A workshop can be an exercise in frustration if so little information exists that the assembled experts can only assess what is *not* known and what should be the top research priorities. While it is important to identify research gaps, you probably can accomplish that without a full-scale workshop (refer to Figure 5.3 for guidance on which type of assessment should be conducted in your ecoregion).

The Amazon River and Flooded Forests ecoregion provides a good lesson regarding workshops. An expert assessment workshop that brought together 25 specialists in a variety of fields was held in March 1999. Although the combined expertise at the workshop was substantial, the biological data gaps were too large to make good progress on an assessment. Additionally, the assessment was modeled on methodologies derived for the terrestrial realm, and these were inadequate for dealing with the complex hydrologic issues of the Amazon River Basin. The outputs of the workshop were useful in helping to guide the ecoregional effort, but the workshop fell short of achieving a comprehensive assessment.

In response to this outcome, WWF-Brazil and WWF-Peru decided to work internally on building a stronger foundation for an assessment and vision. Representatives of the two organizations met and developed a conservation targets chart, which then served to focus efforts at a second, much smaller workshop (see Box 6.1 at the end of this chapter). Participants at this workshop were composed only of WWF staff and biologists at IIAP (Por el Instituo de Investigaciones de la Amazonía Peruana), an Amazonian research organization that had been contracted to synthesize the biological data for Peru. Everyone at the workshop was familiar with the ecoregion conservation process, and the small group was able to develop a new approach for the assessment through consensus and good facilitation. Because so little biological information was available, the approach focused more on identifying representative, intact catchments within each subregion, and then identifying threats and opportunities at both ecoregional and catchment scales. GIS facilities and expertise were available, and it was possible to map results and view them instantly using a projected computer image. Follow-up work remained after the meeting to finalize the assessment and develop a vision, but this second workshop succeeded in making far more progress than the first and provided a strong basis from which to move forward.

There are several key lessons here regarding workshops. First, a small group working together can often achieve as much, if not more, than a large group that must be split up into smaller units working separately. With one group it is possible to change the methodology midstream without sacrificing a standardized product, and it is far easier to discuss changes and reach consensus quickly. The trade-off is that the range of expertise may be narrowed considerably.

Second, when participants all understand and accept the fundamental approach to ecoregion conservation before embarking on an assessment, the process is much more efficient, and time otherwise spent discussing basic principles can instead be devoted to discussions of more complex issues. A workshop consisting of experts who have had no exposure to ecoregion conservation will require a substantial amount of time devoted to discussion of the basic approach, and we have found no way to avoid this (though we present some suggestions in the following section).

Third, when biological information is lacking, a full-scale expert assessment workshop may not be the best use of resources. It may be wiser to construct a preliminary vision based on data surrogates, and then ask experts who would otherwise be invited to a workshop to review the draft (a review could take place in a workshop setting, if appropriate). If key experts are frustrated by a workshop experience because they feel unable to make progress in the face of overwhelming data gaps, they may be unwilling to participate at a later stage in the ecoregion conservation process.

Fourth, good facilitation is critical to any meeting, whether or not it is a full-scale expert assessment workshop. A facilitator will ideally be someone who has a strong understanding of the technical concepts and required outputs, but who is able to focus on facilitation rather than on imparting information. There are mixed opinions about whether the facilitator should be a hired professional, or if a staff member should take on the role instead. If staff will be facilitating a workshop, consider engaging a professional facilitator to help design the workshop structure, articulate questions driving each activity, and identify specific outputs.

Whether or not you choose to hold a workshop, we highly recommend conducting a biological assessment, except in those rare cases where other organizations have already conducted a strong assessment for the ecoregion. Skipping an assessment poses the risks of losing an important opportunity for buy-in, losing access to vital information and expertise, and promoting status-quo targets and activities.

Before you start planning the logistics of a workshop or other assessment forum, articulate exactly what the workshop outputs are going to be. Some workshops are designed to create a nearly final biodiversity vision. Others aim only to identify priorities, and the synthesis of those priorities into a vision occurs afterward. For very large ecoregions or ecoregion complexes, the priorities themselves might be so large that an additional step is required to identify priorities-within-priorities following the workshop. Make sure that you and your team are in agreement about where you are going with the workshop before you plan the particular details.

How should you start planning a workshop?

If you decide to hold an expert assessment workshop, you will embark on two iterative processes that will likely occur simultaneously. The first is planning the workshop logistics (size, duration, timing, location, etc.). The second is developing the workshop methodology. We discuss methodology in the next two chapters (Chapters 7 and 8), and we restrict the remainder of this chapter to logistics.

In many cases, moving forward with logistical arrangements will depend on making progress on methodological decisions, and vice versa. For example, you will not be able to create and produce data sheets until you know what data you will collect, and you may not be able to decide what data to collect until you have a rough idea of the experts who will be present. Similarly, you cannot create maps of focal species' habitats until you have selected those species.

In Box 6.2 we present a checklist of logistical preparations for an expert assessment workshop; this is an actual example from the Congo Basin ecoregion workshop. This list could easily be modified for any workshop, and we would suggest that such a list be annotated with the names of individuals assigned to complete each task. Note that this list does not include arranging for facilitation.

Whom should you invite to the workshop, and how many experts do you need?

The number and composition of participants will have a strong influence on the other features of the workshop, so consider the participants early on. By and large, your budget and the range of available experts will together determine the number of participants you invite. You can begin by identifying the minimum number of experts you would need to evaluate the conservation targets, processes, and threats that you listed earlier. Then you can identify the maximum number of people your budget will cover. You may decide to have a small workshop, where the participants can all work together — in this case, we would recommend having no more than 15 or so at the workshop. Some experts will require a payment in addition to the cost of their travel, food, and accommodations. Decide in advance how you will deal with such requests. Also, be sure to budget for workshop staff. The larger the number of participants, the greater the number of working groups into which they will be divided, and the more working group facilitators that will be needed.

Besides producing an assessment, a role of the workshop is to promote interest and acceptance for ecoregion conservation. Therefore, in addition to those scientific experts mentioned at the beginning of this chapter, consider including representatives of indigenous groups, local NGOs, social scientists, and government officials. In some past workshops, individuals from such groups without the expertise to participate in the assessment have been invited for a special session on the first or last day, in which the approach and/or results are shared. Having too many non-participants observing the workshop process can create an atmosphere that is less open and less productive.

Among scientists, the best participants tend to be those who are regarded by others as authorities for the ecoregion, who have a broad biogeographical perspective, and who have a reputation for building consensus. We cannot stress enough how important it is to have a few wise, experienced, and respected individuals who support the goals of the workshop and who can help all participants focus on the tasks at hand. Some of these individuals will have been participants at the orientation meeting and will be able to answer questions or introduce preliminary ideas about the vision. If you do not hold an orientation meeting, consider meeting before the workshop with one or two key experts who are leaders among their peers to engage them in the process.

Selecting participants can be an exercise in diplomacy. Some individuals will refuse to work with others. Some people not on your list of potential invitees will hear about the workshop and ask to be invited. You may need to invite certain individuals to achieve parity among political units, or because they are essential figures in their agencies and agency buy-in is important. Although it may be difficult, we strongly recommend that you identify the maximum number of participants your workshop format and budget can accommodate, and do not exceed that number. Start by identifying the key experts in each field, and pick your dates according to their availability. Then build your list of invitees from there.

The sooner you send out invitations, the better the chance that experts will be available for those dates. Do not send out invitations, however, until you are nearly certain of the dates — changing the dates, particularly multiple times, will make a bad first impression on the invitees. Keep in mind that biologists tend to have regular field seasons, academics (many of whom are biologists) have regular teaching schedules as well, and state employees will often prefer to attend during the workweek rather than over weekends (although this is a generalization).

Other suggestions for selecting participants include:

- For taxonomists, select participants to represent as wide a range of major taxonomic groups as possible.
- Draw on the national and international scientific communities and their knowledge base. If you can identify experts at the local or regional level, they should be given special consideration, because local acceptance of the process is extremely important.
- Consider soliciting representation from local, regional, and national governments as well as from NGOs that have a scientific mandate as part of their vision.
- Invite social scientists who have a basic understanding of biodiversity conservation to contribute to the process and then take the outputs of the workshop to the socioeconomic assessment.
- Consider extending invitations to representatives of a few donor agencies, at least for the last day of the workshop when participants present a draft biodiversity vision. The ecoregion coordinator will know if the timing of such an invitation is appropriate.

The coordinator should brief all observers about the process beforehand.

How long should the workshop last?

There is a real tension between wanting to devote plenty of time to assessment tasks and wanting to maintain the attention and interest of participants. We have found that two days is too short to conduct a complete assessment and produce a draft vision. Three days is about the maximum amount of time that a single facilitator can maintain his/her energy, plus most people find it difficult to attend workshops that last more than three days. If there are multiple facilitators and/or a good mix of activities, a workshop could last four or even five days (though a five-day workshop should include plenty of "down" time).

Complications can occur if participants do not all speak a single language and simultaneous translation is required. Ideal translators will be familiar with rudimentary scientific concepts and with the ecoregion conservation process. At a minimum, you may want to give the translators the glossary from this document in advance of the workshop. If you opt for sequential rather than simultaneous translation, you may need to add an extra day to accommodate the additional time that will be required for conducting the workshop. However, even simultaneous translation slows the process down somewhat.

Workshop staff will need to arrive several days in advance of the workshop to do intensive preparation, particularly at the GIS facility. We recommend allotting at least one additional day after the workshop for cleanup and organization of data.

Where should the workshop be held?

Decide on a venue for the workshop that is centrally located and that may lend itself, if desirable, to a one-day field trip after or in-between the workshop sessions. A remote location in a natural setting may cause participants to be more inspired and relaxed, and less likely to skip sessions. But, because you will need to arrange for transport of participants to and from the location, there will be difficulties if any participants arrive late or leave early. You will also have limited options if you face equipment breakdowns or supply shortages, and you will need to transport virtually all the equipment to the location.

Holding the workshop in the same hotel where participants are staying is probably the best option, although it will be less expensive if the workshop can be held at the local WWF office. Meeting rooms should have ample space for participants to spread out and work on large-format maps. Hotels designed to accommodate conferences will be in the best position to provide the necessary services.

The ideal workshop site will have dependable electricity and be located near or in a building with GIS facilities, to allow for map generation during the workshop (see Appendix III for more details on GIS). In some cases, such as for very small workshops, it may be possible to forego the production of hard-copy maps during the meeting and instead project them onto a screen using an LCD projector. We strongly caution against relying solely on this method of display, however, particularly if the workshop includes a formal presentation of results to observers. On at least one occasion, problems with the LCD projector prevented the display of results at a critical moment.

Dealing with data in a timely and efficient manner during the workshop will minimize effort afterwards and will also decrease the potential for error. Consider these important features when choosing a GIS facility:

- The GIS software used during the workshop should be compatible with the GIS facility at your headquarters. Verify the compatibility between facilities well in advance of the workshop. Continuity in GIS software will allow the efficient transfer of data between the headquarter and workshop GIS facilities.
- The GIS team should have access to at least one digitizer tablet and also a plotter capable of printing large-format maps. In the absence of a large-format plotter, a color printer will be sufficient (you can print small maps on transparencies and project them using an overhead projector). A digitizer tablet allows the information gathered from the experts to be converted into digital format for immediate review. Access to multiple digitizers will allow this work to be completed more quickly.
- The GIS facility should provide a technical support person to the GIS coordinator. This person will ensure that everything runs smoothly (e.g., will provide assistance in the event of a power outage, computer crash, or lack of supplies such as paper and ink). Additional staff are needed to assist the GIS coordinator at all times. Large sheets of mylar or acetate and a variety of multicolored permanent markers are critical to have on hand in case of equipment emergencies. As mentioned above, for

some components of the workshop, running ArcView on a laptop computer and displaying it on an LCD projector can allow real-time changes to data and analyses.

- The workshop venue and GIS facility should be close enough to each other to allow quick turn-around of maps. Often, government agencies and universities have facilities that meet these requirements and provide better support than do conference centers or hotel meeting rooms.

Additional recommendations for workshops

- Hire a workshop coordinator to handle all logistics.
- Recruit interns from local universities or NGOs to help with data collection and note taking during the workshop.
- When sending out initial invitations to experts, include a "truth in advertising" message saying what will be expected of them. In particular, let them know that they will be asked to prioritize among places and activities.
- Reserve ample time for creating data sheets once the workshop methodology is finalized.
- See Box 6.2 at the end of this chapter for additional considerations.

Post-workshop logistics

Upon conclusion of the workshop you will be exhausted, but undertaking a few additional tasks will prevent extensive delays later. Secure all maps, data sheets, and other outputs generated during the workshop together and in a safe place, and photocopy these where possible so that you will have a back-up set of results. During the workshop make sure that all data sheets are legible and that their authors have written their names on them; double-check this as soon as possible after the workshop, because your memory as to what transpired will fade. At the end of each day, write up notes on the day's activities — you can do this directly on the agenda. At the end of the workshop, combine these notes and add any new thoughts about the workshop process, including recommendations made by participants.

The GIS coordinator will be responsible for two main activities after the workshop.

- The coordinator should download all of the GIS data produced during the workshop onto the headquarter GIS system as soon as possible. He/she should finish digitizing maps, add attributes, and clean up all the errors found in the GIS data layers. He/she should provide documentation (metadata) for each data layer, including:
  - date coverage was made,
  - origin of coverage,
  - names (e.g., of priority areas),
  - number identification system and meaning, and
  - additional useful information.

The purpose of adding this information is to assist future GIS work by others, who will need to know the meaning and origin of the data in the coverage (e.g., the numbers 1-3 are meaningless unless it is known that 1 = high priority, 2 = intermediate priority, and 3 = low priority). Add this information immediately upon conclusion of the workshop while the data and their meaning are still fresh in your memory.

- Once back at headquarters, the GIS coordinator will conduct analyses and produce the maps needed to accompany whatever report is generated. The coordinator should produce full sets of maps that were made prior to and during the workshop and should include appropriate baseline information to assist in interpretation. This activity may take several months. The coordinator will also be involved in producing any CD or Internet products.

Workshops are good assessment tools because they generate a large amount of information quickly. This means that you should anticipate having a large amount of information to process during and after the workshop. The information will not be "clean" — you will need to check it and spend time filling in gaps. The analysis and synthesis of information takes time, but it is in your best interest to complete this process as quickly as possible, so that you maintain the momentum generated by the workshop and the information does not become stale. Ask the experts to review the results as soon as possible, because they will forget the details of their work before long. Consider posting the results on a web site to minimize the cost of printing and mailing draft reports and to speed the review process, but confirm first that experts have Internet access and the capacity to download files.

Agree on post-workshop responsibilities before the ecoregion team disperses, including a timeline for completing activities, and give a copy of the assigned tasks to everyone. This task should include identifying the individual who will be responsible for enforcing the deadlines. Efficient workshop follow-up will go far in retaining the interest and participation of experts.

Box 6.1. Amazon River and Flooded Forests ecoregion workshop summary.

Key lessons

- All participants were familiar with broad ecoregion conservation concepts and had previously agreed on the major conservation targets for the ecoregion. Maintenance of hydrologic and associated ecological processes was considered the most important target.
- Consulting scientists and WWF staff drafted a preliminary biodiversity vision prior to the meeting but understood that it could be overhauled. In the end, the basis of a new vision was built on the old targets but took a much larger-scale approach.
- The meeting benefited from excellent facilitation by WWF staff who were not directly involved in the assessment. Individuals rotated between facilitation and note taking. The agenda evolved as the meeting progressed (through consensus of an informal steering committee), and because the facilitators were ecoregion conservation "insiders" they were able to adjust to the changes.
- Although three languages were spoken, there were no serious language difficulties. Bilingual participants provided translations where necessary.
- The Conservation Science Program helped to guide the meeting, sharing lessons from similar ecoregional experiences, and making recommendations for the approach.
- The group started by identifying entire subcatchments, within which important areas could then be delineated for various protective measures. By working at the scale of major subcatchments, the group was able to develop a vision that addressed the target of maintaining hydrologic processes (see Box 7.2).

Some general challenges to developing a vision for this ecoregion:

- The vast size of the Brazilian Amazon, especially compared with the Peruvian portion, and the much more detailed information available for Peru than for Brazil
- Lack of participation by additional countries containing portions of the Amazon Basin
- Lack of a good map of subcatchments
- Lack of virtually any information on freshwater species at the scale of analysis
- Need to consider headwater areas in the integrity and threat analyses, despite the fact that they are technically outside of the ecoregion (as defined)
- History of country-by-country analyses

Strengths going into and at the workshop:

- Good understanding of different water types and flooded forest flora associated with them
- Relatively good maps available to use for analyses of current and future threats
- Strong GIS capacity at the workshop (and for workshop preparation) — GIS provided by IIAP (consulting research agency in Iquitos)
- Ability to project ArcView maps on a screen using an LCD, allowing entire group to view and work from various map combinations
- Draft vision (equivalent to detailed desk study) read by all participants prior to meeting
- Very good facilitators
- Informal steering committee responsible for revising agenda throughout the meeting
- Single working group (meeting had 17 or fewer participants at all times)
- Meeting devoted exclusively to freshwater, rather than held as part of larger terrestrial workshop

Box 6.2. Logistics preparation checklist for Congo Basin expert assessment workshop.

Participant contacts/invitations

1. Decide in advance if any payments will be made for experts' time.
2. Make initial contacts with experts who have been identified — ask for interest, availability, and payment requirements. For essential experts, ask for alternate dates if necessary.
3. Ask experts what languages they are comfortable working in, and if they will need a translator if the meeting is conducted in either English or French.
4. Arrange for accommodation and travel — assist experts with travel arrangements if necessary, including notification of general visa requirements. This can be a long and arduous process for participants coming from certain countries. Once participants have finalized their itineraries, make reservations for hotel accommodations.

Hotel accommodations

1. Investigate hotels. Look for one that is economical and close to the meeting space. If no meeting space is available at the WWF office, look at hotels with meeting rooms available and see if any discounts are available if participants stay there.
2. After choosing a hotel, reserve a block of rooms immediately to be sure that all participants can be accommodated at the same location. This reservation should be secured quickly since meeting spaces and hotels usually book up months in advance.

Meeting location and particulars

1. If space is available at WWF, this should be the first choice. If not, look for a location that is convenient and is either near lunchtime restaurants or will allow lunch to be delivered (preferred option).
2. If space is not available at WWF, make sure that the meeting facility has basic equipment available: overhead projector and screen, photocopy machine, phones, and plenty of space for 20+ people.
3. Pick a meeting room with a capacity larger than the capacity required for the number of participants to allow working groups to move comfortably and to accommodate any additional participants or observers. Also, additional rooms are useful if participants need to divide into separate working groups.

Workshop budget

1. Calculate the rough costs for travel (including within-town and airport shuttle), hotel accommodation (XX nights), and food for a single participant.
2. Determine the cost of renting meeting space for XX days, if necessary.
3. Estimate the cost of catering lunch for XX days, if preferred.
4. Estimate photocopying charges, per copy.
5. Estimate the amount of time required of WWF for workshop preparation tasks, and give associated estimate of cost.
6. Estimate the cost of hiring one or more translators and translating equipment for XX days.
7. Estimate the cost of equipment rental, if necessary (e.g., portable printer for computer).
8. Estimate any additional costs (phone calls, etc.; see also, workshop materials, below) incurred by WWF.
9. Estimate the cost of hiring (if necessary) students or scribes to record data and discussion notes for each working group.
10. Estimate the cost of any social events, field trips, or receptions.
11. Estimate the cost of hiring a coordinator to help coordinate logistics before and during the workshop.
12. Prepare the workshop budget, given the above information.
13. Outline subcontracts and payment requirements and dates for check requests and direct deposit.

Pre-workshop materials

1. Prepare a draft workshop program.
2. Prepare a draft letter of invitation to experts.
3. Prepare a draft explanation of project and workshop process, to be sent with the invitation.
4. Translate the above documents as necessary.
5. Review and finalize the above documents.
6. Send out invitations and associated materials/instructions.

Written workshop materials

1. Prepare additional background material, to be sent to experts prior to the workshop.
2. Prepare basic instructions (e.g., directions to hotel) for participants.
3. Prepare data sheets for expert assessment of various criteria.
4. Prepare non-map data for review by experts at the workshop.
5. Translate the above documents as necessary.
6. Review and finalize the above documents.
7. Send out background materials/instructions.

Maps for workshop

1. Prepare all map-based data.
2. Print copies of maps for the workshop, including base maps.
3. Transport maps to the workshop.

Workshop supplies and other requirements

1. Obtain, if necessary: paper, pens, flip charts, overhead transparencies and markers, overhead projector, screen, computer printer, name tags, masking tape, colored pencils/markers (for drawing on maps), white-out (for correcting mistakes).
2. Hire translator(s) and equipment, if necessary.
3. Gather books and any other useful reference material.
4. Collect any cash and traveler's checks required for per diems and other needs during the workshop.

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Preparing for an Assessment II: Methodology for Biological Importance 7

Introduction

Because no two ecoregions are the same, no two biological assessments conducted to date have followed identical processes. Each assessment has required, at a minimum, adjustments of the standard approach to accommodate oddities of the data, available expertise, and ecosystem characteristics. This has been especially true for assessments of freshwater features. A single model for a freshwater biological assessment does not yet exist, although most assessments will share some basic components.

Using these basic components as a guide, you can develop an approach tailored to your ecoregion. Develop the approach in full before beginning the actual assessment, particularly if you are conducting an expert workshop. The unexpected always occurs, and it is common to make changes to the approach while the assessment is under way, but the assessment will be most successful if you can keep these changes to a minimum. Although it is hard to devote time to preparations when there is pressure to move ahead quickly, preparing well for an assessment will save time and effort in the end.

In this chapter we begin by discussing representation analyses, focal species and processes, and minimum requirements. These are all subjects that influence the selection of biologically important areas. Next, we cover actual methods for selecting these areas, synthesizing different types of data layers, and assigning levels of biological importance to areas.

Step 1. Agree upon level and types of representation to be achieved, and algorithm for representation analysis

Representation of all distinct biodiversity features is a key goal of ecoregion conservation (see Chapter 1), yet in many ecoregions we lack information about how these features are distributed. For a data-poor ecoregion, you can conduct a representation analysis using surrogates for biodiversity information. A general approach would be to ensure that, within subregions, all major habitat types were represented in each of the subregions in which they occurred a minimum number of times (see Box 7.1 at the end of this chapter for a more detailed example from The Nature Conservancy). This would require having a rough map of where habitat types occurred, or constructing a map of "potential habitat types" based on soils, topography, rainfall, or other abiotic features. A second layer of analysis might check if all conservation targets identified in the conservation targets chart were captured across the ecoregion (see Table 5.2). A third layer might examine if connectivity within and between habitats was addressed, and a fourth might examine if all the processes required to maintain the conservation targets were addressed. We list these layers in order of increasing complexity — for example, almost certainly the protection of physical processes will require ecoregion- or subregion-wide policy initiatives in addition to the protection of priority areas, so incorporating this criterion into a representation analysis will be complicated.

We recommend that you conduct a representation analysis twice, if possible: once on the set of candidate priority areas, and again following the prioritization. For the second round, you will need to decide if you will apply the analysis to the highest priority areas only, or if you will use a larger subset of the candidate priority areas.

The representation analysis will require an algorithm, or set of decision rules. Take, for example, the representation of habitat types. A set of decision rules for candidate priority areas might resemble the following:

1. Within the set of candidate priority areas identified for each subregion, are all naturally occurring major habitat types represented? If yes, go to step 3. If no, go to step 2.
2. Add new candidate priority areas to achieve representation of all habitat types in each subregion. Go to step 3.
3. For candidate priority areas containing potential refugia habitats (e.g., tributary streams), are these habitat types represented a minimum of two times within a given candidate priority area, to

achieve interior redundancy and permit recolonization of habitats after natural disturbances? If yes or not applicable, go to step 5. If no and applicable, go to step 4.

4. Enlarge candidate priority area(s) to create redundancy of refugia habitats. Go to step 5.
5. Is each candidate priority area paired with another area containing similar species and habitats and located in a different catchment, to guard against regional disasters? Note: this is not possible for areas supporting locally endemic biotas. If yes or not applicable, representation analysis of habitats is complete. If no and applicable, go to step 6.
6. Add candidate priority area(s) to create paired areas in different catchments. Representation analysis of habitats is complete.

This is merely an example of a set of decision rules. The representation analysis that you formulate will depend on your ecoregion's conservation targets and habitat types. The more detailed the criteria in your representation analysis algorithm, the more areas you will potentially have to add to satisfy the criteria. You will inevitably have to strike a balance between representation and prioritization.

Step 2. Identify focal species, habitats, and processes, and determine minimum requirements

In Chapter 5 we recommended developing a conservation targets chart listing the biological features (conservation targets) that your vision is designed to conserve and the physical processes that maintain those features (Table 5.2). But what are the minimum requirements for maintaining those biodiversity features, and what will be required to maintain those processes within their natural range of variation? How do we know when our vision is ambitious enough and complete?

One approach is to identify focal species, habitats, or processes — a small subset of those in the conservation targets chart that you can use to set minimum goals. In principle, if we meet the minimum requirements of focal species, we will be protecting other, less-sensitive species as well. If we protect a minimum coverage of focal habitats, or protect them in key locations, we will be going far toward conserving the species that rely on them. Furthermore, protection of both focal species and habitats may be tied tightly to the maintenance of focal processes.

Attributes of focal species

Note that a focal species may meet more than one criterion. *Attributes specific to freshwater species are in italics.*

Biological characteristics

- Space-demanding/wide-ranging
- Population seasonally/daily concentrated, and/or aggregate during part of life cycle
- Limited dispersal ability
- Low reproductive rate
- Large-bodied/largest member of feeding guild
- Specialized dietary, habitat requirements (particularly breeding, nursery sites)
- Dependent upon rare, widely dispersed habitat
- Climatic sensitivity
- *Adapted to particular flow regime, water level, flood cycle*
- *Narrow temperature or water chemistry requirements*
- *Sensitive to pollution*
- *Migratory, with specialized spawning sites*

Population status

- Population small or declining
- Meta-populations with unique genetic compositions

Human-impact factors

- Population threatened by direct exploitation, harassment, or ecological interactions
- Habitat threatened by loss, conversion, degradation, or fragmentation
- New and large markets for consumptive use

Terrestrial biological assessments have typically identified as focal species those requiring large areas of habitat. Combining information about demography with minimum habitat requirements can yield an estimation of the minimum amount of habitat needed to maintain a viable population of that species. As we noted in Chapter 3, we have inadequate demographic information for all but a few aquatic species, and in many aquatic habitats there will not be wide-ranging species.

In certain freshwater habitat types, such as large rivers, there is a greater likelihood of identifying species with sizable habitat requirements. Examples are large aquatic mammals or reptiles. Migratory fish present another possibility — their distance requirements, if known, could shed light on the length of uninterrupted river needed to sustain them.[31] More likely, migratory fish will have particular habitat needs at different life stages, or they may have specific spawning locations. This does not invalidate migratory fish as focal species — it simply means that their minimum requirements may involve a temporal element, and their habitat needs may be location-specific. When considering minimum habitat requirements, remember that aquatic systems, and particularly lakes and wetlands, are three-dimensional systems, and that the volume of habitat (which will be a function of size, depth, and steepness of sides for lakes) may be as important as the areal extent (Preston and Bedford 1988).

Taxa adapted to particular flow regimes or water levels may also be focal species, with their requirements serving the same function as area requirements in the terrestrial model. Particularly in habitats such as small stream systems, where it may be difficult to find examples of large species or those with substantial space requirements, species with other strict habitat needs may be the best focal species. In general, for freshwater species, *the presence of the right kinds of habitat may be more important than the extent of that habitat,* particularly for those that require markedly different habitat types during successive life stages (see Box 3.1). In other words, focal species may require linked focal habitats.

Some focal species may face threats unrelated to habitat loss. For instance, they may be imperiled by exotic species or by overexploitation. In these cases, protection of these species may require not only the establishment of protected areas free of exotics or where exploitation is prohibited, but also the implementation of mechanisms preventing introductions and overexploitation in connected habitats.

As discussed in Chapter 5 (Box 5.3), species and the ecosystems they inhabit occur over different scales. For that reason, focal habitats will occur over different scales as well. Focal habitats could be as small as groundwater seeps or as localized as a set of river rapids, or they could be as large as floodplain forests or as extensive as hyporheic zones. Or, they could be as fixed as peat swamps or as temporary as ephemeral streams. Some focal habitats may not technically be "habitat" for aquatic species at all, but will still be critical for maintaining aquatic biodiversity. For example, in headwaters riparian forests provide essential organic matter inputs and shade to streams, and cloud forests may be critical for maintaining the hydrologic cycle. Some focal habitats will serve their function only if they are protected to a minimum extent. Others must be protected in a particular location. And many cannot be protected without consideration of physical processes. Do your best to articulate the parameters that will define success for protecting focal habitats.

Defining success for the protection of focal processes is likely one of the hardest tasks of developing a vision. It is necessary not only to define the natural range of variation within which the given process operates, but also to identify what will be required to protect or restore the process within that range. In some situations, solutions will be obvious and discrete. For example, in regulated rivers, removing an impoundment or modifying water releases to mimic the natural hydrograph could go far in restoring the flow regime; water withdrawals could be regulated to the same end; or levees could be removed to re-connect a river with its floodplain.[32]

More often than not, however, protection of physical processes will be tied to more diffuse activities on land. The terrestrial landscape lends itself more to thinking in terms of minimum sizes. For instance, we could recommend that 30% of a catchment remain in forest cover to protect overland flows, or that 95% of the riparian zone remain vegetated to buffer streams from sediment and other inputs, to contribute organic material, and to provide shade. Rarely will good studies exist to suggest how much land must be protected, the level of protection it should receive, or how protected areas should be configured (e.g., does it matter if protected areas are scattered throughout the terrestrial landscape, or do they function better if contiguous?). Comparatively more research exists on the width of riparian zones that should be vegetated to function effectively as buffers (Wenger 1999) (Figure 7.1).

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[31] Migratory fish may be true keystone species. There is evidence that in some regions aquatic communities with viable diadromous populations differ from other communities in recruitment dynamics, nutrient budgets, and predator-prey interactions (Angermeier and Winston 1999).

[32] It is worth noting that a natural flow regime might include dry periods and low water levels, to which native species are adapted. Complete or partial drying of streams can be a natural process that is prevented from occurring as a result of reservoir operations (Stanley et al. 1997).

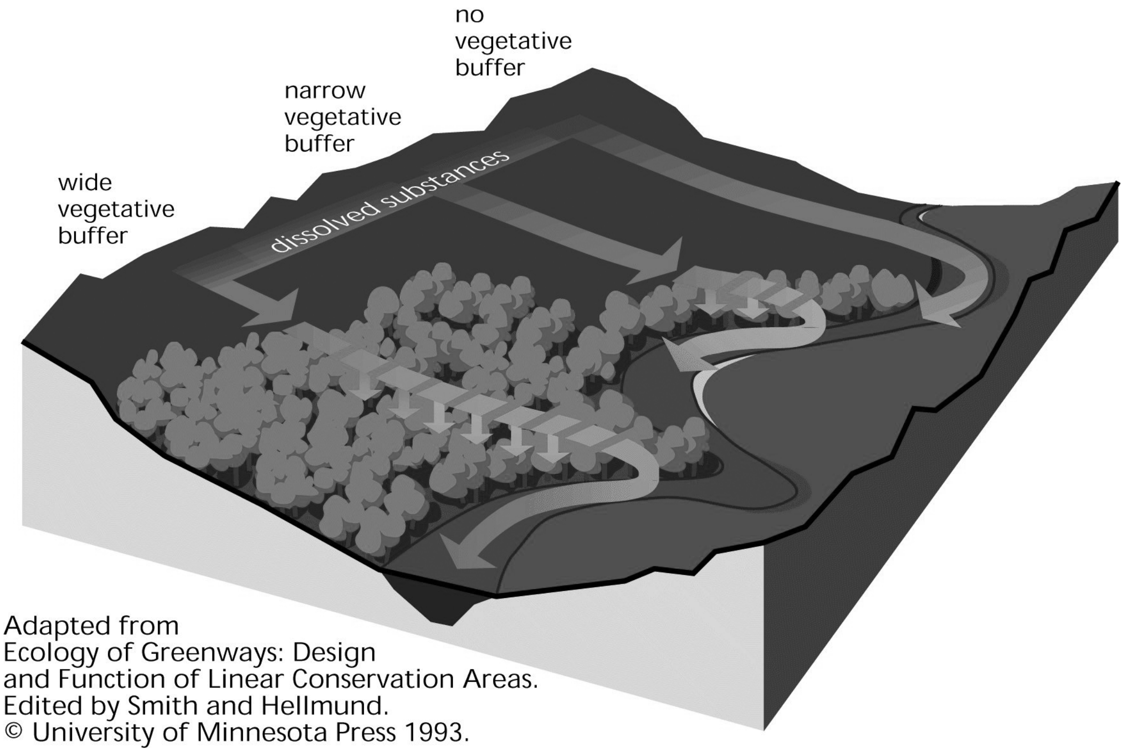

Figure 7.1. Influences of riparian buffer width on filter and barrier functions. (Taken from: Federal Interagency Stream Restoration Working Group 1998. Reproduced with permission by the University of Minnesota Press.)

Identifying minimum requirements associated with focal species, habitats, or processes may necessitate a thorough search of the literature, coupled with educated guesswork. After identifying one or more focal elements, you may find that a desk study is a good avenue for generating information on minimum requirements. This is not necessarily the kind of information that resides in experts' heads, so without doing homework on this subject you may be unable to incorporate focal elements into your assessment in a meaningful way.

Step 3. Agree upon criteria for identifying candidate priority areas

Once you have decided what features to focus on protecting and what you estimate will be sufficient for protecting them (both in terms of minimum requirements and representation), you are prepared to think about how to transfer these ideas to an assessment. Traditionally, assessments have focused primarily on identifying biologically important areas on a map. In Chapter 5 we recommended that you consider how you would capture elements that are not spatial and cannot be represented on a map. Although we focus the remainder of this chapter on map-based priorities, we underscore the importance of giving other kinds of priorities the attention they require in your assessment and vision.

An integral part of ecoregion conservation is the identification of areas that are priorities for some form of protection. Typically, the first step is the identification of candidate priority areas. Refer to your conservation targets chart (see Table 5.2) to choose those criteria that you will emphasize in your identification of candidate priority areas. Most terrestrial assessments have focused on areas supporting endemic species, those with high species richness, those associated with ecological or evolutionary phenomena (e.g., key sites for migratory bird congregations), those containing rare habitat types, or occasionally those harboring imperiled species. All of these criteria certainly apply to freshwater systems as well, but we suggest also considering physical processes. Chapter 4 provides examples that should help to generate ideas. These examples recognize that all priority areas will not necessarily support important biodiversity features, but instead may play important functional roles.

Step 4. Agree upon methods for representing candidate priority areas on maps

Once you have selected the criteria you will use to choose candidate priority areas, you may still wonder what we mean by an area. How big should an area be, and how should it be defined? These questions are especially relevant to an assessment of freshwater features, which can be difficult to represent on a map. Should a map of priorities display only aquatic habitats, or should it identify entire catchments draining to priority habitats? If it identifies whole catchments, how should large river mainstems be treated (this would require delineation of virtually entire major river basins)? How should highly localized important areas (e.g., rapids, caves, springs) be represented on a map? If all headwaters or riparian zones are considered conservation priorities, how should these be delineated on a map? How should important subterranean or groundwater areas be noted?

We cannot offer strict guidelines for addressing these issues, because every ecoregion is different. For most ecoregions, species and habitat distribution data will be spotty, and erring on the side of caution would suggest delineating the entire catchment draining to an area known or suspected to contain important biodiversity elements. This is the approach that the assessment team undertook for the Amazon River and Flooded Forests ecoregion; workshop participants identified priority catchments first, with the understanding that they could subsequently identify smaller areas of conservation importance within them. For the lower Mekong, experts identified widely separated riverine habitats that were known to be important for focal migratory fish species, and they then identified the entire length of river in between those areas as a priority corridor. In this case, the experts chose to use different colors on their maps to signify the different functions of the priority areas. It may be impossible to represent all priority areas in the same manner on a map (some may be linear, some polygonal, etc.), and priority areas may occur at very different scales.

If you are conducting an assessment outside of a workshop venue, the approach to mapping priority areas can evolve as you progress. But if you are conducting an expert workshop, you will need a well-planned approach for mapping priority areas before you begin the assessment. When you present the approach to the experts they may have good suggestions for improving it, which you can incorporate before you begin. But, we caution against entering a workshop without a well-defined approach in mind, because unless you are working with a very small group it is highly likely that individuals will take different routes to delineating areas. Not only will this lead to incompatible priorities, but it can make transferring those areas to a GIS quite challenging.

In addition to those issues raised above, others that you might consider include:

- *Labeling issues.* Most assessments have suffered from difficulties associated with labeling candidate priority areas, and the conversion of those labels when different types of candidate priority areas are combined (see Step 5 for a discussion of combining areas). In freshwater assessments, one of the more common problems has occurred when one expert has identified a subcatchment as a candidate priority area, and another expert working separately has identified one or more small areas within that same subcatchment. The result is embedded priorities at different spatial scales. One potential solution to this problem might be to begin the assessment with a map on which all subcatchments were assigned a unique label (e.g., subcatchments A, B, C...), and all candidate priority areas subsequently identified within those subcatchments were labeled accordingly (e.g., areas within subcatchment A would be labeled A1, A2, A3, etc.). In this way, you could choose to give higher priority to catchments containing multiple sites, especially when those sites were connected.

  Similarly, because catchments occur at multiple embedded scales, experts may identify a priority catchment-within-a-catchment. This occurred in the Congo River Basin assessment, where experts identified the entire Ivindo River catchment as a candidate priority area as well as the entire Ogooue River catchment, which includes the Ivindo. This created difficulties during the prioritization process, because the experts assigned different levels of biological importance and ecological integrity to the two areas. We have no good solution to this problem, other than to establish at the beginning of the assessment the maximum scale at which you expect catchments to be identified, and to prepare the maps accordingly. The Congo Basin assessment was perhaps anomalous because the region of analysis was enormous (composed of 24 individual freshwater ecoregions), and the nearly complete lack of biodiversity data encouraged the identification of very large candidate priority areas.

Consider ways of keeping important areas "linked" via the labeling process if their biological importance depends on the protection of all of them — such as if they provide habitat for different life stages of one or more focal species.

- *Differentiating target types.* It is highly unlikely that all of your candidate priority areas will be identified for the same reasons. Not only will you identify areas (including corridors) that are important for different taxonomic groups, you may also identify focal habitats, areas important for maintaining physical processes, or areas that address the other elements listed in your conservation targets chart (Table 5.2). If you are conducting a workshop with a large number of experts, you will likely divide them into smaller working groups so that each focuses on one or more of these target types.

  When mapping areas, try to differentiate among the different target types. You can achieve this through application of different colors or map symbols, but we recommend also developing a standardized labeling scheme for identifying different target types, because it is difficult to control how individuals draw on maps. Differentiating among target types in a GIS is also useful because you will be able to display the different levels and kinds of conservation actions associated with each target type.

- *Research priorities.* An additional type of target may be areas that experts suspect are important biologically but that require scientific investigation. In poorly studied ecoregions, these areas may be far more numerous than known areas. Before beginning an assessment you should have an idea of how extensive the research gaps are, and you can develop an appropriate approach for mapping them. You may be able to highlight subcatchments that are poorly studied without much difficulty (although you may want to undertake this exercise for each taxonomic group separately). For the Congo Basin, so few areas had been studied that the experts chose to map known rather than unknown areas, differentiating between those for which current information existed and those with historic, unpublished data housed in museum collections.

  In general, we suggest mapping information gaps or research priorities (these are not necessarily identical — be clear about which you are mapping) separately from other priorities. This is a good idea because experts may be reasonably confident that unstudied areas contain important biodiversity features, and they may choose to identify these as candidate priority areas; a separate map of information gaps would show that low data confidence was associated with these areas.

- *Multiple maps.* With multiple types of candidate priority areas, or even multiple taxonomic groups, you will probably want to begin by delineating sets of areas on different maps (as noted above). We caution against allowing experts to delineate the same kinds of candidate priority areas on separate maps, even if it speeds the process, for two reasons. First, two or more experts may identify identical or overlapping areas, and your GIS staff will then have to interpret how to combine those areas in a single GIS coverage. Each area will have its own data sheet, and you will have to decide how to combine that information as well. Second, if experts collaborate on identifying candidate priority areas, the results will probably be more robust and comprehensive than if they work alone.

  In general, we encourage experts to work together in small groups, even if one expert is the only person familiar with a given region or conservation target. In the face of time pressure it is tempting to allow a single expert to work alone on a map, but this not only increases the likelihood of incompatible results but also inhibits information sharing. One of the best features of a workshop is that it provides a forum for experts from different fields to learn from each other and in doing so broaden their understanding of the ecoregion as a whole.

- *Map annotation.* Whoever is delineating candidate priority areas on a map must be responsible for labeling them appropriately. In some situations this will require that an overseer provide that person with the appropriate label — for instance, if several people are working on a map at once and it is unclear what the next number in a series should be. Ideally, to minimize confusion only one area would be delineated on a map at a time, but this seldom occurs. Also ideally, a single person would be responsible for delineating all areas on a given map, to ensure standardization of delineation and labeling. In any case, someone must be responsible for ensuring that all areas on the map are labeled and that a corresponding data sheet exists for each area. This is a critical job, and we recommend explicitly assigning that role to someone.

- *Data sheets.* Areas delineated on a map have little meaning by themselves. It is essential that every candidate priority area have a data sheet on which the "author" of the area has described the features that distinguish it. The design and content of the data sheet is your choice; we offer some examples in Appendix V. For those candidate priority areas that are unexplored scientifically, at a minimum the author should write his/her name, the area label, the area name, the area's general location, and the features that the area is presumed to have. In many workshops we have found that it is more efficient for one or more scribes (with legible handwriting) to be responsible for filling out all data sheets, with the experts dictating what to write in each data sheet field. This tends to result in more comprehensive results (if the scribe is conscientious and presses the experts to give complete responses). One or more workshop participants are often quite willing to serve as scribes. These individuals sometimes have more limited expertise and serving as a scribe maintains their engagement in the process, plus they are able to record the information quickly because they are broadly familiar with the geography and biota of the ecoregion.

  Once you are finished with the identification of candidate priority areas, ensure that no data sheets are missing and, if possible, transfer the information on the sheets to a computer. This will enable you to clear up any confusion while the authors are still present, or at least before they have forgotten what they intended to write.

- *Lentic systems.* Up to this point we have dealt primarily with lotic systems. But how should priority areas for lakes, ponds, and wetlands be represented on maps? For most small lakes (ponds) and wetlands, the process should be relatively straightforward. These areas are easily delineated on a map, and if appropriate the entire catchments draining to them can be identified. For lakes with no outlet (endorheic systems) this approach is a bit problematic, because all lands surrounding the lake will drain to it. In this case, you may choose to highlight the lake as the priority aquatic habitat, and individual catchments draining to the lake as priorities for their role in maintaining physical processes in the lake (or, in some cases, influent rivers will provide essential habitat for spawning lake fish). But what is the approach for very large lakes, or those that define the entire ecoregion (e.g., Lake Malawi, Lake Baikal)? For these systems it will probably be most appropriate to identify priority areas within the lake, as well as priority areas draining to it. The Reconnaissance Study for Lake Malawi provides some excellent ideas about approaches to large lake prioritization (Ribbink 2000).

Step 5. If multiple types or layers of candidate priority areas will be generated, agree upon method of synthesis

As noted above, you will almost certainly generate multiple types or layers of candidate priority areas. Before embarking on an assessment, think about if and how to combine these areas. Will all areas deemed important for fish be combined with all areas important for other taxa, to create a single taxa map? In past terrestrial assessments, areas important for individual taxa as well as for phenomena have been combined into new areas, following areas of overlap (see Figure 7.2); the underlying information is retained, because experts have often decided to give higher priority to areas that were important for multiple taxa.

In past assessments of freshwater features we have not followed this approach for two main reasons. First, we have never had strong biological data for taxa other than fish, and data for fish have only rarely been complete. Given these data gaps, it has not made sense to elevate only areas of overlap; instead, we have carried all identified areas forward in the analysis. Second, we have not found that it is possible to lump different target types together to generate amalgamated areas, because different target types are often represented very differently on maps and the values of these areas cannot be compared objectively to each other. However, we encourage you to think creatively about how to combine multiple candidate (or nominated) priority areas — and, as before, to agree upon a method before embarking on an assessment.

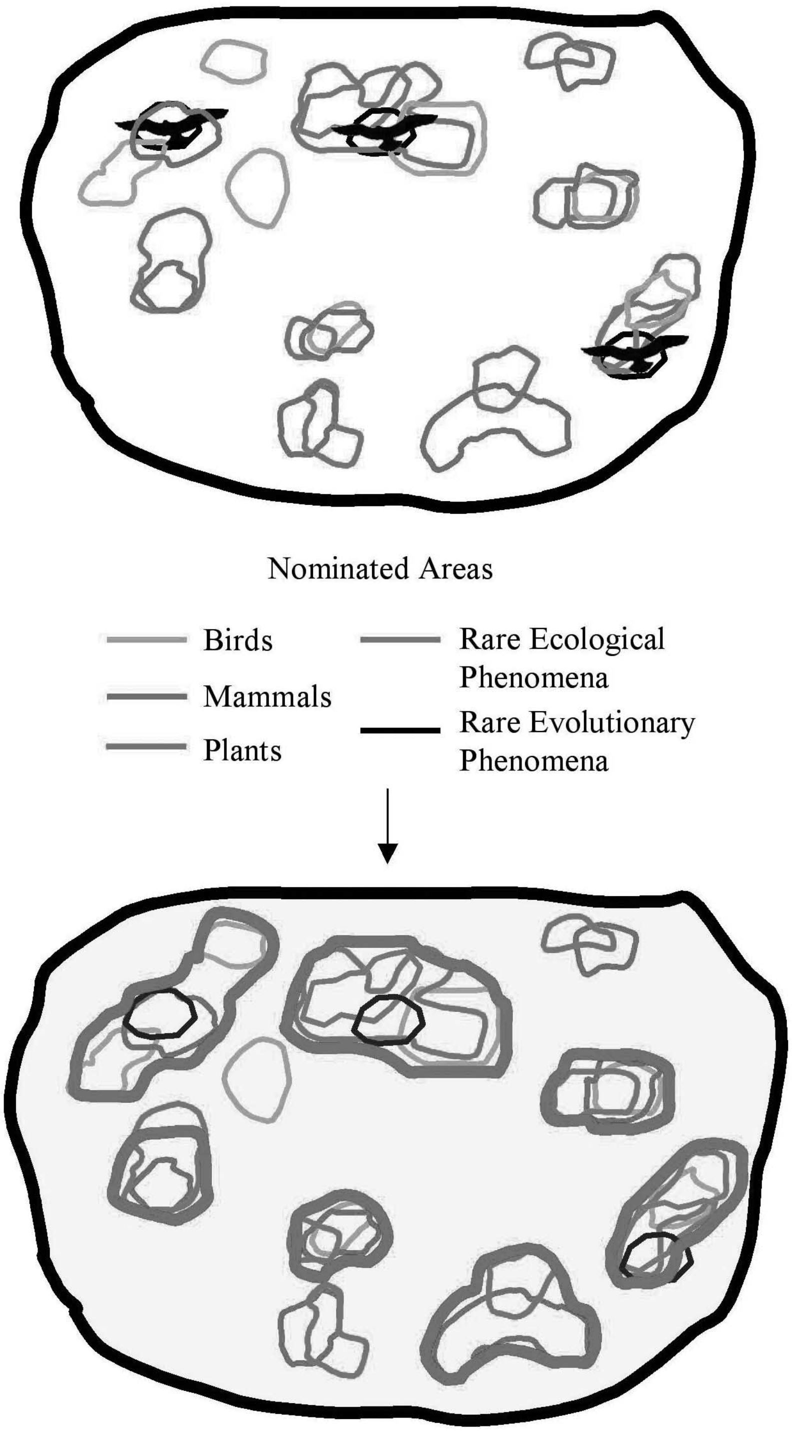

Figure 7.2. Synthesis of multiple nominated (or taxon) priority areas into candidate priority areas, for a hypothetical terrestrial example.

Step 6. Agree upon method for evaluating biological importance of candidate priority areas

In a typical assessment, the step following the identification of candidate priority areas is the evaluation of those areas' *biological importance*. We use the term biological importance broadly to refer to the relative value that these areas confer to maintaining the overall biodiversity of the ecoregion. In other words, a candidate priority area may not contain high levels of species richness or endemism, but it may still have high biological importance because it functions in a way to maintain one or more of the conservation targets identified for the ecoregion.

The method that you choose to evaluate the biological importance of candidate priority areas will be a function of the quality and kinds of data that are available, and the criteria that you have used to identify areas. For data-poor ecoregions, you will probably be unable to assign more than three levels of biological importance (i.e., highest, high, moderate; by definition, an area selected for its importance should not receive a "low" rating). However, it seems that experts are loathe to assign the lowest level to any area, so it may be smart to use a four-tiered or five-tiered system, to achieve better discrimination.

When constructing a method of evaluating priority areas, look to the criteria that you developed for identifying them. You may decide to evaluate each candidate priority area based on all of the selection criteria combined, and then apply decision rules for assigning levels of biological importance (e.g., areas identified because they harbor distinct biodiversity elements plus one other criterion receive a "highest" rating, etc.). Or, you may choose to apply more specific criteria to each type of candidate priority area separately (e.g., for areas identified for distinct biodiversity elements, those with high endemism and richness receive a "highest" rating).

Another method that we have not explicitly tested is ranking all areas in a given group, and then dividing the ranked list into categories (Figure 7.3). This approach is based on the assumption that it can be easier to compare candidate priority areas against each other than against a standard; that is, it seems easier to decide that one area serves a more important function than another than to decide that it contains "very high" versus "high" endemism levels. Also, the ranking approach would allow limiting the number of areas assigned the highest importance level. This approach assumes that all experts are working together in a single group and that they are all familiar with most of the identified areas.

There is no "right" way to evaluate biological importance; simply develop an approach that matches the kind of information that is available. For example, it would make little sense to evaluate biological importance based on species endemism if no species-level distribution data existed. Make the process as standardized as possible, and prepare to document the reasoning behind the evaluations, either on data sheets or in another format.

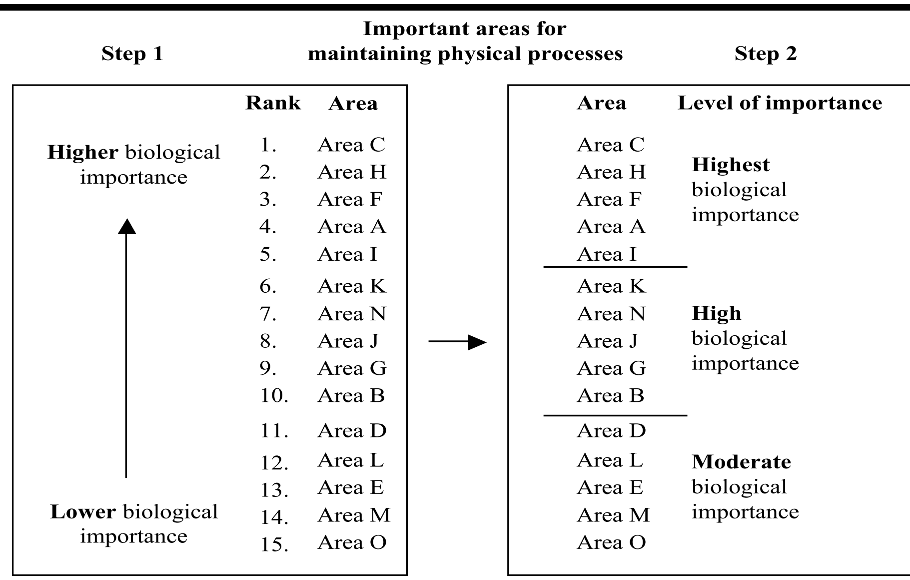

Figure 7.3. Example of a ranking approach for assigning levels of biological importance.

Conclusion

This chapter has covered the basic steps for identifying areas of biological importance within a freshwater ecoregion. We have touched briefly on the subjects of ecological integrity and prioritization, and in the following chapter we examine these topics in more detail.

Box 7.1. Goals for representation of aquatic targets, from The Nature Conservancy. (Adapted from: Smith et al. 2001.)

The Nature Conservancy (TNC) is an international conservation organization that, like WWF, conducts ecoregion conservation. In the southeast United States, TNC has identified "Areas of Freshwater Biodiversity Significance" through a data-intensive methodology. The approach, in brief, is a six-step process:

1. Develop a stratification of freshwater ecoregions (**Ecological Drainage Units**) to create manageable assessment units and to guide protection of conservation targets in all ecological settings.
2. Select **Conservation Targets** (**Freshwater Species** and **Aquatic Ecological Systems**) to be the focus of conservation assessment efforts.
3. Set **Conservation Goals** for targets (e.g, how many occurrences across what spatial ranges and environmental gradients do we need to protect to ensure survival?)
4. Identify **Viable Occurrences** of aquatic targets.†
5. Delineate **Areas of Freshwater Biodiversity Significance** for each ecoregion.
6. Identify **Data Gaps** and analyses to further work.

Ecological Drainage Units (EDUs) are a set of ecologically-based assessment units within ecoregions. EDU's are groups of watersheds (8-digit U.S. Geological Survey Hydrologic Units) with similar patterns of physiography, drainage density, hydrologic characteristics, connectivity, and zoogeography. Identifying and describing EDUs allows for the stratification of basins into smaller units to better evaluate patterns of aquatic biodiversity and set conservation goals.

The Freshwater Species targets for each ecoregion include imperiled, endemic, declining, and wide-ranging species. Target lists include fishes, mussels, aquatic snails, crayfishes, and some aquatic insects and obligate aquatic amphibians and reptiles.

Aquatic Ecological Systems are rivers, streams, and lakes with similar geomorphological patterns tied together by ecological processes (e.g., hydrological and nutrient regimes, access to floodplains) or environmental gradients (e.g., temperature chemical, and habitat volume), and form a distinguishable unit on a hydrography map. They are used as "coarse filters" to assure that untracked common species and communities are also captured in the ecoregional portfolio.

Conservation goals define the number and spatial distribution of on-the-ground occurrences of targets that are needed to adequately conserve them in an ecoregion for at least 100 years or 10 generations (whichever is longer). Setting such goals also enables planners to measure how successful a portfolio of conservation areas is at representing and conserving targets in an ecoregion. Goals are constructed with the assumption that EDUs are the fundamental subregional units of environment, zoogeographic, genetic, and evolutionary process variation within a species distribution. The most biologically meaningful goal is assumed to be the number of populations required to maintain an acceptable probability of target persistence within an EDU. Conservation goals are shown in the tables below.

† One of the primary differences between the TNC and WWF approaches is that TNC identifies only viable (intact) populations and habitats within its prioritization.

Goals for representation of species targets.

*Global rank**	*Distribution relative to basin*	*Stream/river size inhabited by target*	*Number of populations desired per EDU*
G1-G2	Endemic (>90% of range in basin)	Large rivers	1
		Small rivers	2
		Creeks/headwaters	3
	Widespread	Large rivers	1
		Small rivers	2
		Creeks/headwaters	3
G3-G5	Endemic (>90% of range in basin)	Large rivers	1
		Small rivers	1
		Creeks/headwaters	2
	Widespread	Large rivers	1
		Small rivers	1
		Creeks/headwaters	2

* G1 = Critically Imperiled (typically 5 or fewer occurrences or 1,000 or fewer individuals)
G2 = Imperiled (typically 6-20 occurrences or 1,000 to 3,000 individuals)
G3 = Vulnerable (rare; typically 21 to 100 occurrences or 3,000 to 10,000 individuals)
G4 = Apparently secure (uncommon but not rare; some cause for long-term concern; usually more than 100 occurrences and 10,000 individuals)
G5 = Secure (common; widespread and abundant)

The first table shows goals for species targets. For example, an imperiled species that is endemic to the region of analysis and occurs in large river habitats should be represented at least once in each EDU. An imperiled, endemic species that occurs in small river habitats should be represented at least twice, or three times if it occurs in creeks/headwaters. These numbers were chosen because the number of intact large river reaches of the minimum size (40 km) will be fewer in any given EDU, but each will probably support multiple populations (occurrences) of that species. The goals are slightly reduced for less imperiled species.

The second table shows the goals for aquatic ecological system targets. In addition to the species targets, there must be at least one large or medium river represented in each EDU, 2 small rivers, and 3 creeks/headwaters. Additionally, there are minimum size requirements for each habitat type, based on general information about the length of river or stream required to support a viable species population.

Conservation goals for aquatic ecological systems targets.

Category of target	*Number of occurrences by EDU*	*Minimum length*
Large or medium rivers	1 per EDU	40 km
Small rivers	2 per EDU	15 km
Creek/headwater	3 per EDU	5 km

Box 7.2. Identifying biologically important areas and conducting a representation analysis for a data-poor ecoregion.

The identification of biologically important areas will likely be quite different for data-rich versus data-poor ecoregions. Box 7.1 describes an approach for representation that The Nature Conservancy has applied to data-rich ecoregions in the Southeast USA, and Figure 5.2 displays a habitat classification for a similarly data-rich region in the Pacific Northwest, USA. But what kind of representation analysis and biological importance assessment can you undertake for an ecoregion with little or no data at such fine scales?

The Amazon River and Flooded Forests ecoregion provides an example of one possible approach. The ecoregion team had species-level data for relatively few locations, and expert familiarly with the vast ecoregion was equally uneven. The team was, however, able to classify the major aquatic and flooded habitats through interpretation of satellite images (Landsat) at a scale of 1:250,000. The habitat types were:

- lakes
- small rivers and streams
- complexes of riparian habitats
- swamps (herbaceous/shrub-dominated)
- islands
- *terra firme*
- beach habitat — Brazil
- aguajales (palm-dominated) — Peru
- degraded/deforested habitat

To conduct a prioritization, the ecoregion team first divided the ecoregion into subregions. Fourteen subregions were delineated, based on catchment boundaries, floodplain dynamics, amplitude of flooding, limnological variations, sedimentation patterns, and the influence of the marine environment. These subregions are shown in Figure 7.4.

The next step was dividing the subregions into large catchments. These catchments served as the unit of analysis for the remainder of the prioritization effort. Within the final prioritization, at least one catchment within each subregion had to be represented, based on the assumption that this approach would ensure the representation of all major biotic communities. The catchments are shown in Figure 7.5.

Without species-level data, the ecoregion team decided to base its biological importance assessment on the diversity and uniqueness of habitats within each catchment. The criteria for deriving a biological importance "score" for each catchment are given in Table 7.1.

After scoring each catchment's biological importance, the ecoregion team then undertook similar analyses of conservation status (habitat intactness), threats, and opportunities for each catchment (described in Tables 8.1 and 12.1). This information was combined with biological importance to identify priority catchments. These priority catchments still constitute enormous areas, and the ecoregion team's next steps included identifying location-specific strategies within those catchments as well as ecoregion-wide strategies to address overarching threats.

Figure 7.4. Subregions of the Amazon River and Flooded Forests ecoregion.

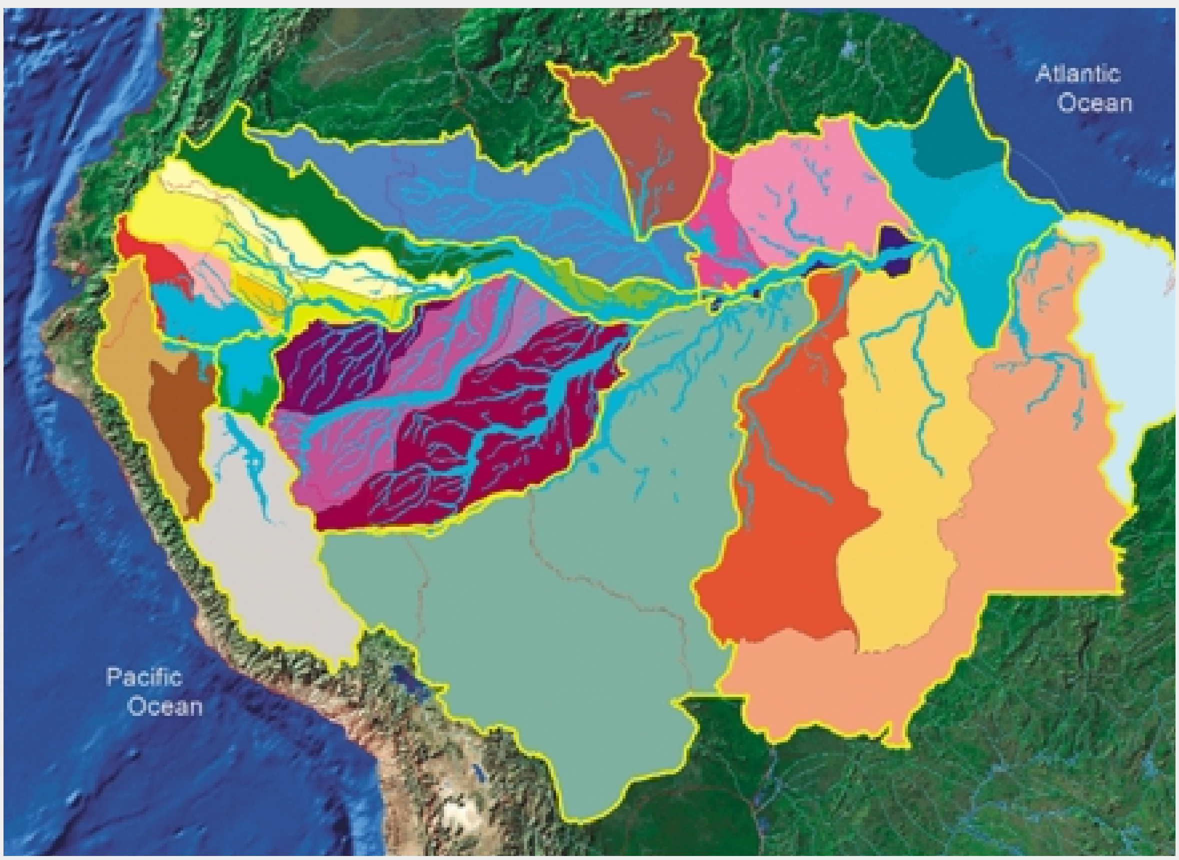

Figure 7.5. Major catchments within subregions of the Amazon River and Flooded Forests ecoregion.

Table 7.1. Biological importance criteria for the Amazon River and Flooded Forests ecoregion.

Criteria	*Indicators*	*High*	*Medium*	*Low*	*Weight*
Shannon-Weaver Index (total area of each habitat type as proportion of flooded forest portion of each catchment)	index	high	medium	low	30%
lakes (>50 hectares)	percentage of flooded forest	high	medium	low	5%
	classes of water	>2	2	1	5%
secondary rivers and streams	percentage of flooded forest	high	medium	low	5%
	classes of water	>2	2	1	5%
islands (>500 hectares)	percentage of flooded forest	high	medium	low	10%
rapids	number in each catchment	high	medium	low	10%
biological importance (as determined by PRIOBIO, PROVARZEA, expert analysis)	percentage of catchment prioritized in prior exercises	>50%	25–50%	<25%	10%
habitat singularity	presence/absence of singular habitats with respect to the entire ecoregion	high	medium	low	20%

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Preparing for an Assessment III: Methodology for Evaluating Ecological Integrity and Prioritizing Important Areas 8

New approaches place less emphasis...on the total number or area of habitat preserves and more emphasis on the spatial and temporal relationships of preserves to one another.

— Bisson (1995)

Introduction

In the last chapter we focused on identifying areas that are important for maintaining an ecoregion's biodiversity features. But not all important areas will exhibit the same degree of habitat intactness. Some will be in good condition and, with sufficient protection, could remain intact. At the other extreme, some areas will be so degraded that no amount of restoration outside of heroic efforts could bring them back to life. And then there are the majority of areas that fall somewhere in between the two extremes.

Even intact areas, however, may be unable to support viable populations of focal species over the long term because of insufficiencies of size, connectivity, or other characteristics. When prioritizing among biologically important areas, we need to go beyond habitat intactness to consider issues of *ecological integrity* — the likelihood that the species and communities in that area can endure over the long term, barring additional disturbances. And yet, even areas whose current condition confers high ecological integrity may face serious impending threats, so we need to consider future threats when developing a conservation strategy.

In this sourcebook we have already presented the major principles related to ecological integrity. In Chapter 5 we recommended constructing a conservation targets chart that identified the physical processes necessary to maintain key biodiversity features, as well as the threats to those processes and features. In Chapter 4 we discussed issues of connectivity, refugia, and the need to represent habitats more than once to guard against stochastic disturbances.

In this chapter we address methods of evaluating ecological integrity and ways of integrating this information with biological importance to prioritize among areas. When everyone on the ecoregion team agrees how to conduct these steps, you will be in a good position to conduct an assessment. Note that we discuss additional assessment steps requiring less preparation in Chapters 9-13.

Step 1. Agree upon method for evaluating ecological integrity of candidate priority areas

Habitat intactness

When evaluating the habitat intactness of candidate priority areas, you will probably be concerned with some or all of the following issues:

- Size and extent of remaining intact habitats within the candidate priority areas (How big are functional wetlands? What is the extent of unfragmented stream reaches? What is the width and length of riparian buffer zones?)
- Longitudinal distribution and connectivity of intact habitats (How are intact aquatic and riparian habitats distributed among upstream, middle, and downstream parts of the catchment, and are they contiguous or interrupted?)
- Transverse distribution and connectivity of intact habitats (Are aquatic habitats connected with floodplains and riparian zones? Are main channel habitats connected with backwaters, floodplain and oxbow lakes, etc.?)
- Distribution of intact habitats (How are intact habitats distributed spatially and among different habitat types?)
- Extent of upland development within catchments (What percentage of original land cover remains?)
- Extent of fishing and other species exploitation within otherwise intact habitats
- Degree of habitat fragmentation as a result of impoundments, channelization, pollution, etc. (Where are there barriers to instream migration?)
- Extent of hydrologic modifications in space and time (How natural is the flow regime, taking into

account volume, seasonality, and duration of flows?)
- Degree of heterogeneity of aquatic habitats at the catchment scale
- Degree to which exotic species have become established and the existence of dispersal mechanisms
- Extent of protected areas, their overlap with intact aquatic habitats, and the degree of protection actually afforded to aquatic habitats (Is fishing prohibited? Are entire subcatchments covered?)
- Degree of water quality degradation from point or nonpoint source pollution (e.g. thermal pollution, excessive sedimentation)
- Existence of "time bombs" — past or present activities with a high probability of seriously degrading freshwater systems in the future (e.g., catchment deforestation leading to irreversible salinization, presence of aging pipelines)

With these kinds of issues in mind, decide the best way to evaluate the intactness of candidate priority areas. In most ecoregions, experts will have visited only a fraction of the candidate priority areas in the recent past (unless they have favored their own study sites in their selection of candidate priority areas), so they will be unable to evaluate the intactness of all areas from their own experience. Furthermore, freshwater biologists are often unaware of catchment-wide land uses and even of the state of aquatic habitats upstream or downstream from their study sites. This argues for involving experts with a good understanding of land uses at the landscape scale, who can complement taxonomists and other specialists. It also requires that we develop methods for evaluating the habitat intactness of candidate priority areas without having to rely on existing field measurements.

There are a number of methods for estimating the level of intactness of aquatic habitats at a broad scale, ranging from simple analyses requiring a minimum of landscape-scale data to much more sophisticated models (see Johnson and Gage 1997 for an overview). Most of these methods are based on the principle that the quality of aquatic habitats is related largely to land use within the catchment. For these approaches, then, catchment maps are a prerequisite. If your candidate priority areas correspond to catchments, whole-catchment analyses will provide information that you can use directly in your evaluation of habitat intactness. If your candidate priority areas are portions of catchments, you will need to consider if you can use catchment-scale measurements or if you will need to develop a different approach. By and large, you probably could evaluate the intactness of such areas on the basis of the intactness of the catchments in which they occur.

Here we briefly describe some possible approaches; in Chapter 15 we provide some additional information on using remotely sensed data for these analyses. This is not an exhaustive list of approaches, and you may have access to a dataset that we do not discuss here.

- *Proportion and number of land uses in a catchment*. There is ample evidence that the proportion of land use in a catchment is highly correlated with water quality (sediment load and nutrients), and that land uses affect overland flow (runoff) (Kiersch 2000). A coarse way to evaluate the level of intactness of a catchment's aquatic habitats is to look at the proportion of land uses in that catchment, through classification of remotely sensed imagery. Depending on the natural vegetation cover, the types of current land use, and the resolution of available imagery, you could do any of a number of analyses. Some possibilities include:

  - Proportion of catchment area with anthropogenic land cover (e.g., the U-index, which is the proportion of urban and agricultural land cover[33]) (Jones et al. 1997)
  - Proportion of catchment area with agricultural land cover
  - Proportion of catchment area in row crops and proportion in pasture
  - Proportion of catchment with forest cover
  - Number of natural land cover types per unit effort (e.g., per 100 km^2)

  More sophisticated analyses are possible if you have appropriate data. For example, it is possible to identify the hydrologically active areas in a catchment, defined as the areas that produce surface runoff (Hunsaker and Levine 1995). You can then restrict the calculation of land cover types to those areas.

- *Configuration and size of land use*. There is some evidence that the spatial pattern of land use affects aquatic habitat integrity, although the results of studies addressing this issue have been mixed (Hunsaker and Levine 1995; Hunsaker et al. 1998). In general, studies find that the greater the size, con-

[33] Including pasturelands.

nectivity, and dominance of forest patches, the better the water quality of aquatic habitats. Analyses that could follow from this include:

- Average forest patch size as a percentage of catchment area
- Index of forest connectivity (e.g., probability that a randomly selected forest spot on the map is adjacent to another forested spot)
- Dominance (measure of the extent to which one or a few land uses dominate the landscape)

■ *Land uses adjacent to aquatic habitats.* There is ample literature discussing the benefits to aquatic habitats of riparian zone vegetation (see Chapter 4 for overview), and the technology for mapping riparian zone vegetation is improving (see Chapter 15) (Muller 1997; Neale 1997; Russell et al. 1997). Although some studies question if forests adjacent to streams are associated with higher water quality than forests located elsewhere in a catchment, riparian (and floodplain) vegetation confers benefits beyond the protection of water quality (see, for example, Box 5.4). If you have a map of natural surface water features (e.g., rivers, lakes, springs), coupled with relatively high-resolution remotely sensed imagery, consider the following analyses:

- Proportion of total stream length or other aquatic habitat margin with forest cover (choose a buffer width based on your data resolution and available information for your ecoregion)
- Proportion of total stream length or other aquatic habitat margin with anthropogenic land cover (or separate analyses for row crops, pastureland, urban)
- Connectivity of riparian forest (probability that a randomly selected forest spot in the riparian zone is adjacent to another forested spot) (see Figure 8.1)

If you are able to assign stream orders (see Chapter 2) to the mapped stream segments, you can perform additional analyses to discriminate among land uses bordering streams of different sizes. This may be important if certain activities are concentrated in either headwaters or lowlands.

■ *Erosion potential.* One of the reasons that land cover is used to predict water quality is that certain land uses are associated with higher rates of erosion. Numerous GIS models are available for estimating erosion (or soil loss potential). Most of these require fairly location-specific data inputs, but some are designed to use coarser information. If maps of erosion potential do not already exist, you should be able to find literature for your ecoregion or region that describes the conditions under which erosion becomes a problem.

If erosion is contributing substantially to habitat degradation in your ecoregion, we suggest consulting with agronomists in the region to determine the most appropriate method of estimating present erosion rates. For large lakes, it may also be possible to obtain remotely sensed imagery showing sediment plumes contributed by influent tributary rivers. One of the simpler methods for estimating the degree of erosion potential in a catchment is to combine information on land use with slope. One possible calculation is proportion of the catchment in cropland/agriculture on slopes greater than 3%.

■ *Potential nutrient export.* If nutrient inputs are known or suspected to be an important threat to the aquatic habitats in your ecoregion (this may particularly be the case for lake systems), you may want to go beyond simple measures of land-use proportions and generate more sophisticated predictions of nutrient loadings per catchment. Again, researchers have developed a plethora of models for estimating nutrient transport and loading, but these tend to be location-specific (for example, see the AGricultural Non-Point Source Pollution Model 2001 (AGNPS 2001), described at http://msa.ars.usda.gov/ms/oxford/nsl/). A relatively simple approach is possible if you are able to obtain coefficients for estimated export rates of nitrogen and/or phosphorus under different types of land uses. You can then multiply each coefficient by the amount of area in that land use to obtain a rough estimate of nutrient transport for the catchment under consideration. At a minimum you may want to consult with experts to identify catchments or specific land uses that are making substantial nutrient contributions.

■ *Resource extraction, processing, and industrial activity.* In some ecoregions, mining, drilling, logging, or processing of extracted materials may pollute aquatic environments and create other disturbances. If you can map the locations and extents of these activities, you can conduct analyses to suggest the relative impacts of the activities on the catchment. For instance, you might calculate the number of mining permits per unit area of the

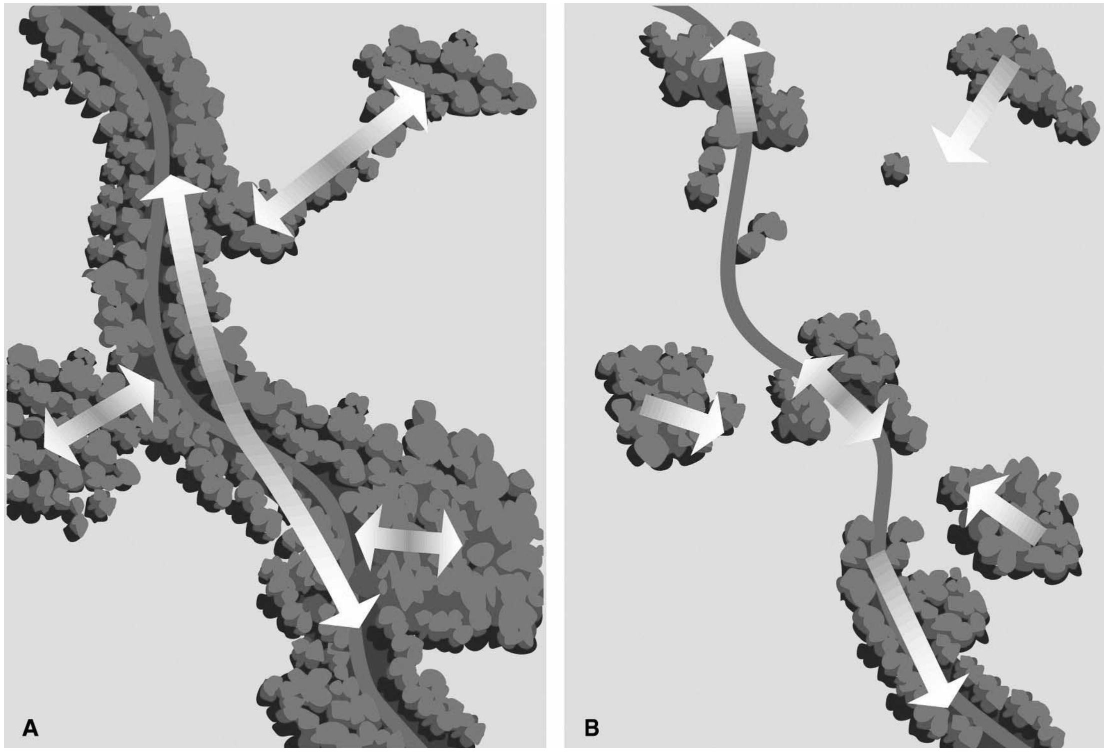

Figure 8.1. Landscapes with (A) high and (B) low degrees of riparian forest connectivity. (Taken from: Federal Interagency Stream Restoration Working Group 1998. Reproduced with permission.)

catchment, or the proportion of catchment area covered by logging concessions. You may also be able to map large-scale industrial facilities and calculate similar statistics. For point-source dischargers, you might choose to calculate the number of facilities within a certain distance (e.g., 200 or 400 m) of aquatic habitats within each catchment.

- *Roads*. Roads affect aquatic habitats and species through chemical pollution, altered hydrology, erosion and sedimentation, landslides, channelization, fragmentation, and other means (see Box 8.1 at the end of this chapter) (Jones et al. 1997; Forman and Alexander 1998; Forman and Deblinger 2000). Try to obtain or synthesize the most complete road map possible. Note that logging roads are quite damaging to aquatic habitats, and that maps of these roads may come from a different source than maps of roads for public transport. In general, unpaved and unmaintained roads can cause substantial damage to aquatic habitats through erosion and slope failure, especially in high-gradient areas. Both because unmaintained roads can be "time bombs," and because the effects of roads on aquatic habitats can be delayed for decades, old maps of roads may be just as useful as new maps.

  With a map of roads you could conduct any of the following analyses:

  - Road density (average number of kilometers of roads per square kilometer of catchment area)
  - Percentage of catchment area containing road of any type (number of pixels with a road divided by total number of pixels)
  - Roads along streams (number of pixels where both a road and a stream occur, divided by the total number of stream pixels in the catchment)
  - Proportion of total stream length or other aquatic habitat margin with roads within a certain unit distance (the U.S. EPA uses 30 meters)
  - Road-stream crossings (number of roads crossing streams per unit stream length)
  - Roadless areas (percentage of catchment that consists of pieces at least 10 km^2 (or appropriate size) in area and at least 200 meters (or other distance) from a road)

- *Pipelines*. If natural gas or oil pipelines figure prominently in your ecoregion, they probably pose threats related to ruptures, and there may be roads or other construction associated with them. Although the possibility of spills relates less to current habitat intactness than to future threats, you may decide that the presence of one or more pipelines renders the catchment less suitable for long-term conservation investment because, like unmaintained roads, these pipelines are "time bombs." Because pipelines are linear features, the analyses that you could perform for pipelines would be similar to those for roads.

- *Grazing.* If pasturelands are not discernable in remotely sensed images, you may be able to obtain information on livestock density. This information will almost certainly be organized according to administrative units; you will need to estimate livestock density for the catchment by aggregating these units. Depending on the scale of information available, you may also be able to analyze livestock density in proximity to aquatic habitats.

- *River channel modification.* Many rivers around the world have been dredged and straightened so that they can serve as transportation corridors.[34] These projects are generally restricted to larger rivers. A map of rivers that have undergone these transformations will allow you to calculate the amount (in length) of aquatic habitat lost directly as a result of such projects. A related, and more insidious, alteration is the straightening of smaller streams, primarily for the purpose of flood control. These projects are not generally documented, but if you have access to historic images it may be possible to determine where these changes have occurred. To quantify the change, you could consider any of the following calculations:

  - Loss of river edge (current length of river edge subtracted from historic length of river edge, divided by historic length of river edge)
  - Change in sinuosity index over time
  - Historic images may also allow you to determine changes in floodplains (Muller at al. 1993)

- *Flow modification structures.* Not all threats originate on the terrestrial landscape — some of the most damaging threats occur directly in the aquatic environment. Impoundments are among the most significant threats to biodiversity because they modify the natural flow regime and create barriers to the movement of species and materials (Ligon et al. 1995). It can be difficult to find comprehensive maps of impoundments, particularly small ones.[35] However, mapping impoundments can be critical for ecoregions where they pose a substantial threat, and we urge you to attempt to construct a map if none is readily available. For example, reservoirs of moderate size may be detectable from remotely sensed imagery. With a map of impoundments you could generate analyses such as:

  - Percentage of hectares (or other unit) within catchment containing an impoundment (number of units containing an impoundment divided by total number of units)
  - Total capacity of reservoirs per catchment (this information would come from regulating agencies)
  - Number of impoundments per catchment
  - Impoundment density (number of impoundments divided by the total stream length in the catchment)
  - Loss of upstream habitat available to migratory organisms (total stream length above impoundments, divided by total stream length in catchment)
  - Number or length of free-flowing streams, divided by number or length of impounded streams, by subcatchment

  Maps of other flow modification structures will likely be even more difficult to obtain. These structures include diversions, interbasin water transfers, dikes, canals, and levees. If maps of such projects do exist, similar analyses could be performed using that information. If detailed data on the downstream thermal effects of impoundments exist, this could potentially be mapped as well.

- *Flow modification.* Models for calculating changes in a river's flow regime over time are becoming increasingly sophisticated, but most of them require information on river flow from at least two points in time. If determining changes in the flow regime of a river is important to assessing habitat intactness in your ecoregion, we recommend consulting with a hydrologist who is familiar with various methods and with the available data. It may be possible to evaluate the relative flow contributions of individual subcatchments, and to evaluate how those contributions had changed from historic values.

[34] In Latin America, the term for such a project is hydrovia.

[35] The hydropower industry defines a large dam as one higher than 15 meters or with a reservoir volume greater than 1 km^3. A major dam is one higher than 150 meters, with a volume greater than 15 million m^3, a reservoir storage capacity of at least 25 km^3, and/or a generating capacity greater than 1,000 megawatts.

- *Wetland loss*. You might take several approaches to determine the loss of wetlands, if wetlands were natural features of your ecoregion. If you have historic images, you may be able to compare these with current images to determine where wetlands have been drained or paved over (Haack 1996). You may also be able to predict where wetlands should occur if you have information on soils, slope, and drainage area. You could then calculate a statistic such as percentage of wetland loss per catchment (current wetland coverage subtracted by historic wetland coverage, divided by historic coverage).

- *Human population density and population centers*. Maps of urban areas do not give information on the density of people in those areas. Moreover, a catchment may be relatively heavily populated, but that population may be dispersed among rural areas. As with grazing data, population data will probably be organized according to administrative units, and you will need to aggregate them. Consider, if possible, conducting the following analyses:

  - Population density per catchment (total catchment population divided by catchment area)
  - Number of large cities (with populations greater than 100,000) per catchment
  - Population density and/or number of cities within a given distance of aquatic habitats
  - Percentage of population employed in the agricultural sector

- *Exotic species*. Although exotic species pose one of the biggest threats to aquatic biodiversity (see Box 8.2 at the end of this chapter), ascertaining where exotics have taken hold and where they are absent can be quite difficult. In general, exotic species are more likely to become established in degraded habitats or where native species assemblages are altered. In well-studied areas there may be comprehensive data on the presence of exotic species, but in most cases the information will be spotty. If aquaculture operations exist in the ecoregion you should attempt to map them, as they are a primary source of exotics. Also, you can use museum collection records to map the occurrence of exotic species of particular concern; it is probably safe to assume that if an exotic was collected at one location in a catchment, it probably exists elsewhere in that catchment (at least for lotic systems). Using aerial photography, it may be possible to identify the presence of invasive riparian plants; fine-resolution satellite imagery may show large areas covered by floating vegetation in lakes (see Chapter 15) (Lehmann and Lachavanne 1997). If information on exotic species distributions is critical to your assessment, you may want to consider contracting a desk study that assimilates available information and evaluates which catchments probably remain free of exotic species of particular concern.

- *Species exploitation*. Like exotic species invasions, the degree to which humans exploit aquatic species may not technically fall under "habitat intactness." Unlike exotics, however, effective enforcement of measures to curb overexploitation should help to reverse the effects if good habitat remains, populations of exploited species exist elsewhere, and individuals from these populations are able to disperse to the affected area. Map-based data describing species exploitation may be difficult to find, and the information may be mostly anecdotal. Areas of overexploitation may in fact signal that those locations are preferred habitats for target species (and hence can provide information for the identification of candidate priority areas). Local fishermen may be the best sources of information about where and when species congregate as they migrate, spawn, or feed.

- *Level of protection*. Although the presence of protected areas does not necessarily confer actual protection, a measure of the protected-area coverage in the catchment gives some information about the conservation mechanisms that may already be in place. Different levels of protection could easily be incorporated into simple analyses. These might look at:

  - Proportion of catchment in protected areas
  - Proportion of land in protected areas within a given distance from aquatic habitats
  - Proportion of land in protected areas within hydrologically active areas
  - Distribution of protected areas in a catchment (by elevational zones or stream orders)
  - Extent of linear riverine protected areas
  - Protected area connectivity

The analyses we have described are examples only. Depending on your ecoregion, other analyses may be more appropriate. Perhaps you will want to focus on water depth in lakes, water temperature, wetland functions, riparian plant species, or woody debris.

You should be able to perform computerized analyses prior to conducting a biological assessment, so that the results are on hand for the evaluation of habitat intactness. If you are unable to generate computerized analyses such as those suggested here, it is still possible to use available mapped information in a more subjective format (i.e., if you are unable to digitize hard-copy maps). For example, in an expert assessment workshop, participants could classify each catchment's degree of deforestation into one of several levels (e.g., high, moderate, low, none) through visual assessment of forest cover maps. Computer-generated analyses will help you to evaluate habitat intactness more objectively, but we urge you not to rely exclusively on GIS analyses and models. The data that go into these analyses are never flawless, and experts will probably be able to identify errors in the maps.

After deciding what kinds of analyses are appropriate to your ecoregion and achievable with the available data, you can decide how to incorporate the results into an evaluation of habitat intactness. You may decide to generate several composite indexes based on related analyses (e.g., a human population index, a land-use index, a roads index), but there remains the issue of how to integrate them. The method that you devise will depend in large part on your data and the analyses that you have generated.

In many assessments, three or more levels have been developed for each index, and point scores assigned to each level (e.g., high = 3, moderate = 2, low = 1). Experts have often chosen to weight certain indexes that they perceived to represent more serious disturbances, such as hydropower dams. Each candidate priority area is evaluated for each index, and the appropriate score applied. Scores for all indexes are then summed, to reach a total habitat intactness score that places the area in one of several habitat intactness categories. We illustrate this method in Table 8.1, which shows the scoring approach for the Amazon River and Flooded Forests ecoregion workshop. In this workshop, maps of the various disturbances were available, and the participants used them to make visual assessments for each catchment.

If you have little or no map-based data available to evaluate habitat intactness and you are forced to rely on expert assessment, you may choose to develop broad categories of intactness to which areas are assigned. Categories could resemble the following:

- *Intact:* Upland land uses such as grazing, logging, urbanization, or agriculture are limited or well managed. Habitats are largely undisturbed by altered hydrologic regimes, pollution, fragmentation, or other forces. Few exotic species are established, and native species face little or no exploitation pressures. Large fish, aquatic mammals, or

Table 8.1. Habitat intactness criteria for the Amazon River and Flooded Forests ecoregion.

Criteria	*Indicators*	*High*	*Medium*	*Low*	*Weight*
natural vegetation coverage within flooded habitats	percentage	100–90%	89–50%	<50%	25%
natural vegetation coverage within the catchment	percentage	100–90%	89–50%	<50%	25%
population centers within the catchment	presence/ absence + size	<10,000	10,000–100,000	>100,000	10%
urban, petroleum, mining, and farming within the catchment	presence/ absence of activities+assessed degree of impact	none	presence of some activities	presence with major impact	10%
presence of dams within the catchment	number + location	none	dams in tributaries but not in principal channel	dams in principal channel	30%

aquatic reptiles may currently be absent from some habitat where they originally occurred because of exploitation, insufficient area, or diminished resources; however, such areas sustain many native communities and populations of plant, invertebrate, and vertebrate species and their associated ecological processes.

- *Altered or degraded:* Human disturbance has extirpated many sensitive species, but habitat remains suitable for some native species. Species composition and community structure are altered, but native species will probably return given sufficient time for recovery and adequate source pools. Examples are freshwater systems receiving point-source pollution, stream reaches isolated by low-head dams, and areas where riparian cover has been removed.
- *Heavily altered:* Many species are already extirpated or extinct. Habitat is almost completely altered. Surrounding land development, the presence of large permanent structures altering hydrographic integrity, established exotic species, and consistently poor water quality make recovery of original habitat unlikely without large and expensive restoration efforts. Examples are de-watered or heavily channelized streams in areas of agricultural development, or highly polluted lakes in industrial or urban areas.

Table 8.2 gives another example of a slightly more detailed evaluation for large floodplain rivers that is modified from Regier et al. (1989). The authors developed this classification from a fisheries perspective, but it is nonetheless generally applicable to an evaluation of habitat intactness for large river systems. Note that the three categories in Table 8.2 basically correspond to the three categories of threat that we identified in Chapter 5 (habitat, catchment scale, and biota).

Because of the element of subjectivity in assigning levels of intactness, it can be helpful to choose reference areas first. Particularly in an expert assessment workshop, it is useful for the group, working together, to assign one or two well-known candidate priority areas to each intactness category. If an ecoregion contains very different aquatic habitat types, conducting this exercise for each habitat type separately would be a good option.

Population and species viability

After deciding how to evaluate the habitat intactness of candidate priority areas, consider broadening the analysis to encompass additional factors related to population and species viability, and to the requirements of individual organisms over their life cycles. We encourage developing an additional set of criteria that address issues such as connectivity, size, habitat complexity, and replication of habitats. Use your conservation targets chart to focus your thinking (see Table 5.2). Here we provide some questions, modified from Moyle and Yoshiyama (1994), to help guide your definition of these criteria:

- Does the area contain the resources and habitats necessary for the persistence of the biodiversity features for which it was selected?
- If appropriate, does the area encompass the habitat needs of the largest and most mobile focal species that you have identified? If not, is it connected to additional candidate priority areas such that all the areas taken together encompass these habitat needs?
- Does the area encompass refuge habitats? If not, is it connected to refuge habitats elsewhere?
- Is the area large enough to contain the range and variability of environmental conditions necessary to maintain natural species diversity (this includes hydrologic processes as well as habitats)? Does the area encompass water sources, including aquifers, stream headwaters, or lake tributaries?
- Is the area relatively resistant to invasion by exotic species, either because it is remote from invaded areas or there are barriers to entry?
- Are habitat types or populations of focal species repeated within the area, to reduce the effects of localized species extinctions? Do dispersal corridors between these habitats/populations exist?
- Is the area paired with at least one other area that contains most of the same species but is far enough away that both are unlikely to be affected by a regional disaster? Do connections exist between these paired habitats or populations, to allow for the movement of organisms?
- Are the populations of focal species present in the area large enough to have a low probability of extinction resulting from random demographic and genetic events?

Decide how to incorporate questions such as these into your evaluation of each candidate priority area. You may choose to make changes to your candidate priority areas, or add new ones, in response to these questions. You might develop a system that assigns value of high, medium, or low population viability to each candidate priority area, and then design an integration matrix to derive an ecological integrity level (Table 8.3).

Table 8.2. Stages in the modification of large floodplain rivers. (Modified from Regier et al. 1989.)

Stage of River Modification	***Basin Use***	***Fish Communities***
Unmodified River channel and floodplain retain most characteristic natural features. Flood regime unmodified by direct human interventions, but indirect effects of activities located elsewhere in the river basin may be apparent	*Unmodified* In unaltered state, the basin is often forested, supporting large vertebrates. Seasonal occupation by nomadic fishermen, hunters, and pastoralists. Slash and burn agriculture may be practiced in basin.	*Unmodified* Fish species diversity may resemble natural condition, but fishing in river channels and standing water may modify the fish community's size structure. The whole channel and floodplains are available as fish habitat. Accidental introductions could result in the presence of several exotic fish species.
Slightly modified Some drainage channels have been constructed for more rapid and efficient removal of floodwaters from the floodplain. Smaller depressions are filled or drained. Flooding is still largely unaltered in its timing and duration. Some small dams may be built on smaller streams.	*Slightly modified* The floodplain is largely cleared of forest, with some wetland agriculture in suitable depressions. Some areas are reserved for grazing, and there is often highly developed zonation of floodplain for different uses. Settlement occurs on levees and higher ground, or on artificial islands and stilt villages.	*Slightly modified* Fish communities are largely unaltered, although larger species may be becoming rarer with size structure heavily biased toward smaller individuals. Some depressions may be dammed as holding ponds, or for extensive aquaculture, or fish holes may be excavated. The whole floodplain is available as fish habitat.
Extensively modified Smaller streams are largely dammed for flood control or irrigation. Drainage and irrigation are common, with some flood control through dams and levees that contain the main channel. Depressions are usually filled or regularized. Flooding is often modified in timing and duration.	*Extensively modified* Floodplain agriculture (usually rice) and intensive dry season agriculture exist. Dryer areas are well settled, with the beginnings of urbanization. Much of the floodplain is still subject to flooding. Degradation of smaller streams results from deforestation and intensive agriculture, mining, industrial pollutants, and untreated urban sewage. Pesticides and herbicides from large-scale monoculture treatment also enter the river.	*Extensively modified* The fish community is modified, with disappearance of larger species. Intense fishing pressure exists in the main river channels, with some new fisheries in reservoirs. Most long-distance migrant fish species have disappeared. Drain-in ponds and some intensive fish culture in regularized depressions exist. River area available as fish habitat is restricted.
Completely modified Flooding is controlled by large upstream dams and by levees. The main channel is sometimes channelized. The floodplain is largely dry, although still subject to occasional catastrophic floods. The river is often reduced to a chain of reservoirs.	*Completely modified* The river basin is urbanized and is intensively used for agriculture, industry, and habitation. Mining and industrial and urban pollution are controlled to some degree, but eutrophication is usual. Pesticides and herbicides are regular inputs to the river system.	*Completely modified* Fish communities are changed by the loss of some species through pollution and channelization, and sometimes by the introduction of exotic species. Some sport fisheries exist in main channels or in a few lakes that have been retained on the floodplain. Some intensive aquaculture is present in specially constructed ponds. The river area available as fish habitat is very small, but intensive fisheries may be developed in the reservoirs.

Table 8.3. Example of a matrix to assign ecological integrity levels to candidate areas.

Habitat Intactness	*Population/Species Viability* High	Medium	Low
Intact	High	High	Medium
Altered/ degraded	Medium	Medium	Low
Highly degraded	Low	Low	Low

Or, you might use these questions to differentiate additional "levels" of ecological integrity for your areas. For example, if you chose to stress the importance of connectivity with other habitats, you might differentiate the following levels:

1. Intact, high connectivity
2. Intact, low connectivity
3. Altered/degraded, high connectivity
4. Altered/degraded, low connectivity
5. Highly degraded, high connectivity
6. Highly degraded, low connectivity

Similarly, you could incorporate issues of restoration potential, particularly for ecoregions that are largely disturbed. More levels of ecological integrity will permit a finer discrimination among candidate priority areas. When there are few levels of either ecological integrity or biological importance, an integration can result in a large number of highest priority areas — which suggests an inadequate job of making the hard choices necessary for priority setting.

Step 2. Agree upon method for integrating ecological integrity with biological importance

In Chapter 4 we presented a number of approaches, taken from the literature, for identifying areas to protect as part of a landscape-scale conservation strategy (e.g., ADMAs, ADAs). All of these approaches stress the importance of giving highest priority to intact catchments with high ecological integrity. In fact, they often use intactness as a primary filter to separate out the "lost causes" from the gems. This seems to be a distinguishing feature of much of the current thinking in freshwater conservation planning, at least for lotic systems: Protect the most intact remaining freshwater habitats first, because these will provide the best opportunities for restoring species and communities to degraded areas. According to this approach, we do not have the luxury of focusing our immediate efforts exclusively on degraded areas and putting the intact areas aside for later protection. Once landscapes are disturbed — and we can assume that human disturbance will eventually reach virtually all unprotected areas — recovery of aquatic biodiversity can be a slow process, particularly if there are no source pools of potential colonizers nearby (Niemi et al. 1990). The good news is that the recovery of disturbed systems is facilitated by the connected nature of most freshwater systems, barring any dispersal barriers.

Conservationists have designed most of these approaches with regard to riverine systems distinguished more by migratory species than by endemic biotas. In systems with highly localized and isolated endemic species, such as some lakes and spring complexes, giving degraded areas secondary priority might be an untenable option, because further degradation could lead to species extinctions. Nevertheless, it would probably be a poor use of resources to invest heavily in areas that were so degraded that there was virtually no hope of their recovery (in some workshops, such areas have been termed "critical" or "extinct").

The participants at WWF's ecoregional assessment workshop for the Chihuahuan Desert faced this dilemma. Exceptionally high levels of local endemism characterize the freshwater habitats of the Chihuahuan Desert, yet many of the areas are highly degraded as a result of water withdrawals and other impacts. Given the large number of areas with endemic biotas, the experts gave secondary priority to those areas with low intactness, but the decision was a difficult one because many of these areas were on the brink of extinction.

The freshwater component of South Africa's Cape Action Plan for the Environment (CAPE) approached this dilemma in a different way (van Nieuwenhuizen and Day 2000). Like the Chihuahuan Desert, the freshwater habitats of the Cape Floral Kingdom are characterized by low species richness, high endemism, and high threat. The CAPE approach gave those areas with the lowest conservation status (those whose habitats have been most altered by anthropogenic activities) and the highest conservation value (the equivalent of biological importance) the highest priority for action. Nevertheless, the plan singled out several whole river systems that remained relatively intact as high priority for protection (e.g., the Doring River). It would certainly be possible to develop an approach that gave highest priority both to degraded and to intact systems — the decision is up to you, your team, and the experts assisting you.

In general, we recommend developing an *integration matrix* to make the process of prioritization as transparent and standardized as possible (Table 8.4). Levels of biological importance would run along one axis, and levels of ecological integrity would be on the other. Each cell representing a unique combination of the two indexes would be assigned a priority level. If necessary, you could develop separate matrices for each type of priority area (e.g., habitat for focal species, maintenance of physical processes).

We provide Table 8.4 as a purely hypothetical example of an integration matrix. If you are engaging experts in the assessment, we recommend constructing a matrix yourself and then asking experts to react to and potentially modify it.

Once participants agree upon the integration matrix, you can apply the matrix to the actual candidate priority areas. The assignment of priority levels should be a simple process that you can complete quickly through use of a spreadsheet program like Excel. We strongly suggest not allowing the participants to refer to the biological importance and ecological integrity scores of the candidate priority areas while they are constructing the matrix, because their biases toward certain candidate priority areas could color their decisions.

Conclusion

This chapter and those preceding it have provided ideas for conducting a biological assessment. In general, we suggest that for each activity in the assessment process you articulate a set of questions to be answered, a description of the expected output, and a process for incorporating that output into the larger assessment. We apply this framework in the following chapters as we run through each step in the assessment.

Particularly if you are holding an expert assessment workshop, it is critical that the participants understand why they are performing certain tasks and how their work will be used. It is also important that they understand what they are working toward. If you are developing the assessment methodology as the workshop unfolds, the experts may be left with little faith in the process.

Finally, think about how to structure a workshop so that the experts feel positively about the work that they have done, even if the prognosis for the ecoregion's biodiversity is grim. Ending on a good note may seem like a trivial concern, but if you are able to achieve this the experts will be much more willing to continue participating as the ecoregional plan unfolds.

The next four chapters walk you through the steps of a biological assessment. We have already covered most of the background for these steps. No amount of planning will prevent alterations to the approach once the assessment is underway, but working through your anticipated "game plan" with your entire assessment team beforehand — including how you will deal with changes midcourse — should allow you to have as streamlined an assessment as possible.

Table 8.4. Example of an integration matrix for assigning priority levels to candidate areas

	Biological Importance		
Ecological Integrity	High	Medium	Low
Intact, high connectivity	I	II	II
Intact, low connectivity	I	II	III
Altered/degraded, high connectivity	I	III	IV
Altered/degraded, low connectivity	III	IV	V
Highly degraded, high connectivity	IV	V	V
Highly degraded, low connectivity	V	V	V

Box 8.1. Effects of roads.

In its recent assessment of water resources on its lands, the U.S. Forest Service identified roads as a major threat to aquatic biodiversity and ecosystem health (Sedell et al. 2000). The authors noted the following:

- "Many studies have shown that roads in forests have elevated erosion rates and often increase the likelihood of landslides in steep or unstable terrain. Both of these effects can be especially pronounced where roads cross or run near streams, resulting in sediment discharge to surface waters. Roads are also likely sites for chemical spills associated with traffic accidents, with the highest risk of water contamination where roads cross streams."
- "Other transportation corridors, such as pipelines and powerline rights-of-way, also pose problems and risks."
- "The specific effects of roads are strongly influenced by a variety of factors, including road-building techniques, soils and bedrock, topography, and severity of storm events."
- "Remarkably little is known about road effects on hydrology at watershed and subbasin scales, so there is inadequate basis to evaluate the hydrologic functioning of the road system at large scales."

In one example, studies on national forest lands in northern California (USDA Forest Service 1999) found that "roads at or near ridgetops had far fewer failures and generated far less sediment to streams than roads in lower slope positions." This finding, which is perhaps counter-intuitive, suggests the importance of understanding roads within the context of a particular ecoregion. Because roads parallel streams and rivers so often (see Figure 8.2), understanding the potential impacts of these features is an important piece of evaluating ecological integrity.

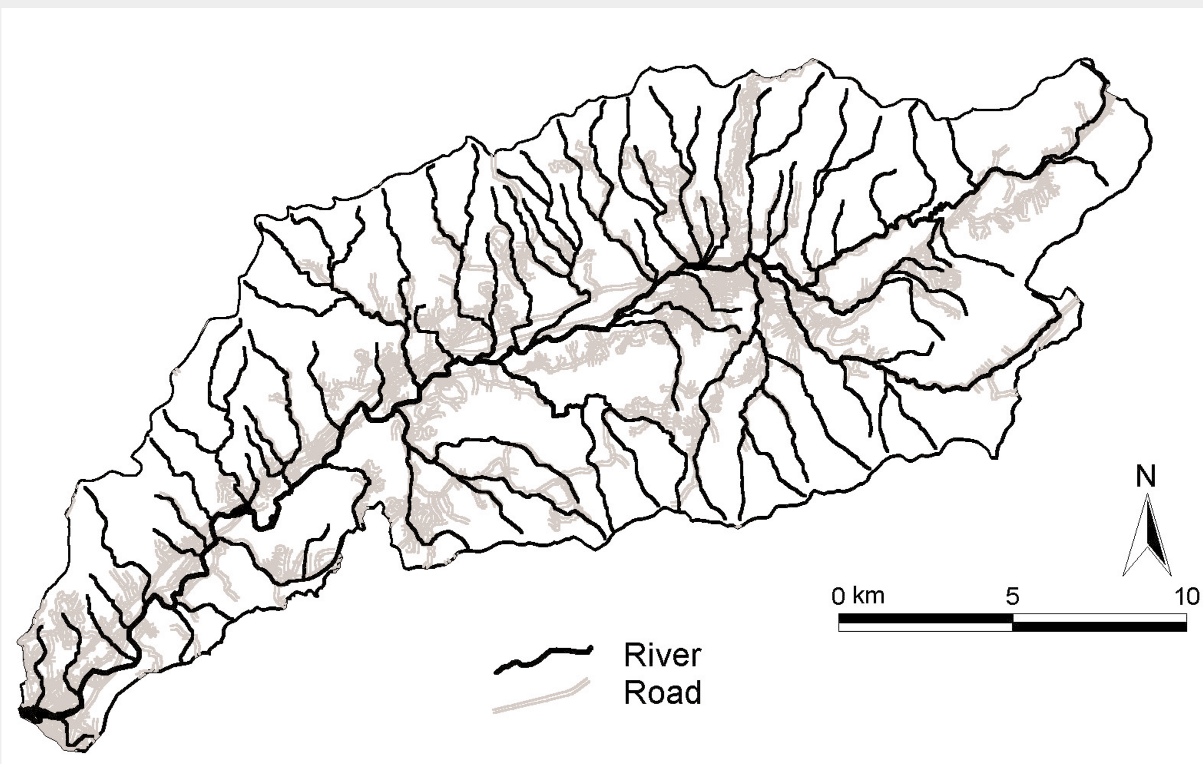

Figure 8.2. Example of roads and streams in the Valley River catchment of the Tennessee-Cumberland ecoregion, USA.

Box 8.2. Loss of genetic and species diversity through establishment of exotic species.

The establishment of exotic species and the loss of genetic diversity in populations of native species are two of the most serious, and seemingly intractable, threats facing freshwater biodiversity.

It is usually impossible to eradicate established exotic species, so the challenge is to prevent their introduction or to contain their spread. Obligate aquatic animals will normally be unable to enter new catchments unless they are transferred (accidentally or intentionally) or there is a hydrologic connection created (such as through an interbasin water transfer). The task of ecoregion conservation may be to identify systems free of exotics where there is a high risk from invasion or introduction, and to develop safeguards against the establishment of non-natives. This might include identifying potential vectors of exotics, like aquaculture ventures or the live fish pet trade, and working with them to prevent new introductions.

The introduction of exotic species may lead to a loss of genetic diversity in populations of native species, through hybridization between species or through genetic pollution from hatchery releases of individuals from different stocks. Other factors may also be responsible for loss of genetic diversity. For example, genetically distinct fish stocks may be spread across the tributary system of major catchments, and rare stocks may be easily and unknowingly overfished. Selective fishing may also lead to the harvest of large fish, resulting in evolutionary change toward reaching maturity at smaller sizes and younger ages (Curtis Freese, Senior Fellow, WWF-US, personal communication).

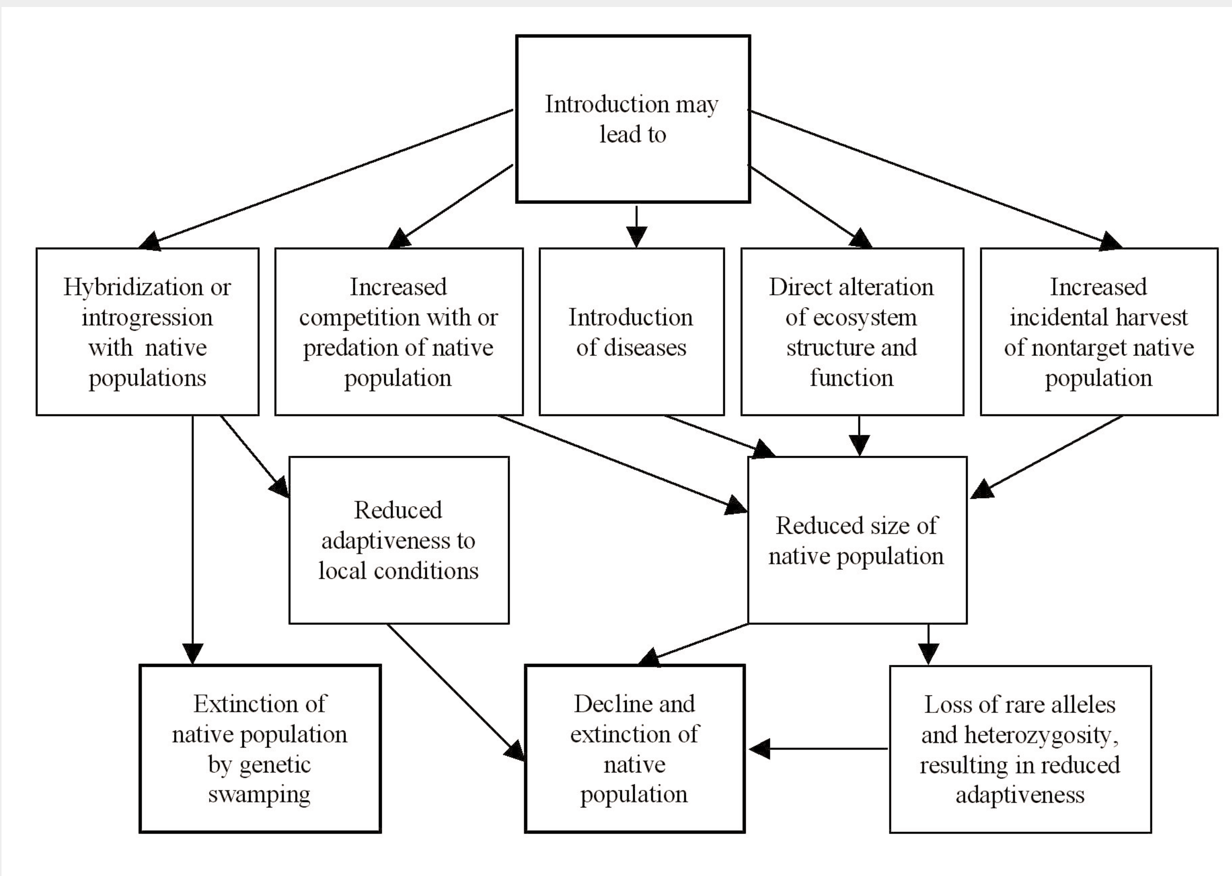

Figure 8.3. Mechanisms by which introductions of exotic species and stocks lead to decline and extinction of native species. (Taken from: Freese 1998.)

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Conducting the Assessment I: Biological Importance

9

Introduction

One of the key principles of ecoregion conservation is that the biodiversity vision should drive the development of a conservation plan, and one of the key principles of the biodiversity vision is that biological features should drive the selection of candidate priority areas. We have described several approaches that emphasize protecting intact catchments, but they do not focus on habitat intactness to the exclusion of biological importance; in fact, all of these approaches recognize the fundamental importance of first identifying distinct biodiversity features and building a strategy around them. So, we strongly recommend beginning your assessment with an evaluation of your ecoregion's biodiversity features and the processes that maintain them. This requires focusing on the original, or historic, distribution of species, communities, and habitats in the ecoregion, rather than considering what is on the map today.

In Chapter 7 we provided background for identifying and assessing biologically important areas. In this chapter we walk through basic steps recommended for conducting the assessment of biological importance, and in the following chapter we do the same for ecological integrity. These suggestions should apply equally whether or not you hold an expert assessment workshop, as long as you engage experts in some capacity as you conduct the assessment.

Consider how to introduce each step to the experts, keeping in mind the need to balance time constraints (and information overload) with the need to avoid confusion. For each step we offer examples of questions to guide the exercise, expected outputs, and a description of how the step relates to the overall assessment. In a workshop setting in particular, providing this kind of information may help experts understand quickly what is expected of them and why.

Although we have not included it as an explicit step, providing an introduction to the basic concepts of ecoregion conservation is essential for an expert workshop. *Most important may be stressing that the assessment should focus on biodiversity-derived conservation targets.* It is also critical to discuss issues of scale, both spatial and temporal. Decide how much introductory material to present at once, since participants will become impatient during protracted presentations. Consider creative ways of engaging experts in activities early and often in a workshop.

For any assessment, whether it includes an expert workshop or not, it is essential that all participants (and facilitators) have a conceptual understanding of a biodiversity vision, so that they know what they are working toward. Provide visions for other ecoregions as examples. Also consider developing a *vision statement*[36] before embarking on the actual assessment, and then returning to the statement at the end of the assessment to see if the process has remained true to it.

Step 1. Revisit ecoregion boundaries, using collected information and expertise

Questions:

- Do the proposed ecoregion boundaries adequately capture biogeographic patterns, and do they make sense from a conservation standpoint?
- If not, how should they be altered?

Outputs:

- A map showing the revised ecoregion boundaries
- A brief written justification of why the boundaries were changed

Relevance to the assessment:

- The ecoregion boundaries determine the region of analysis for the remainder of the assessment.
- A well-delineated ecoregion will include all of the critical resources, habitats, and processes required to maintain the ecoregion's conservation targets.

[36] See Chapter 13, Step 4, for a detailed discussion of vision statements.

In preparation for the assessment you will have collected basic information on species and habitat features, and on the physical processes operating in the ecoregion to maintain those features. With this information, as well as with the input of experts, revisit the ecoregion boundaries to confirm that they represent the area that makes the most sense from a biogeographic and conservation standpoint.

At this stage, it is important to give all the experts participating in the assessment the opportunity to comment on the region of analysis, both to secure buy-in and so that everyone understands the reasoning behind the delineation. If you have engaged key experts prior to the assessment there may be few if any boundary changes.

For this step we recommend starting with a base map showing, at a minimum, major catchments, surface water features, and proposed ecoregion boundaries. Consider also including topography, soils, vegetation, or other physical features, particularly if your ecoregion does not correspond to catchments.

Incorporate any boundary changes immediately, so that the remainder of the assessment can proceed using the new boundaries. Consider the best way to make these changes quickly and with the least disruption to the assessment, given the GIS technology and map products available.

Step 2. Refine biogeographic subregions

Questions:

- Do the proposed subregion boundaries adequately capture broad biogeographic patterns within the ecoregion?
- Is the number of proposed subregions sufficient for a representation analysis?
- How should the subregions be altered, if necessary?

Outputs:

- A map showing the revised subregion boundaries
- A brief written justification of why the boundaries were changed
- A brief written description (or list) of the features defining each subregion
- Consensus on an appropriate name for each subregion

Relevance to the assessment:

- The subregions will be integral to the representation analysis. The representation analysis will ensure, at a minimum, that all subregions are represented in the final portfolio of highest priority areas, and that all habitat types are represented in all subregions where they occur naturally.
- Within an expert assessment workshop, working groups may be defined for each subregion.
- For particularly large ecoregions, the subregions may serve as more manageable units for conservation planning.

After there is consensus on the ecoregion boundaries, repeat the process for the refinement of subregion boundaries. Again, integrate any changes as quickly as possible. Consider simultaneously incorporating into the GIS any changes to the ecoregion and subregion boundaries.

Step 3. Revisit habitat types, focal elements, minimum requirements

Questions:

- Is the proposed list of freshwater habitat types comprehensive, and will it allow for an appropriate level of resolution in the representation analysis? If not, how should the list be changed?
- Do the proposed focal biodiversity features and processes, detailed in the conservation targets chart, capture the important elements that characterize the ecoregion? If not, what features or processes should be added?
- What information exists describing the minimum habitat requirements of focal species, and the conditions necessary to maintain key physical processes and habitats?

Outputs:

- A revised list of habitat types, with a brief description of each type, if appropriate
- A revised list/description of focal biodiversity features and the processes required to maintain them
- A revised list/description of minimum habitat requirements of focal species, and the conditions necessary to maintain key physical processes and habitats
- A list of key information gaps related to assessing minimum requirements
- If appropriate, consensus on which focal species, habitats, and physical processes the assessment will concentrate upon

Relevance to the assessment:

- The list of habitat types is integral to the representation analysis, because the final portfolio of highest priority areas should capture all habitat types in all subregions where they occur naturally.
- The discussion of focal species, habitats, and processes is critical to the assessment by giving it direction and focus. The discussion of physical processes may be of particular importance.
- The discussion of the minimum conditions for maintaining focal species, habitats, and processes will help to set goalposts for the vision. Without a rough idea of minimum conditions, it will be very difficult to evaluate if the vision is ambitious enough.

This step does not necessarily require the use of maps and may take the form of a facilitated discussion within a workshop setting. Presenting the draft conservation targets chart should help to generate ideas (see Table 5.2). Experts may be frustrated by the lack of information available to set minimum requirements, but good facilitation should help them to draw from their own experiences and think broadly. It is important to achieve some level of consensus on the conservation targets, as these will drive the selection of candidate priority areas to a large degree.

Step 4. Select candidate priority areas

Questions:

- How were species, communities, and habitats historically distributed within the ecoregion?
- What are the most important areas within the ecoregion for conserving the identified conservation targets and the physical processes required to maintain them?

Outputs:

- Maps showing candidate priority areas, classified by target type (e.g., richness, processes) if appropriate
- Completed data sheets for each candidate priority area, describing basic characteristics, habitat type(s), and reason for selection

Relevance to the assessment:

- The highest priority areas highlighted in the biodiversity vision will be selected from the candidate priority areas identified in this step.

We have found that overlaying pieces of transparent mylar on top of base maps, and then delineating candidate priority areas directly on the mylar, allows for the most efficient transfer of information to the GIS. Whatever method you use, provide a brief orientation to experts on the method for drawing on maps. You may want to bring a list of "do's and don'ts" to which experts can refer (e.g., register all mylar overlays using tic marks, connect lines to create closed polygons). It is also useful to lead the group through the delineation of a few areas, so that everyone has the same understanding of the process before they split into working groups. Each working group should have a "leader," but it is vital that the facilitator or other workshop representative circulates among groups to ensure that they are taking comparable approaches.

Step 5. If multiple types or layers of candidate priority areas are identified, synthesize if appropriate

Questions:

- Do the various layers or types of candidate priority areas need to be synthesized into a single layer and, if so, how?

Outputs:

- A synthesized map of multiple types or layers of candidate priority areas, with new area numbers and names assigned, if appropriate
- Completed data sheets for each new candidate priority area, combining the information from the original candidate priority areas

Relevance to the assessment:

- Candidate priority areas are combined to show the heightened importance of areas capturing multiple targets, and to make the area boundaries inclusive of all component targets. This step highlights hotspots — areas that contain habitat for multiple taxa or serve multiple important functions.

Depending on your approach, GIS resources, and timing, you may be able to conduct this step mechanically, rather than manually. In other words, GIS analysts may be able to combine candidate priority areas relatively easily, and experts can then review the synthesized areas for any errors. If you can process the data sheets quickly, and if you have a system in place for combining descriptive information via a database, you can generate new data sheets for the synthesized candidate priority areas, and experts can refer to these sheets during the remainder of the assessment.

If you do not have the ability to combine candidate priority areas using a GIS, consider an approach that will be as "clean" as possible, producing uncluttered maps with standardized annotations. Also think about how to keep the data sheets for component areas together. One method that we have employed is to obtain clear plastic sheet protectors (multi-page capacity sleeves), and to keep all data sheets for a given candidate priority area together in a single sleeve. We have then placed the sleeves in a binder, ordered by candidate priority area number, so that all information relevant to each area is easily accessible at any point during the assessment. As new data sheets are generated with each successive step, they are added to the appropriate sleeve.

Step 6. Conduct representation analysis

Questions:

- Are all habitat types occurring naturally in each subregion represented in at least one candidate priority area?
- Are all subregions adequately represented in the portfolio of candidate priority areas?
- Are additional representation requirements, as defined in the decision rules, also met?

Outputs:

- Documentation that all habitat types and subregions are represented adequately, following pre-established decision rules
- Revised map of candidate priority areas if new areas are added to achieve representation
- Documentation for any new candidate priority areas

Relevance to the assessment:

- One of the key goals of ecoregion conservation is representation of all biodiversity elements. Without complete information on the distribution of species and communities, we can use habitats as a proxy. We conduct the representation analysis now to ensure that the set of candidate priority areas is representative, and we conduct it again later to ensure that the portfolio of highest priority areas is representative as well.

Before beginning the representation analysis, vet the decision rules for representation with the experts to ensure that the rules are appropriate and that everyone understands them. If the decision rules are clear, and if you have designed the assessment up to this point with the representation analysis in mind, then this step should be completed easily. For instance, in advance of this step you can set up a simple table that allows you to quickly evaluate if all habitat types have been captured (Table 9.1). Table 9.1, offered as an example, assumes that each candidate priority area

Table 9.1. Example of representation of habitat types within subregions. Numbers in cells correspond to candidate priority areas.

Subregion/ Habitat Type	*Subregion 1*	*Subregion 2*	*Subregion 3*	*Subregion 4*	*Subregion 5*
Habitat 1	1, 5, 6	12	20, 21	29	
Habitat 2	2, 4, 5	12, 14	24, 27	30, 33	39, 40
Habitat 3	7	13, 16	23		43
Habitat 4		12, 15	22	35, 36, 37	46
Habitat 5	8, 9	17	25, 26	31	45, 46, 47
Habitat 6	3, 5	18	27, 28	32, 34, 35	41, 42
Habitat 7	10	16, 15	20, 21	38	
Habitat 8	6, 11	19	28		

could contain multiple habitat types, but the same framework could apply if each area was assigned a single habitat type. In this example, presuming that all habitat types occurred naturally in all subregions, subregions 1, 4, and 5 would require additional candidate priority areas to achieve full representation.

If your representation decision rules have additional components beyond the representation of all habitat types in all subregions, think ahead about how to expedite the analysis so that you can quickly identify gaps and address them.

Step 7. Analyze set of candidate priority areas to determine if all focal elements, and the minimum conditions for maintaining them, have been addressed

Questions:

- Does the set of candidate priority areas adequately capture all of the identified focal elements?
- Have the minimum requirements for maintaining those elements been addressed?

Outputs:

- Revision of candidate priority area set to address all focal elements and minimum requirements for maintaining them
- Documentation of all new or revised candidate priority areas
- Documentation of any gaps that cannot be addressed

Relevance to the assessment:

- It is essential that the assessment be comprehensive of all important biodiversity features, and that potential priority areas be delineated and configured to meet minimum requirements. This step serves as a "check" to ensure that the assessment is following the defined goals.

The final portfolio of highest priority areas will be drawn from the set of candidate priority areas. If the candidate priority areas are inadequate to conserve the ecoregion's conservation targets, now is the time to fix them. We suggest repeating this step with the final portfolio as well. As with the representation analysis, if you add or modify areas, document the changes.

Step 8. Assess biological importance of candidate priority areas

Questions:

- How do the candidate priority areas compare to each other in terms of their importance to biodiversity conservation?

Outputs:

- Assignment of a level of biological importance to each candidate priority area
- For each area, documentation of the reason for assigning the particular level
- A map depicting the levels of biological importance of the candidate priority areas

Relevance to the assessment:

- The levels of biological importance help to discriminate among candidate priority areas during the later priority-setting step and ensure that the most important areas are given highest priority, where possible. Without evaluating biological importance, a large proportion of areas could receive the highest priority status, which would be less useful for decision making.

In Chapter 7 we described possible approaches for assigning levels of biological importance. In some situations you may be able to define standardized criteria for assigning levels, but in the end there is always an element of subjectivity. We recommend that, if possible, all experts work together to assign levels, so that they can achieve consensus on the assessment results. Once the areas are sorted by level of importance it may become clear that some areas need reassignment, perhaps because they were evaluated early in the process before the experts established adequate reference points. Or, there may be a disproportionate number of areas in a certain category. Build in the opportunity for areas to be re-evaluated. Experts may be biased when evaluating their favorite study sites, but normally if the entire group engages in a review of all the evaluations such discrepancies come to light and are corrected.

Conclusion

After identifying candidate priority areas and evaluating their biological importance, it is time to switch gears to think about current threats and opportunities. This shift presents a chance to regroup and informally appraise the assessment up to this point. If you are conducting the assessment within a workshop setting, you may choose to reorganize the experts into thematic or regional groups for the following steps.

Conducting the Assessment II: Ecological Integrity

10

Introduction

The evaluation of ecological integrity requires a shift in focus, from thinking about aquatic species and habitats to considering the entire catchment. The ecological integrity assessment considers both past and present impacts on the landscape (defined broadly here as both terrestrial and aquatic areas), and evaluates how these bear upon the long-term survival prospects of populations, species, and communities. The assessment of future threats, which we discuss in Chapter 12, looks forward to consider potential threats on the horizon and the urgency of addressing them.

As we have presented it in this sourcebook, ecological integrity has two parts. The first is habitat intactness, and the second is those conditions necessary for population and species viability. In separating these two parts we make an artificial distinction, because the quality of habitat has a direct influence on the survival of individual organisms, which in turn affects population persistence. We make the distinction because it is generally possible to evaluate habitat intactness through map-based analyses without explicit reference to the needs of particular species, but evaluating population and species viability involves an additional set of questions that are less empirical and potentially more species-focused (see Chapter 8). Furthermore, modifying the boundaries of candidate priority areas may increase the areas' ecological integrity (e.g., by extending them so that they are connected with other areas), but we cannot "improve" habitat intactness in the same way. In effect, population and species viability relates in large part to issues of reserve design (see Box 10.1 at the end of this chapter). We include both parts of the ecological integrity assessment here, and leave it to you to decide whether to retain them as separate pieces or to combine them in a way that suits your ecoregion.

When introducing the ecological integrity assessment to experts, you may want to refer back to the conservation targets chart to focus the discussion (see Table 5.2). There may be myriad activities that alter the landscape, but some will be more relevant to the protection and persistence of freshwater conservation targets. Consider posing the question of whether the current threats listed in the conservation targets chart are reasonably complete, or if others should be added. Present your suggested approach for evaluating these threats, such as through a combination of map-based analyses and an evaluation of population/species viability. Include any proposed algorithms for combining the results of various analyses, so that all participants will understand how the results will be used. Also be clear that a subsequent step will evaluate future threats, and that the present step is restricted to current threats.

Chapter 8 described what we think are the key decisions to make before embarking on the ecological integrity assessment. This chapter is short, but the actual length of the analysis will depend on the approach that you take and the degree to which you are able to process landscape-scale data prior to the assessment.

Step 1. Evaluate habitat intactness of candidate priority areas

Questions:

- How intact are the aquatic habitats contained within each candidate priority area?

Outputs:

- Results from analyses of habitat intactness for each candidate priority area or catchment
- Identification of key information gaps hindering an evaluation of habitat intactness

Relevance to the assessment:

- Habitat degradation is the primary cause of species imperilment.
- The results of the habitat intactness analyses will comprise a large part of the ecological integrity assessment.

If you choose not to evaluate habitat intactness using the proposed catchment-by-catchment approach (see Chapter 8), or if you are not using catchments in your assessment, you will need to consider other approaches. It is certainly possible to do the evaluation purely through expert assessment, but we have found that freshwater experts sometimes have poor knowledge of activities on the terrestrial landscape. At a minimum, we recommend that experts have access to maps of land use and/or vegetation cover, so that they can "eyeball" the potential impacts of land-based activities on each candidate priority area. This requires overlaying the candidate priority areas with these data layers (which argues for delineating candidate priority areas directly on mylar).

Step 2. Evaluate population/species viability of areas, add or change boundaries if necessary

Questions:

- How likely is the long-term persistence of the target populations, species, and communities in each candidate priority area, given issues of connectivity, size, shape, and configuration?

Outputs:

- An examination of population/species viability for each candidate priority area
- Revision of candidate priority area map to confer higher viability to candidate priority areas, where possible
- Documentation of any modifications to candidate priority areas
- Identification of key information gaps hindering an evaluation of population/species viability

Relevance to the assessment:

- Except in ecoregions characterized by species with highly localized distributions or life histories confined to small areas, issues of population/species viability will be critical to the long-term persistence of freshwater biodiversity.
- Issues of population/species viability will be integrated with habitat intactness to derive ecological integrity levels for candidate priority areas.

In Chapter 8 we list questions that might drive the evaluation of population/species viability. These questions also touch on the life history needs of individual organisms, particularly wide-ranging ones. In effect, this step asks whether candidate priority areas with high intactness might nonetheless have low integrity, and if it would be possible to improve the integrity of such areas through modification or addition of new areas. Conversely, degraded areas with high connectivity might have the potential for high integrity if threats were abated and/or habitat was restored.

This step is strongly related to the design of protected areas. Depending on the size of the ecoregion and the scale of the candidate priority areas, this step may be better suited to post-assessment work. We include it here because of the critical importance that issues of connectivity, refugia, and the movements of organisms play in freshwater conservation planning. Raising these issues during the assessment will allow contributing experts to consider them actively and make their decisions accordingly.

Step 3. Assess ecological integrity of candidate priority areas

Questions:

- How likely is the long-term persistence of each candidate priority area's biodiversity features, given its habitat intactness and probable population/species viability?

Outputs:

- An evaluation of the ecological integrity of each candidate priority area, and justification for assigning the particular level
- Identification of key information gaps hindering an evaluation of ecological integrity

Relevance to the assessment:

- The results of the ecological integrity analysis are integrated with the results of the biological importance assessment to assign priority levels to candidate priority areas.

As with all steps in the assessment, carefully document the process through which you derive ecological integrity levels for each candidate priority area. Ideally, all experts would participate in the assignment of ecological integrity levels, for the same reasons that we recommend a group effort when assessing biological importance. Again, finding "benchmark" candidate priority areas that everyone agrees represent the different levels is often a good way to begin. Once the levels are assigned the areas can be sorted by level to see if the assignments make sense.

Conclusion

After completing both the biological importance and ecological integrity assessments, you are ready to set priorities. In some past workshops we have integrated future threats into the prioritization, but our experience suggests that a better route is to evaluate future threats following the prioritization and to use that information to inform recommendations for conservation action. This is because incorporation of future threats can radically change priorities, yet there is a high degree of uncertainty in our assessment of them. We discuss future threats in Chapter 12, following a discussion of priority setting in Chapter 11.

Box 10.1. Freshwater reserve design.

Freshwater reserve design is far more complicated than simply fencing off a water body from human use. As many authors have noted, a freshwater protected area should ideally cover the entire catchment of a target water body. However, few such reserves exist, and in most places this is an unrealistic goal, particularly for large rivers.

Skelton et al. (1995) offer general observations and recommendations for reserve design when whole-catchment protection is not an option:

- The effectiveness of a reserve depends on the extent of the catchment within the conserved area, and in the configuration of the reserve with respect to the catchment area.
- An effective freshwater reserve must secure the minimum water quantity and quality requirements of the entire community of species in the system.
- As far as possible natural hydrological cycles must be maintained.
- Alien organisms, especially high-impact predators like bass and trout, need to be effectively excluded.
- Migratory or diadromous species must have free passage.
- Small species in small communities may have fairly limited requirements but the larger species and larger communities have broader more diverse environmental requirements.
- Reserves placed higher in a catchment will be better protected and easier to manage than reserves further downstream.

Where it is not possible to afford strict protection to a reserve, other levels of management will be necessary. Forms of protection that integrate human use with conservation include certified forests, biosphere reserves, riverine linear reserves, conservation management networks, and covenants on land use in catchments. Lesser forms of protection would include ecosystem services schemes, such as those designed to maintain or enhance environmental quality through payments to landowners.

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Conducting the Assessment III: Prioritizing Areas at the Ecoregion Scale 11

Introduction

Setting priorities for conservation might best be called a "necessary evil." If we are honest about the trade-offs made in the process of setting priorities, such as sacrificing critically imperiled areas for the opportunity to protect intact ones (or vice versa), the process can become less arduous. When the approach is transparent and all information contributing to the prioritization is presented, decision makers or other conservationists also have the option of choosing different priorities using their own set of decision rules.

Generating priorities among candidate priority areas is not equivalent to generating a biodiversity vision, although it is an essential step in the process. Subsequent chapters deal with evaluating overarching and specific threats, identifying actions to address those threats, and incorporating that information with the biological assessment results to construct a complete vision.

Setting priorities among candidate areas does not mean tossing out those given lower priority. In fact, the set of candidate areas may already constitute the minimum required to meet your representation goals, meaning that all areas are important to achieving the vision. Prioritizing among areas is intended to identify those areas that are highest priority for immediate conservation action, for certain types of activities, for certain organizations, or for any combination thereof. The ecoregion team must agree upon what the areas are being prioritized for before prioritizing them, and convey that information to participating experts.

Step 1. Assign priority levels to candidate priority areas using integration matrix/algorithm

Questions:

- What are areas being prioritized for?
- Does the proposed integration matrix represent a reasonable philosophy toward setting priorities among candidate priority areas? If not, how should it be changed?

Outputs:

- An integration matrix assigning a priority level to each combination of biological importance and ecological integrity
- A brief description of the philosophy behind construction of the integration matrix
- Assignment of priority levels to each candidate priority area
- Map of resulting priority areas

Relevance to the assessment:

- The integration matrix is used to assign priority levels to the candidate priority areas, and the design of the matrix will vary depending on the underlying philosophy about priority setting.

Because priority setting can be a contentious issue, we recommend entering this stage of the assessment with a proposed matrix design in hand. Encourage all participating experts to voice their opinions and work to seek consensus, but if consensus is unattainable you will have the option of reverting to your original proposal. We recommend discussing the integration matrix without reference to particular candidate priority areas, to minimize the chances of experts' bias coloring the discussion. Once the matrix has been applied, if the experts are truly unhappy with the priorities assigned to a number of particular areas, the group can revisit either the matrix or those areas to determine if changes to the process or analyses are warranted. For example, on reviewing habitat intactness results the group may find they gave lower scores on average to the first areas that they evaluated.

Step 2. Conduct representation analysis again, and elevate the priority level of one or more areas if necessary

Questions:

- Are all habitat types that occur naturally in each subregion represented in at least one priority area?

- Are all subregions adequately represented in the portfolio of priority areas?
- Are additional representation requirements, defined in the decision rules, also met?

Outputs:

- Documentation that all habitat types and subregions are represented adequately, following pre-established decision rules
- Revised map of priority areas if areas are elevated to achieve representation
- Documentation for any areas with elevated priority levels

Relevance to the assessment:

- One of the key goals of ecoregion conservation is representation of all biodiversity elements in priority areas.

After assigning different priority levels to the candidate priority areas, you can run the representation analysis again. Employ the same decision rules as those used when conducting the representation analysis for candidate priority areas (see Chapter 9, step 6), but this time apply the analysis only to the highest priority areas, or to another pre-defined subset (Table 11.1). If you find that there are representation gaps, address these by elevating the priority level of one or more candidate priority areas.

In the course of conducting a representation analysis you might discover patterns in the distribution of priorities. These patterns could be spatial (many highest or lowest priority areas in certain subregions), related to habitats (e.g., many highest priority areas in headwaters but few in lowlands), or even jurisdictional (e.g., few in one country or province compared with other places). Identifying such patterns is easier if you can show the different priority levels on a map. Skewed distributions are not necessarily bad — for example, one jurisdiction may simply have more intact habitat remaining — but you should take this opportunity to look for any bias in the analyses.

As noted in the introduction to this chapter, if the set of candidate priority areas already constitutes the minumum needed to achieve representation, you can assume that you will not be able to achieve the same level of representation with a subset of those areas.

Step 3. Analyze portfolio of priority areas to determine if conservation targets have been addressed, and elevate the priority level of one or more areas if necessary

Questions:

- Does the set of priority areas adequately capture all of the identified focal species, habitats, and processes?
- Have the minimum conditions for maintaining those focal elements been addressed?

Table 11.1. Example of representation of priority I areas among habitat types and subregions. Numbers in cells correspond to priority areas. Exercise could be repeated for additional priority levels.

	Priority I Areas				
Habitat Type/ Subregion	***Subregion 1***	***Subregion 2***	***Subregion 3***	***Subregion 4***	***Subregion 5***
Habitat 1	5, 6	12	20	29	
Habitat 2	5	12	27	33	39
Habitat 3	7	16			43
Habitat 4		12	22	35	46
Habitat 5	8	17	25	31	46
Habitat 6	5	18	27	35	41
Habitat 7	10	16	20	38	
Habitat 8	6	19	28		

Outputs:

- Revision of priority area set to address all focal elements and minimum conditions for maintaining them
- Documentation of all areas elevated in priority level
- Documentation of any gaps that cannot be addressed
- Final map of priority areas

Relevance to the assessment:

- It is essential that the assessment captures all important biodiversity features, and that priority areas are delineated and configured to meet minimum conditions. This step serves as a "check" to ensure that the assessment has followed the defined goals.

Most likely, your representation analysis will not have addressed the representation of all the conservation targets identified in your conservation targets chart. As with the candidate priority areas, evaluate your portfolio of priority areas to determine if you have adequately captured all of the targets that you set out to conserve. For example, even if all major habitat types are represented, the assessment may have missed key habitats for a particular focal species. If one of the goals is to protect that particular species, meeting that goal may require the elevation of one or more candidate priority areas.

As you go through your conservation targets chart (see Table 5.2), consider noting which priority areas address each of the targets. There may be some targets that simply cannot be addressed through the identification of priority areas, and these should be noted as well, with recommendations for addressing them through other means.

Step 4. Analyze overlap of priority areas with protected areas and with results of other priority-setting exercises

Questions:

- How do the priority areas identified in this analysis compare with protected areas already existing or planned?
- Could existing or planned protected areas be adjusted to confer greater protection to priority freshwater areas?
- How do the priority areas identified in this analysis compare with those identified in other priority-setting exercises (including terrestrial assessments for the same area)?
- What are the main reasons that priority areas differ between this exercise and others?

Outputs:

- Map showing overlap of priority areas and current and planned protected areas
- Identification of where gaps in protection exist, and recommendations for improving protection through adjustment of current or planned areas
- Map showing overlap of priority areas with results of other priority-setting exercises
- Identification of differences between sets of priorities and of reasons for differences
- Modification of priorities if omission is detected through comparison with the results of other exercises, or to better complement protected areas

Relevance to the assessment:

- A protected-areas overlap analysis may reveal obvious gaps in the protected-areas system, which would be a strong message to send to decision makers. Additionally, the analysis could point to protected areas that, with some modification, would confer greater protection to freshwater systems.
- A comparison of priorities from different exercises could reveal gaps that should be addressed, and/or areas of congruence that would highlight the importance of this assessment's results. Decision makers will want to understand how this assessment differs from others that preceded it, and why they should pay attention to a new portfolio of priorities.

After developing a portfolio of priority areas, there is an opportunity to evaluate how they compare with current and planned protected areas (in effect, we can think of these as the state's priority areas) and the areas identified by other priority-setting efforts. We discuss these two overlay analyses here because the results will likely inform the construction of the biodiversity vision. Additionally, understanding how protected areas are situated in relation to priority areas will assist with evaluating future threats.

Protected areas are as important to conserving freshwater biodiversity as they are for terrestrial systems. Few existing protected areas have been created explicitly to protect freshwater species or habitats, however, and even fewer are designed in such a way that this goal is achieved. For example, Noss and Cooperrider (1994) note that "while limitation of hunting has been common practice in terrestrial reserves, fishing has rarely been excluded from any aquatic system, freshwater or marine. Even national parks, which have a long history of excluding hunting, have traditionally allowed fishing. Yet if an aquatic reserve system is to conserve biodiversity and provide benchmarks for comparison with exploited areas, core areas will need to be closed to fishing." At the same time, a river or lake system in which fishing is prohibited will not be fully protected unless the larger catchment is under some form of protection from development, and impoundments and other habitat modifications are forbidden.

When conducting a gap analysis, then, it is fundamental to understand the degree to which existing protected areas actually confer protection to freshwater biodiversity. Beyond getting information on the types of activities permitted or forbidden in a given protected area, it is useful to see how the area is situated in relation to the habitat of concern. Any protected area within a catchment gives some benefit to freshwater habitats downstream, but the location of the area could make a substantial difference.

To start, we suggest overlaying a map of protected areas with priority areas and identifying places of congruence and obvious gaps in protection.[37] For example, an entire subregion or priority catchment may have little or no area under protection. Or, conversely, an existing protected area may be near or adjacent to a priority freshwater area, and a relatively small extension of the protected zone might generate large benefits to the freshwater system. In some cases, a protected area might encompass a priority freshwater system, but the protective measures in place might fail to protect freshwater species or habitats (e.g., if water extraction or fishing were unregulated). Any observations regarding gaps in protection will probably be useful to decision makers, so we recommend documenting such observations and incorporating them into the vision.

Decision makers will also be interested to know how the assessment's priorities compare with those of other priority-setting exercises for the region, if any exist. Be prepared to justify why a new assessment was necessary, how the methodology of this assessment differed from prior efforts, and how and why the priorities are similar or different. In general, if you can show how this assessment's priorities build upon previous efforts, decision makers should be more likely to consider them.

When comparing the priorities generated by terrestrial and freshwater assessments of the same area, a similar approach would be appropriate, highlighting the value of the current effort and illustrating how the two assessments can work together. Draw attention to the gaps inherent in a strictly terrestrial approach, as well as to the opportunities for maximizing protection through protected areas designed to benefit the biodiversity of both realms.

Conclusion

After developing a portfolio of priority areas, you are nearly ready to construct a biodiversity vision. If you have chosen to follow the order of steps that we have proposed here, however, you will not yet have considered threats expected to occur in the future. The following chapter walks through assessing both overarching threats to the ecoregion and specific threats to individual priority areas. Once you have completed the future threat assessment you should have most, if not all, of the pieces to construct a vision for the ecoregion.

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Noss, R. F., and A. Y. Cooperrider. 1994. Saving nature's legacy: Protecting and restoring biodiversity. Defenders of Wildlife and Island Press, Washington, D.C., USA.

[37] It may be more appropriate to do an overlay with all candidate areas rather than only the highest priority areas, if the set of candidate areas represents the minimum required to achieve the vision.

Identifying Specific and Overarching Threats

12

Introduction

To this point we have not discussed future threats, although they have been implicit in some instances (e.g., population issues). If we assumed that the stresses currently impinging on freshwater habitats and species were likely to continue into the future and intensify, in many cases we would probably be right. But some stresses, such as certain types of land use, might shift in nature, and other threats might appear where they had never existed before. A prime example in the freshwater realm is the construction of new dams, since these are often built on rivers where no dams currently exist. Governments or communities will obviously plan large projects such as hydropower dams and highways before building them, and such plans are one source of information for assessing future threats. At the other extreme, the location and timing of stresses such as armed conflict may be impossible to predict with any precision.

Threats also occur over different spatial scales. A large hydropower dam, for example, may cause widespread damage, but the actual dam will be highly localized. It might be most appropriate to focus short-term conservation efforts on the dam itself, but a long-term strategy would need to consider the region's energy policy. In headwater regions a multitude of small dams might together imperil headwater biotas, but each dam individually might have a small impact. In this case, is the threat localized or widespread? We might argue that it is widespread, because the threat must be addressed broadly rather than dam by dam. And yet, if small communities are building their own dams without government assistance, a strategy might need to include working at the community level in addition to at higher policy levels. At the far extreme is climate change, which will affect vast areas and must be addressed globally (see Box 12.1). We offer these examples to illustrate the range of spatial scales over which threats may originate and operate and to emphasize that addressing a given threat may require a multi-layered approach.

There are also important issues of intensity, or magnitude, of threat. A point-source discharge of pollutants, such as the outflow from a small industrial plant, might represent a relatively low-intensity disturbance. A large dam is similarly a location-specific threat, but most freshwater biologists would consider it to be a high-intensity disturbance because of the enormity of changes it generates.

These distinctions of predictability, spatial scale, and intensity of disturbance are important, because they determine the most appropriate conservation actions for priority areas and for the ecoregion as a whole. We suggest evaluating future threats first at the scale of priority areas, then evaluating overarching future threats. This approach should permit the identification of specific actions or kinds of conservation required at various scales, as well as the urgency associated with those actions. For the assessment of threats specific to priority areas, you may want to assign a threat level (e.g., high, medium, low), which you can display visually and also use to identify patterns among priority areas (e.g., all lowland river areas may be under high future threat).

Why not incorporate future threats into the prioritization of areas?

In past assessments, it was common to incorporate future threats into the prioritization, by using the threats to modify the ecological integrity level prior to integrating ecological integrity with biological importance. Several complications come with this approach. First, it is not necessarily clear whether high future threats should confer a lower or higher priority to a candidate priority area; some people argue that areas under high future threat should receive protection first, others believe that the areas should be dismissed as "lost causes." Dividing threats into "unavoidable" and "avoidable" categories would probably help to solve this dilemma.

But we are aware of two additional problems with less obvious solutions. First, assessments of future threats are often based largely on a combination of current conditions and speculation. If an evaluation of future threats is based on current conditions, incorporating the results into the prioritization will add little new information to the assessment. Second, in some ecoregions a large proportion of candidate priority areas would be considered at high risk from future threats, in part because experts tend to err on the side of caution. In this case, incorporating future threats into the prioritization would result in either a large increase or decrease in the number of high priority areas, depending on the approach. In either situation, discrimination among areas is reduced.

For these reasons we discourage incorporating future threats into the assessment before prioritizing among areas. Assessing future threats separately may actually give you the freedom to conduct a more sophisticated analysis and incorporate more details of the results into the vision. However, you may decide that the ecoregion and approach lend themselves to incorporating threats earlier; the following recommendations for conducting threat analyses should still be applicable.

Many assessments have evaluated both threats and opportunities. Opportunities represent situations or conditions that favor conservation and can be considered the opposite of threats.

Approaches for assessing future threats

Decide in advance what information you want to capture in your threat assessment, and use the conservation targets chart to help guide your thinking (see Table 5.2). In addition to considering how to assess future threats, also decide if you will evaluate threats for the whole ecoregion, only for candidate priority areas, only for high-priority areas (e.g., those receiving a level I or II), or for some other units. We recommend at a minimum looking at high-priority areas and also at overarching threats occurring across the entire ecoregion.

There are no definitive approaches for assessing future threats. In addition to maps of planned projects (e.g., impoundments, roads/highways, interbasin water transfers, canals, energy plants, logging or mining concessions, industrial plants), you can also use time-series data to assess trends. The most obvious example is population growth data, which will be available from census agencies. You could add to these data by estimating the spatial trajectory of growth within catchments or other units. The same basic method could be applied to other changes over time, such as changes in land use, riparian forest cover, or water withdrawals. Data on fish catches or other harvests might reveal changes over time; a sharp decline in catches or in the size of individuals caught might indicate severe overharvest, which in turn might presage local extinction.

For some ecoregions, such as those distinguished by lakes or springs, the introduction and/or invasion of exotic species may pose one of the greatest future threats (see Box 8.2). Some researchers have attempted to model the spread of exotic aquatic organisms (Buchan and Padilla 1999; Buchan and Padilla 2000), but this is still at best an inexact science. Consider how to evaluate future threats such as exotics that are difficult to represent on a map.

If you choose to assign future threat levels to priority areas, consider following a similar method to that which you adopted for evaluating habitat intactness. Some of the same data layers may help to identify opportunities as well. You could evaluate threats and opportunities by using a relatively objective measure (see Table 12.1, for the Amazon), or you could define more subjective levels. As an example for assigning threat levels:

- *High:* In 20 years, native aquatic species will be highly imperiled as a result of high-impact land uses in the catchment, the presence of large permanent structures altering hydrographic integrity, excessive water extractions, widespread habitat fragmentation, consistently high pollution, extreme overharvest of native species, the proliferation of exotic species, and other high-intensity disturbances. Without immediate conservation interventions, this priority area will reach a state from which it cannot be restored.
- *Moderate:* In 20 years, some native aquatic species will be imperiled as a result of localized moderate-impact disturbances, or more widespread low-intensity disturbances. These disturbances could include low- to moderate-impact land uses (e.g., appropriate crop production, low-density road networks), small- to medium-sized impoundments on a few tributaries, moderate water extraction, localized habitat fragmentation, point-source pollution, contained harvest of common species, or moderate competition/predation from exotic species. Without conservation intervention over the next 20 years, the more sensitive species are expected to disappear, and it may be highly difficult to restore impaired habitats.
- *Low:* In 20 years, the native aquatic species assemblages are expected to change little from their current state. High or moderate-impact activities are not anticipated for the area, because of the area's remoteness or protective measures. Low-impact disturbances such as small-scale land conversion or subsistence harvest of species may occur. No new highly invasive exotics are expected to spread within the area.

Table 12.1a. Criteria for assessing threats in the Amazon River and Flooded Forests ecoregion.

Criteria	*Indicators*	*High*	*Medium*	*Low*	*Weight*
roads in catchment	presence/ absence + state of completion	finished	under construction	planned	12.5%
	location*	parallel/close to the main river channel	transverse to the main river channel	absent	12.5%
hidrovías in/ along flooded forest habitats**	usage for fluvial transport	high traffic	average amount of traffic	low amount of traffic	10%
	state of completion	built	under construction	planned	
deforestation in headwaters of catchment	percentage of headwaters deforested	<10%	<10%	10–50%	20%
dams in catchment	presence/ absence + state of completion	under construction	in process of financing	planned	25%
population centers along flooded forest habitats***	presence/ absence + size	>100,000 inhabitants	10,000–100,000 inhabitants	none or <10,000 inhabitants	5%
	growth rate	>3%	2–3%	<2%	5%
fishing in/along flooded forest habitats	type of fishing	commercial	subsistence/ local sale	subsistence	10%

* Brazil used only the criterion of location, giving it the full 25% for the overall roads criterion
** Brazil used the constuction criterion (10%) while Peru used the “usage” criterion (10%)
*** Peru used both criteria (at 5% value each) while Brazil used only the growth rate at 10%

Table 12.1b. Criteria for assessing opportunities for the Amazon River and Flooded Forests ecoregion.

Criteria	*Indicators*	*High*	*Medium*	*Low*	*Weight*
protected areas in flooded forest habitats	% of surface area covered by protected areas	>50%	25–50%	<25%	25%
	state of approval of areas	approved	planned	none	25%
indigenous communities in flooded forest habitats	% of surface area in communities	<10%	10–50%	<10%	30%
local legislation (state or municipial control over resource management)	quality of legislation	good	moderate	bad	10%
action of local institutes	quality of local institutes	all sectors involved	some sectors involved	none	10%

We recommend trying to discriminate among three future threat levels, if possible (e.g., high, moderate, and low). Note that the participants at the Amazon River and Flooded Forests workshop decided to restrict their analysis of future threats to those that they could evaluate using mapped data, with the intention of conveying additional information on current and future threats in the text of their vision.

Step 1. Identify future threats specific to priority areas and the intensity of those threats

Questions:

- What future threats are expected to impinge on the freshwater biodiversity of each priority area within the next 20 years?
- What is the intensity of these future threats, and how urgent will it be to address them?

Outputs:

- Identification of the major threats expected to impinge on each priority area's biodiversity features within the next 20 years
- Agreement on the intensity of impact associated with different threats
- An evaluation of the future threat level of each priority area, and justification for the assignment of levels

Relevance to the assessment:

- The threat analysis alerts us to impending threats — both those that are acute and must be addressed immediately (e.g., proposed dams) and those that are chronic and will require a long-term strategy (e.g., overexploitation of water resources).
- The threat analysis suggests the most appropriate conservation actions to undertake in each priority area.
- Comparing threats among priority areas can reveal patterns operating at larger scales.

Identifying the main threats expected to impinge on each priority area's freshwater biodiversity features should be a relatively straightforward task, even if there are few data to inform the exercise. Obviously, a high degree of uncertainty is involved in this assessment, so note when confidence in the results is low. We suggest that, if possible, all experts work together to identify specific threats, because this will help to generate ideas and will lead to more standardized results.

Comparing threats among priority areas will help to identify broader patterns. For example, examining how threat levels were distributed among priority levels might speak to the urgency of conservation within highest priority areas (Table 12.2). Equally revealing might be a simple correlation analysis to determine if the ecological integrity levels of areas are associated with their future threat levels. If they are, you might consider if the future threat analysis truly added new information to the broader assessment.

Another possibility would be to do the same analysis by habitat type, either for each priority level individually or lumped together (Table 12.3). This would give an idea as to whether high threats were more prevalent for certain habitat types. You could do the same for each subregion as well.

Or, analyzing different future threats separately (e.g., dams, roads, deforestation), as the group did for the Amazon River and Flooded Forests, might reveal patterns of threats within different subregions or habitat types. This could be the most informative analysis related to threats, because it would help to identify more widespread or overarching pressures.

Note that these same analyses could be conducted using habitat intactness or ecological integrity information, to assess current threats.

Step 2. Identify overarching threats to the region, ecoregion, and subregions and their intensity

Questions:

- What broad threats are expected to impinge on the freshwater biodiversity of the subregions, ecoregion, or larger region within the next 20 years?
- What is the intensity of these future threats, and how urgent will it be to address them?

Outputs:

- Identification of overarching threats expected to impinge on the freshwater biodiversity of subregions, the ecoregion, or the larger region within the next 20 years
- Agreement on the intensity of impact associated with different threats, and appropriate responses to them
- Agreement on the scale over which the threats operate, and the source of the threat (if outside the region of analysis)

Relevance to the assessment:

- Many of the threats expected to occur within the next 20 years originate and/or occur over larger areas than single priority areas. Preventing or mitigating these threats will require designing a strategy that is scale-appropriate.

Table 12.2. Example of distribution of threat levels among priority levels.

Priority Level	*# of Areas*	*High Threat*	*Moderate Threat*	*Low Threat*
I	6	45%	30%	25%
II	8	25%	15%	60%
III	9	30%	20%	50%
IV	7	10%	20%	70%
V	6	45%	25%	30%

Table 12.3. Example of distribution of threat levels among habitat types.

Habitat Type	*# of Areas*	*High Threat*	*Moderate Threat*	*Low Threat*
A	6	45%	30%	25%
B	8	25%	15%	60%
C	9	30%	20%	50%
D	7	10%	20%	70%
	6	45%	25%	30%

- Socioeconomic experts will use the results of this threat analysis to focus their assessment of the ecoregion.
- The results of the analyses of overarching threats and priority area-specific threats will be combined to suggest the most appropriate conservation actions and timetables for implementing them.

The analysis of overarching threats should focus on those threats that directly affect biodiversity, rather than on root causes (e.g., poverty) or on the results of threats (e.g., sedimentation). A root causes analysis will be an essential part of developing a conservation strategy, but biologists are generally not the best people to engage in this analysis. We define overarching threats as those that are pervasive throughout the ecoregion or subregions, or those that have pervasive impacts (e.g., large dams may not be located in headwaters regions, but they will have the effect of isolating upstream populations from those downstream). Similarly, activities with local rather than ecoregion-scale impacts (e.g., small point-source polluters) may pose overarching threats if they are widespread within the ecoregion.

The identification of overarching threats will probably be a subjective exercise, as it is difficult to evaluate these threats using mapped information. It may be most useful to ask experts to work in subregional groups, because the dominant threats may vary across the ecoregion. Recognize that there may also be real differences among jurisdictions, particularly countries. Consider designing a simple framework to help experts organize their thoughts as they identify threats, such as by providing broad categories derived from the conservation targets chart or from the identification of threats in priority areas. Encourage participants to be as specific as possible when identifying threats; for example, "water extraction" will not be as helpful for later analyses as will "water extraction for irrigation" or "water extraction for industry."

Some past ecoregional exercises have attempted to identify, through expert assessment, the most prominent overarching threats. You may want to consider trying to generate such a "worst offenders" list, which you can include in the vision to draw attention to these pressures. Or, it might be equally if not more useful to categorize overarching threats in terms of their intensity and/or the urgency with which they should be addressed.

The analysis of overarching future threats will probably focus largely on pressures that already exist in the ecoregion and are expected to continue or intensify. For this reason, the recommended actions derived from this analysis should be equally applicable to the current situation.

Step 3. Identify specific actions or kinds of conservation required for each priority area, subregion, or larger areas, and the urgency of action

Questions:

- Based on the results of the threat analysis, what specific actions or kinds of conservation will be required for each priority area? How urgent is the need for these actions?
- Based on the results of the threat analysis, what specific actions or kinds of conservation will be required for each subregion and for the ecoregion as a whole? How urgent is the need for these actions?
- What information gaps are hampering the identification of appropriate conservation actions?

Outputs:

- Identification of specific actions or kinds of conservation required for each priority area, with timelines for implementation based on urgency
- Identification of specific actions or kinds of conservation required for each subregion and the ecoregion as a whole, with timelines for implementation based on urgency
- Identification of information gaps hampering identification of appropriate conservation actions

Relevance to the assessment:

- The conservation actions identified in this step will be an integral part of the biodiversity vision and potentially the final conservation plan.
- The ecoregion team can focus on the most urgently needed conservation actions while the biodiversity vision is being reviewed and finalized and the conservation plan is being developed.

After generating the list of threats projected to be important within each priority area, as well as within subregions and the ecoregion as a whole, you can identify specific actions to address the threats and the types of conservation expected to be most effective (see Box 12.2). For example, if loss of riparian vegetation were a serious problem throughout the ecoregion, you might identify conservation actions focused on creating ecoregion-wide policies to protect riparian zones and educating residents about the importance of riparian vegetation. Additionally, more in-depth analyses looking at why people have cleared riparian zones, when the trend began, who owns most of the cleared lands, and how wide a riparian buffer zone should be to confer sufficient protection to different aquatic system types might be warranted. Findings from these types of analyses would shed light on the most appropriate types of conservation initiatives. The experts might recommend that restoring riparian zones within priority areas should take immediate priority, whereas working across the ecoregion would be a longer-term goal.

Try to be as specific as possible when identifying recommended actions, even if those actions concern a broad geographic area. For example, a recommendation to protect riparian zones in headwaters is too vague to give much direction to conservationists or decision makers, and in fact could be arrived at without undertaking an assessment. If it is impossible to make more specific recommendations, this may point to an information gap that might be a research priority.

Conclusion

If you are able to generate specific recommendations grounded in the assessment analyses, you will have accomplished a great deal and will have valuable information to share with decision makers. Conversely, if you generate recommendations that have little relation to the biological assessment, you may have difficulty justifying them. Each step in the assessment is intended to build on previous steps so that the process is transparent and additive.

Once you have chosen candidate priority areas, assessed their biological importance and ecological integrity, integrated this information to choose priorities, conducted a representation analysis, and analyzed future threats, you should be ready to pull all of this information together into a robust biodiversity vision. The next chapter deals with constructing the vision, and the following chapters are devoted to advanced topics that may be relevant to your assessment.

Box 12.1. The potential effects of global climate change on freshwater biodiversity.

The impacts of global climate change on freshwater systems and habitats will probably be severe. Whatever the direction and magnitude of climate changes, they will be manifested in precipitation and air temperatures, which in turn will affect water temperature, water quantity, and water quality (Meisner and Shuter 1992). Carpenter et al. (1992), in their summary of the potential changes to freshwater ecosystems and consequent effects on fish, observe that:

- Climate change may alter the composition of riparian vegetation.
- Distributions of aquatic species will change as some species invade more high latitude habitats or disappear from the low latitude limits of their distribution.
- Small, shallow habitats (ponds, headwater streams, marshes, and small lakes) will first express effects of reduced precipitation. Of greatest concern are the severely limited desert pool and stream habitats now occupied by threatened and endangered fishes. Similarly, the spawning habits of many species require small and shallow habitats as refuge and nursery for both gametes and early life history stages.
- Projected increases in air temperature will be transferred, with local modifications, to groundwaters, resulting in elevated temperatures and reduced oxygen concentrations. At low latitudes and altitudes these changes may have immediate adverse effects on eggs and larvae, which are usually deposited at sites of groundwater discharge.
- Many major river systems have an east-west drainage pattern. Lacking the opportunity to move north within the river courses, many freshwater fishes will not have access to a thermal refuge.
- Warming of freshwater habitats at higher latitudes is more likely to open them to invasion.
- In a warmer, drier climate many perennial streams fed by runoff might become intermittent because of their high flow variability, while groundwater-fed streams would be buffered against such changes. Streams fed by snowmelt, which have highly predictable flood and flow regimes, might become less predictable with winter warming (increased rain-on-snow events). Increased aridity may render flows of many more streams unpredictable.
- As streams dry, mobile organisms are concentrated and biotic interactions intensify.
- Reduced flows can concentrate pollutants.

Researchers studying high-latitude and high-altitude lakes have reported additional threats related to climate change. Sommaruga-Wögrath et al. (1997) report that in alpine lakes there is a strong positive correlation between pH and mean air temperatures, and that climate warming may consequently promote lake acidification. Schindler et al. (1996) have found that climate warming may be more important than depletion of stratospheric ozone in increasing the exposure of aquatic organisms to biologically effective UV-B radiation. And Schindler et al. (1990) suggest that a combination of increased evaporation and decreased precipitation could have the effect of warming boreal lakes and concentrating pollutants in them, which would lead to the exclusion of stenotopic fish species.

Although all aquatic taxa will be affected by global climate change, freshwater fish have received the most attention in the literature. In the temperate zone, the distribution of fish species is tightly correlated with water temperature, and the seasonal water temperature cycle has a substantial influence on life history and reproductive success. Future climate scenarios suggest that the temperate zone will experience changes in seasonal maximum and minimum temperatures, and in the timing of events such as freeze-up and spring thaw (Meisner and Shuter 1992). Such changes have serious implications for the ability of fish to grow, survive, and reproduce.

In the tropics, air temperature varies little over the course of the year, but precipitation undergoes wide and predictable seasonal variations. The cyclic swelling and drying of rivers directly affects aquatic organisms in terms of basic habitat availability, oxygen levels, turbidity, and food resources (Meisner and Shuter 1992). During the wet season, habitat is plentiful, and species can move into swamps, lagoons, and floodplain pools to feed and reproduce (Welcomme 1979). These habitats are considered marginal, because with the dry season they become isolated from the main river channel and can dry up. Fish that remain in these marginal habitats during the dry season are subject to very low oxygen levels and possible desiccation, as well as to changes in pH and conductivity (Meisner and Shuter 1992). The availability of marginal habitats during the wet season, and the severity of conditions in those habitats during the dry season, are both dependent on the hydrologic regime, which in turn is dependent on precipitation. Models predict that future changes in precipitation will be greatest in the tropics, suggesting extreme consequences for those species that are unable to persist and reproduce in main channel habitats (Meisner and Shuter 1992).

What are the implications of these predictions for conservation planning? First, maintaining longitudinal connectivity in riverine systems will be critical, so that species may have access to thermal refugia at higher elevation habitats. Second, even though groundwater temperatures will increase in conjunction with rising annual air temperatures, protecting groundwater inputs may be important in arid areas or other locations where surface waters may dry up or become critically hot. Because degraded systems may be easily invaded by exotics once the barrier of limiting water temperatures disappears, it will be even more important to protect remaining intact systems. Vegetation cover within a catchment helps to maintain the natural hydrologic regime, and as climate change alters precipitation the regulating effect of vegetation will be critical. Similarly, the shade generated by riparian trees may create thermal refugia. Finally, massive information gaps regarding the life histories of freshwater species hinder our ability to plan for climate change, and research to address those gaps would have equal applicability for conservation planning in today's climate regime.

Box 12.2. Recommended conservation actions for the Congo River Basin ecoregion complex.
(Modified from expert assessment workshop, Libreville, Gabon, April 2000.)

1-year actions

- Inventory species and do environmental impact assessment for impending dam on Kouilou-Niari
- Develop management plan for Barombi Mbo
- Inventory existing, historical data housed in museums and georeference it to determine actual data gaps and develop prioritized strategy for inventories
- Inventory high priority survey areas (particularly Cuvette Centrale)
- Build awareness regarding exotics and investigate/promote responsible aquaculture with natives (particularly regarding *niloticus* in the Ivindo)
- Develop regional expert database for improved communication and information sharing
- Document micro-endemism in Central African freshwater biota
- Identify the most threatened headwaters (e.g., from forest concessions, mining)
- Promote development and use of FishBase by wider conservation/research community

3-year actions

- Research the size/extent/composition of riparian forests required to maintain headwater and downstream habitats
- Establish regional network of interested parties for facilitating information sharing, collaboration
- Develop coastal conservation action plan targeting mangroves, swamp forests, estuaries, lagoons
- Develop recovery plan for Niger Delta
- Develop long-term management plan for Lac Télé/Likouala-aux-Herbes Ramsar site (including survey)
- Re-survey Thysville Caves
- Develop regional training program in monitoring and management of freshwater biodiversity
- Create and fund "mixed fellowships" for graduate work abroad combined with field work at home
- Build awareness about value of freshwater biodiversity conservation (including link between human health and biodiversity)
- Conduct rapid assessments and monitoring of priority areas
- Develop and implement species action plans for red-listed species
- Conduct risk assessment to identify hazards across region of analysis (e.g., pollution sources)
- Develop management plan for SW Cameroon (including field interpretation center at Barombi Mbo)

10-year actions

- Put in place headwater protection
- Develop regional center for freshwater biodiversity for Central Africa (similar to center for West Africa)
- Create field guide for Central African fish
- Develop and provide practical alternatives to resource use in biologically important areas
- Designate large-scale biosphere reserves or other key areas as sites of global importance (including trans-frontier “peace parks”)
- Create other sites of biodiversity importance (e.g., designate Ramsar sites using fish criteria)
- Conduct complementarity analysis with neighboring African regions
- Invest in water treatment
- Within protected areas, educate wardens and other managers about the importance of freshwater biodiversity (or create wardens specifically for aquatic species)

Ongoing

- Ensure responsible dam construction (with focus on rapids)
- Conduct environmental impact statements before development projects are implemented
- Better integrate terrestrial and freshwater conservation initiatives, e.g., when establishing protected areas. Inclusion of hydrologists and limnologists in planning process is essential.

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Developing a Biodiversity Vision

13

Introduction

A biodiversity vision articulates what will be required over the next 50 years and beyond to conserve or restore an ecoregion's biodiversity features. A vision does not necessarily equal a report, although in many cases it takes that form. There is no standard format for a freshwater biodiversity vision. Rather than forcing a freshwater vision into a framework developed for the terrestrial realm, we suggest deciding first what messages the vision should include and then building the vision around them. Recognize that you may be unable to convey some of your results using maps; this may be particularly true for overarching threats and recommendations to address them. When deciding the form that your vision will take, consider who your audience will be. If you have multiple audiences you may need multiple forms of the vision; for example, if you are targeting decision makers, you may want to create a stand-alone executive summary that presents the most important messages without all of the supporting information.

Before embarking on constructing the vision, we suggest undertaking a few more steps to assess if all of the priority areas and actions, taken together, would achieve the long-term conservation of the conservation targets you have identified. When conducting these steps, focus on connectivity between priority areas, maintenance of physical processes, and the likelihood that populations, species, and habitats will persist over the long term. Also take the opportunity to synthesize the information gaps and key research questions that have been identified throughout the course of the assessment.

We focus here on developing a vision for freshwater targets only. If you are charged with the task of integrating freshwater and terrestrial priorities into a single vision, you will face more of a challenge. It will be difficult to mesh freshwater and terrestrial assessments and priorities seamlessly, because the approaches will almost certainly be different. Where possible, keep details of the assessments separate, and then combine the priorities in a way that highlights areas of congruence but also retains priorities that are unique to one realm or the other. Even if you are not developing a combined freshwater-terrestrial vision, it will be useful to include an analysis of how the freshwater priorities compare with any terrestrial priorities identified through separate analyses.

Step 1. Evaluate if priority areas and actions, taken together, would result in the long-term maintenance of the ecoregion's conservation targets, and add new priorities if necessary

Questions:

- Will the priority areas and recommended actions, taken together, maintain the ecoregion's target biodiversity features over the long term? If not, what additional areas or actions will be required?
- Are there information gaps hampering identification of additional required areas or actions? If so, what are they, and how should they be addressed?

Outputs:

- Identification of additional areas or actions that will be required to maintain the ecoregion's freshwater biodiversity over the long term, and full documentation of these additions
- Description of information gaps hampering the identification of additional required areas or priority actions

Relevance to the assessment:

- A vision that fails to address the maintenance of biotic and abiotic processes will be incomplete. This step encourages looking at all of the pieces of the assessment to evaluate how they fit together to maintain these processes.
- Key information gaps identified in this step will be incorporated into an overall list of research priorities.

This step may be among the most difficult ones of the entire assessment, because of the uncertainty regarding what is required to maintain biotic and abiotic processes. Return to the work that you undertook in preparation for the biological assessment, as well as the results of the biological importance and ecological integrity assessments, to help with this task. Be as analytical as possible, making sure to identify any information gaps that make it impossible to articulate "what success looks like" for the ecoregion. It may seem very late in the process to add new priority areas or actions, but developing a biodiversity vision and conservation strategy is an iterative process.

Some suggestions:

- If you have focused on identifying discrete priority areas, pay particular attention at this point to connectivity. Can you identify areas that should be protected as corridors?
- If your priorities cover aquatic habitats only, consider expanding them to include riparian zones/floodplains to ensure the maintenance of lateral connectivity.
- If you have not considered individual species, consider if known requirements of focal taxa have been met (e.g., are migratory corridors protected?)
- If you have not paid close attention to the representation of habitat types among priority areas, consider if important habitats are well distributed among subregions and/or catchments. Also consider if different habitats are connected where necessary (i.e., many aquatic species require access to multiple habitat types throughout their lives, from headwaters to estuaries).
- Taking a landscape-scale perspective, can you identify potential buffer habitats around priority habitats?
- Have you considered the current system of protected areas, and if there are opportunities to maximize the protection they confer to freshwater systems through modifications to the protected areas?
- Are the priorities ambitious enough to protect the hydrologic regime or other key physical processes?
- Have you taken an ecoregional perspective?

If you do add new priority areas, be sure to document why you have added them as well as any information describing them. For new priority actions, describe the scale at which they should be implemented and note the urgency of undertaking such actions.

Step 2. Synthesize key information gaps and research priorities

Questions:

- What are the key information gaps and research priorities that the assessment has highlighted?
- What is the urgency associated with the different research priorities?
- What are recommended avenues for catalyzing research to address key questions?

Outputs:

- Synthesis of information gaps and research priorities identified through the assessment, with associated information on scale
- Ranking of research needs in terms of urgency and importance
- Suggested avenues for catalyzing research into key questions

Relevance to the assessment:

- All ecoregions will suffer from information gaps, and many ecoregional efforts will be severely hampered by them. Identification of research priorities will be an important addition to the vision, although research should not serve as a substitute for taking conservation action.

Several steps in the assessment will have highlighted information gaps that hinder robust analyses. Some of these pieces of information may be critical for developing a vision or undertaking conservation actions, while others may be important for generating a comprehensive picture of the ecology of the system but less essential for moving conservation forward. Once you have listed all of the information gaps, you may find it useful to categorize them according to their type (e.g., related to species, habitats, physical processes, threats), scale (e.g., related to a single priority area, the entire ecoregion), or other feature. You may also want to identify the kind of research that would address the gap, as this will help to generate more specific recommendations. Many of the experts with whom you are working will be the best people to articulate basic research designs, so it is important to get their input. Finally, prioritize among the research needs, to highlight those that are most urgent. In addition to being an important part of the vision, a list of research needs will be helpful if you have the opportunity to suggest research questions to students or others hoping to integrate their efforts into the ecoregional effort.

Step 3. Combine priority areas map and priority actions into comprehensive vision

After doing as much as possible to develop priority areas and actions for the ecoregion, you should be ready to synthesize your results into a comprehensive vision. As we mentioned at the beginning of this chapter, there is no standard template for freshwater visions. Simply strive to create a product that explains what distinguishes the freshwater biodiversity of the ecoregion and what will be required to conserve it. Again, consider the audience carefully. If readers will be unfamiliar with the basic concepts of freshwater biodiversity conservation, consider including some background information, just as we have tried to do in this sourcebook. If readers will be interested in descriptions of each priority area, consider if you want to include these in the vision or as a supplement. Be careful not to use excessive ecoregional jargon, unless the vision is intended exclusively for an internal audience. For a comprehensive vision, try to organize any data and results in a way that will illustrate the process through which the vision was constructed.

Creating a vision is a time-consuming process that requires more than simply compiling the results of the assessment. All ecoregion coordinators find that they need to strike a balance between creating a comprehensive vision and getting a product out for review in a timely manner, before the momentum from the assessment is lost. Consult with other ecoregion coordinators who have undertaken assessments and visions to get recommendations for expediting the process.

Step 4. Draft a vision statement

As biodiversity visions have evolved, it has become clear that even the most streamlined visions are still too bulky to communicate the overall message succinctly. The vision statement serves this purpose, boiling down the goals of the vision into a phrase, sentence, or paragraph. Some statements have been quite specific to the ecoregion, while others have been more generic expressions of the goals of biodiversity conservation. The statement should send an ambitious message and may even serve as a rallying cry. As an example, the vision statement that experts crafted for the Congo River Basin and Lower Guinean drainages was:

> Our vision for the Congo Basin and Lower Guinean drainages is to conserve, to the fullest possible extent, their globally outstanding richness, diversity, and uniqueness in terms of the habitats, fishes, and other aquatic taxa. There must be clear and achievable conservation goals and programs must be properly planned, knowledge-based, and incorporate sound science – including fundamental data on species identity, distributions, and life cycles. Specially designed aquatic reserves, the protection of headwaters, and the minimization of the impacts of commercial aquaculture and damming are required. These aquatic conservation goals should be fully integrated into terrestrial conservation programs and vice versa. Conservation planning must be sensitive to the sustainable requirements of various stakeholders, such as fishing peoples and the agricultural community. Sound education, awareness, and training programs, and a regional network for the study and interpretation of aquatic biodiversity, will be crucial in securing the vision. The essentially unspoiled nature and vast scale of this aquatic ecosystem makes it a singularly compelling conservation challenge.

At the other extreme, the working statement for WWF-Brazil in the Pantanal is simply "Pantanal Forever." As with the vision itself, tailor the vision statement to its intended audience.

Step 5. Identify next steps

After generating a draft biodiversity vision, you should chart the steps that will be required to finalize it. These will probably include adding information that was missing during the assessment, finishing incomplete maps, sending the vision out for review by participating experts and others, and incorporating any changes into a final version. Obtaining peer review of the vision is critical for obtaining buy-in; participating experts will probably have identified others who could make a contribution to the report, and you can start by asking these individuals for their input. Be sure to emphasize that all products prior to the final vision are in draft form and subject to change.

More than likely, the data that you will have amassed during the assessment will be a valuable resource for conservation planners, so consider how to make it broadly available. For large maps and databases, consider distributing the data on a CD.

As with planning for a workshop, clearly define roles and timelines for those who will be involved in finalizing the vision and disseminating the results. Conducting an assessment can be an exhausting affair, and following up with next steps can be difficult, particularly if sufficient time and resources have not been budgeted.

Conclusion

If you have incorporated even a small fraction of the suggestions that we have presented in this sourcebook, you have probably conducted a more thorough assessment and developed a more comprehensive vision than any other efforts to date. As we said at the beginning of this volume, the "science" of freshwater ecoregion conservation is continually evolving, and your efforts will add volumes to existing experiences. Every biological assessment and biodiversity vision has built on the lessons derived from previous experiences, and we expect that your work will move thinking about freshwater conservation forward even further.

PART III:

Advanced Topics

Restoration of Aquatic Ecosystems 14

Restoration measures should not focus on directly recreating natural structures or states, but on identifying and reestablishing the conditions under which natural states create themselves. The focus is on ecosystem processes and patterns at larger scales, within which local habitats and individual organisms are embedded.
– Frissell and Ralph (1998)

The restoration of freshwater ecosystems has received as much if not more attention than strict protection, perhaps in part because so few undisturbed ecosystems remain (Noss and Cooperrider 1994). In some places, aquatic restoration has become an industry unto itself, responsible for undoing the constructed systems, such as channelized and impounded rivers, that are now considered antithetical to biodiversity conservation. Restoration measures include re-vegetating riparian zones, rebuilding stream channel form and instream habitats, removing impoundments or simulating natural flow regimes, reversing eutrophication in lakes, restoring flow to drained wetlands, and reintroducing native species. Restoration of natural land uses within a catchment constitutes another category of actions that is critical to a long-term plan for a degraded aquatic system.

In ecoregions that are heavily degraded, the bulk of a conservation strategy may entail restoration measures. Restoration is generally a resource-intensive process, however, so prioritization among areas is still important. As a result of a comprehensive landscape assessment of national forest lands in one large river basin, the U.S. Forest Service recently concluded that "effective restoration of all degraded areas is simply not feasible. We do not have the resources to make a difference at landscape scales unless we strategically focus our restoration efforts. Focusing on selected watersheds at the scale of 200,000 to 500,000 acres [8094 to 2023 km^2], where we can hope to make a difference, is a more realistic and promising approach" (Sedell et al. 2000). For these national forests, the authors suggest that catchment restoration measures would include thinning, prescribed burning, and other management projects applied at a landscape scale to prevent large-scale erosion, flooding, and nutrient loss.

Restoration is an attempt to re-create a pre-disturbance ecosystem (Federal Interagency Stream Restoration Working Group 1998). Therefore, characterization of the pre-disturbance ecosystem's structure and functioning is essential to formulating an explicit restoration goal (Ebersole et al. 1997). Removing the disturbance(s) will often go far in restoring the target habitat, particularly in the case of riverine systems. But, where native species have been extirpated and connections to source pools do not exist, a program of careful re-introductions may be required. Because native species have adapted over time to particular dynamics, the long-term survival of re-introduced populations depends on the degree to which the habitat has been restored to its original state (Stanford et al. 1996).

Restoration projects should be conceived and implemented at a spatial scale that is appropriate to the disturbance. Historically, most restoration projects have been at small scales (e.g., recreating instream pools and riffles), but such projects are normally effective only when the disturbance is also local. Larger-scale restoration projects, such as at the river reach or catchment scale, are rare but not unprecedented (Frissell and Ralph 1998). With each new project the knowledge base about restoration grows, but the long-term success of such endeavors is still largely unproven.

A biodiversity vision would probably focus on appropriate strategies rather than on the details of site-specific restoration projects. Having a general understanding of what such projects entail, however, is important before building a vision around them. Restoration of even an individual freshwater site is a complicated undertaking because it almost always requires attention to processes within the larger catchment. Here we give a brief overview of two restoration topics that are particularly relevant to freshwater ecoregion conservation: restoration of flow regimes in impounded rivers and restoration of riparian vegetation.

Restoration of flow regimes in impounded rivers

Flow-regulating impoundments normally reduce annual flow amplitude, increase baseflow[38] variation, and change temperature, mass transport, and other biophysical processes and attributes (Stanford et al. 1996). Where removal of a dam is not a realistic option, dam re-operation can achieve some measure of restoration of normative attributes (see Box 14.1). Re-operation is the process of modifying water releases to mimic a river's natural hydrologic and temperature regimes.

Re-operation for the purposes of river restoration involves (Stanford et al. 1996):

- restoring peak flows needed to reconnect and reconfigure channel and floodplain habitats,
- stabilizing baseflows to revitalize food webs in shallow water habitats,
- reconstituting seasonal temperature patterns (e.g., by construction of depth-selective withdrawal systems on storage dams), and
- maximizing dam passage to allow recovery of fish metapopulation structure.

According to Stanford et al. (1996), these goals are achievable without substantially compromising storage or hydropower (see Figure 14.1). With re-operation, baseflows are stable enough to keep shallow habitats watered, annual peak flows are high enough to maintain flood-dependent habitats and processes, and sufficient water is available throughout the year to satisfy downstream user needs.

The details of re-operating a particular impoundment depend on the type of river and impoundment (see Box 14.2. for the case of hydropower dams). We supply this overview to illustrate that a biodiversity vision should not automatically exclude all impounded rivers from consideration within a conservation plan. Different classes of conservation action are appropriate for different priority areas, and restoration through re-operation may be an option for rivers that have historically harbored important biodiversity elements.

Restoration of riparian zones

Riparian zones are key areas for maintaining the health of freshwater systems, plus they provide essential habitat for both aquatic and terrestrial species (see, for example, Gregory et al. 1991; Décamps 1993; Naiman and Décamps 1997; Tabacchi et al. 1998). Riparian zones are also among the most degraded habitats worldwide (Petersen et al. 1987; Wissmar and Beschta 1998). Petersen et al. (1987) recommend that, if whole-catchment management is impractical, "then strong riparian control measures can constitute an effective starting point."

Riparian zone restoration often involves active re-vegetation, but re-vegetation is pointless without mitigation of the causes of riparian disturbance (see Box 14.3). Disturbances generally stem from agricultural activities, flood-control measures, livestock grazing, or recreational activities (Briggs 1996). With the cessation of incompatible riparian uses (or the removal of flood-control structures), native riparian land cover may recover on its own. Briggs (1996) attributes this resiliency of riparian ecosystems to the fact that they typically experience high levels of disturbance. Riparian sites that recover naturally tend to share three traits (Briggs 1996):

1. They experience floods of sufficient magnitude to remove streamside plants, deposit fresh alluvium, and saturate floodplain soils.
2. They have seed sources located in or near the site.
3. They are no longer subject to degraded ecological conditions (e.g., low groundwater, channel instability, high soil salinity) or severe direct impacts (e.g., overgrazing).

Re-vegetation may be successful at sites without these characteristics, but long-term viability of any site will probably require that these conditions be met. Maintenance of a natural flood regime, connectivity with other riparian habitats, and mitigation of upland disturbances will be essential to the sustained success of any riparian recovery project.

Conclusion

Restoration can be a major undertaking with uncertain results, but it may be the only or best option for degraded areas of critical biological importance, or for corridors between intact areas. When developing a biodiversity vision at the ecoregion scale, and when designing conservation landscapes within priority areas, restoration may be an important long-term strategy.

[38] Also referred to as "groundwater flow," baseflow is that part of stream discharge not attributable to direct runoff from precipitation, snowmelt, or a spring, but instead coming from groundwater effluent.

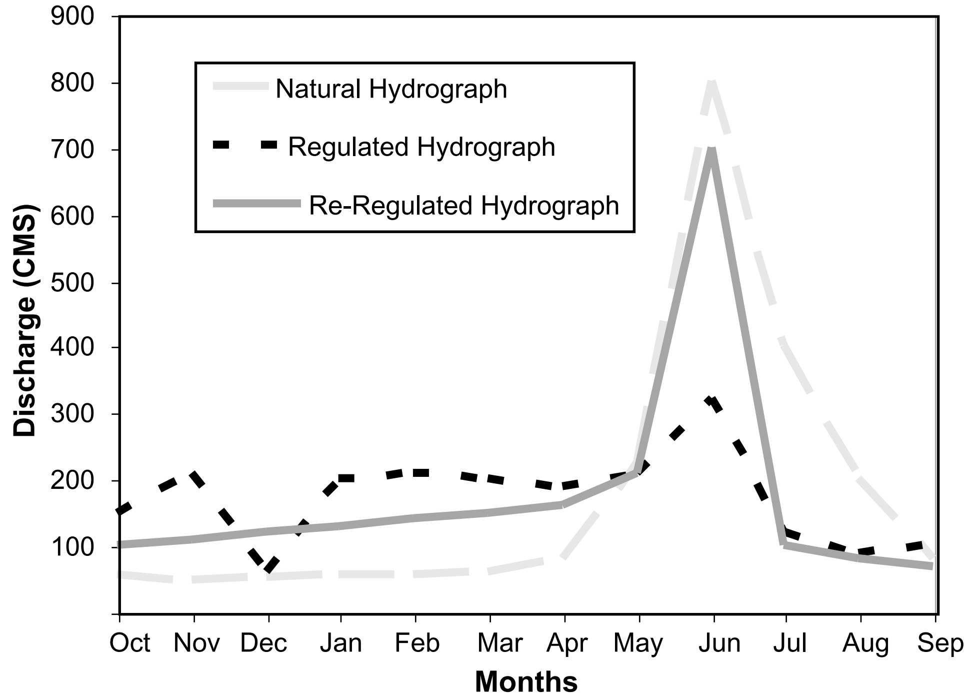

Figure 14.1. Simulated annual discharge (m^3/s x 10, mean monthly flow) patterns for natural, regulated, and re-regulated hydrographs. The same volume of water passes through the reach in each of the three scenarios. (Re-drawn from: Stanford et al. 1996.)

Box 14.1. Restoring regulated rivers.

The following, paraphrased from Stanford et al. (1996), assesses the potential for restoring rivers whose flow is regulated by impoundments. We recommend that anyone working on large river conservation read the original paper, as it gives an excellent summary of the function of floods in maintaining biodiversity.

Evaluate the current state of the river system

Restoration of large, regulated rivers first requires recognition that a river represents a biophysical continuum from its headwaters to its mouth. Restoration also requires an evaluation of the extent to which a river has retained or lost its capacity to sustain biodiversity. To do this, one must assess the river's current state, both in terms of its biology (e.g., past and present distribution of native biota) and its physical characteristics (e.g., channel configuration) (Frissell et al. 1993). Because it is difficult to determine accurately the distribution and abundance of river organisms, indices of biological integrity may be useful. Such indices are designed to indicate the status of an ecosystem based on the relative abundance of organisms within a small sample (Angermeier and Karr 1994). Identifying the generation times and comprehensive habitat requirements for keystone species (those exerting a disproportionate influence on the ecosystem relative to their abundance; Power et al. 1995) may help to suggest the appropriate spatial and temporal scale for restoration.

Consider the entire catchment

Most large river restoration projects will need to consider the entire river catchment, from the headwaters to mouth. Where rivers support anadromous fisheries, it is necessary to consider connectivity between estuarine and ocean habitats and the river system.

Re-regulation of water releases can go far towards restoring habitats

Flow and temperature are critical factors in the maintenance of riverine ecosystems. Re-regulating dam operations so that releases resemble natural flow and temperature regimes will substantially contribute to the restoration of riverine ecosystems. Re-regulation involves changing the duration and timing of flow releases from impoundments to mimic natural conditions better. Restoring peak flows can maintain instream and floodplain habitats (in the absence of retaining walls), and stabilizing base flows can revitalize shallow and slackwater habitats. In most rivers, re-regulation can be accomplished without substantially compromising water storage or hydropower. Removing impoundments would generally be a preferable alternative in terms of restoring ecosystem health, but this option is most often infeasible from a sociopolitical perspective.

Enable the passage of riverine organisms to allow recovery of metapopulations

Without the removal of dams and reservoirs, the next-best way to achieve longitudinal connectivity is to maximize the ability of riverine organisms to bypass dams. Flowing ladders, travelling screens, surface-release attractors, and other bypass devices increase the chances of survival for fish traveling up- or downstream. Dams without bypasses fragment and isolate populations, which restricts recolonization and prevents populations from exchanging genetic material. Restoring longitudinal connectivity, flow, and temperature seasonality may allow native species persisting in isolated refugia to disperse, repopulate depressed areas, and re-establish functioning metapopulations (Sedell et al. 1990; DeVore et al. 1995). A key strategy for restoring large rivers should be to identify, stabilize, restore, and reconnect isolated river segments to core areas containing viable species populations and assemblages.

Conclusions

Reregulation of large river systems from headwaters to mouth for the purpose of restoring and reconnecting hotspots of native biodiversity and bioproduction has not been accomplished anywhere to date…The reality is that sustainability of natural attributes of large river ecosystems is vastly compromised by [flow] regulation. Site-specific mitigation activities that ignore the biophysical continuum hold little promise and can be very costly when continued without evaluation year after year…The logical alternative is to try restoring biophysical connectivity of an entire regulated river ecosystem…Restoration of some large portion of lost capacity to sustain native biodiversity and bioproduction seems possible, especially in large rivers with a substantial portion of the continuum remaining in a free-flowing state. The cost may be less than expected because the river can do most of the work (Stanford et al. 1996).

Box 14.2. Mitigation options for hydropower dams.

American Rivers is a nongovernmental organization in the United States that has developed extensive materials on the effects of hydropower dams on river ecosystems. The following, reproduced with permission, is from the American Rivers web site, "River Renewal: Restoring Rivers through Hydropower Dam Relicensing. Mitigation Options" (http://www.americanrivers.org/hydropowertoolkit/rrmitoptions1.htm). American Rivers targets dams in the United States but the following applies as well to dams elsewhere.

Instream Flow

Hydropower projects can be separated into two general categories: run-of-river operations and peaking operations. In run-of-river operations, reservoir water levels are not mechanically regulated. Water flows over the dam in proportion to the amount entering the reservoir upstream. Peaking hydropower operations, however, store water behind the dam until it is most economical to release the water and generate electricity (e.g., storing water at night to release during the day). These peaking operations cause downstream stretches to fluctuate between low or no flows and surges of high water. This fluctuation erodes soil and vegetation, and either floods or strands wildlife downstream. In addition, peaking operations alter the natural seasonal flow variations of the river, such as high spring flows from snow melt, that trigger growth and reproduction cycles in many species.†

By establishing minimum and maximum instream flow requirements, it is possible to return healthy flows of water to reaches of river which previously received reduced flows, and to minimize the damaging effects of peaking hydroelectric operations. Seasonal minimum and maximum flows can also be established to protect spawning areas or other seasonal habitat needs. It is also possible to convert some dams from peaking to run-of-river generation. In many cases, minimum flow decisions are made to accommodate both fish and wildlife concerns and river recreation.

Bypassed Reach Restoration

In order to generate electricity, many hydropower projects divert almost the entire flow of the river between the dam and the powerhouse away from the riverbed, leaving it completely dry. The water is generally channeled through penstocks (pipes) or diversion canals and released at the base of the powerhouse. The dry "bypassed" reaches of a river can be as short as a few hundred yards, or as long as 15 miles. By bypassing stretches of river, the dam operations not only kill any preexisting aquatic or riparian wildlife, but also destroy the river's continuity as a migration corridor. Through settlement agreements and licensing decisions, flows can be redirected into dry river segments, and a healthy riverine ecosystem can be restored.

Reservoir Operation

Peaking power hydroelectric operations require reservoir fluctuations, where the level of water in the reservoir behind the dam is lowered for energy production (drawdowns can also be conducted for dam maintenance or flood control purposes). The fluctuation of reservoir water levels is damaging to a variety of avian and aquatic species. For example, birds such as the loon construct nests in close proximity to the reservoir water line, where significant fluctuation in either direction could flood the nest or strand the incubating mother. Eggs laid in shallow areas by certain fish species are in similar danger. In order to lessen environmental and ecological injury, reservoir fluctuation limitations (both annual and seasonal) are often provided for in settlement agreements and relicensing decisions.

Fish Passage and Protection

Fish Protection: Fish mortality rates in rivers dammed by hydroelectric projects are often high, as migratory and resident fish are wounded or killed after being swept into and through the dam's turbines (this is called entrainment). In order to reduce this damage, fish screens can be constructed at the intake area for each turbine. Trash racks (metal grating installed to prevent debris from entering the turbines) can also be used to hold back fish, provided that the bar spacing is sufficiently narrow.

Fish Passage: Hydroelectric dams also impede both the upstream and downstream movement of many migratory fish species, such as salmon, sturgeon, and shad. These migratory (or anadromous) fish hatch in the upstream reaches of a river, travel downriver to live out their lives in the ocean, and return to the same river years later to reproduce and often die. Because dams block both up- and downstream migration for most migrating fish species, it is beneficial for settlements and license agreements to include provisions for the installation of upstream and downstream fish passage facilities on rivers supporting anadromous fish populations. In some circumstances, fish passage may also be appropriate for resident (non-migrating) fish species.

Upstream Fish Passage: Numerous upstream fish passage techniques have been developed, including fish ladders, lifts, lock systems, and trap and truck methods. Fish ladders are staircase-like devices, usually off to one side of a dam, through which water is channeled. Some migratory fish species are able to travel up the ladder to arrive at the upstream reaches of a river. However, since fish must physically jump from one tier to the next, the ladders offer effective upstream passage for only strong swimming fish like salmon and trout.

Lifts and locks operate on the same principles as an elevator. With a fish lift, downstream fish are collected in a large container which is then mechanically lifted above the dam and emptied into the reservoir. A fish lock collects fish in an enclosed area. The surface level of the water is then raised to the top of the dam by adding water. When a trap and truck method is used, fish are drawn into a tank with the aid of a pump or a lift and transported by overland vehicles to a release site above the dam.

Like the fish ladder, lift, lock and trap and truck methods are only effective for certain types of fish. Those fish transported by these methods are often injured or stressed as a result. The overcrowding that results from these upstream passage methods increases the incidence of disease. Although many technologies exist for upstream passage, little data exist evaluating the success of these techniques in passing viable numbers of a given fish species.‡

Downstream Fish Passage: Downstream fish passage facilities have historically been considered less of a priority than have upstream facilities, as it was assumed that young fish would simply travel over the falls of a dam or through the turbines. However, declining numbers of anadromous fish have demonstrated that dams must provide improved downstream migration facilities. In many cases, downstream passage is provided through a canal over or around the dam that supplies a steady flow of water around the structure without a precipitous drop in elevation.

Peaking hydroelectric operations pose an obstacle to downstream migration when peak generation times do not coincide with spawning seasons. Fish prepared for rapid downstream currents during spawning season may become disoriented by the lack of water or stagnant reservoir. Under such conditions, it may be possible to arrange for a reservoir drawdown (also called a controlled spill) in order to flush the fish downstream. Barging fish downstream has also been tried experimentally to transport fish around dams and out to the ocean. Barged fish, however, experience increased disease, heightened stress, and decreased homing instincts when they attempt to migrate back upriver later in life.

† In rivers that have naturally highly variable flows, dry periods can be as important as wet periods to restore.
‡ The design of fish passage structures is species-specific.

Box 14.3. General guidelines for riparian restoration projects.

Briggs (1996) offers lessons derived from riparian restoration projects in the American Southwest. These are broadly applicable to other regions.

- One of the most critical lessons learned…is the importance of evaluating site conditions to understand current conditions, the extent to which they have declined, and the reasons for their decline. In general, we are often guilty of jumping to conclusions about the causes of degradation, how we are going to address the causes, and what the end point should be.
- The causes of riparian decline can best be understood by considering the riparian area in context of its watershed; this requires that reaches upstream and downstream from the degraded riparian area, the tributaries of the drainageway that passes through the degraded riparian area, and the uplands be included in the evaluation process.
- In line with the above, strategies for repairing degraded riparian ecosystems need to take a top-down approach that begins by addressing upland problems. Focusing recovery efforts on the bottomlands and neglecting upland problems may not bring about the intended results. Some of the more effective riparian recovery efforts were focused on solving upland problems, allowing the riparian environment to come back naturally.
- Addressing impacts that occur directly in the riparian zone is also an important ingredient for bringing the riparian area back to health.
- Riparian ecosystems are resilient. Understanding the potential for natural recovery may, in some cases, eliminate the need for riparian re-vegetation or other types of streamside recovery efforts. More important, working with natural processes to foster natural regrowth should be the aim of all riparian recovery efforts.
- Effective riparian recovery efforts need to be based on a sound understanding of site conditions, with an understanding of water availability, channel dynamics, and soil conditions being the most important.
- Generally, riparian re-vegetation is effective within a fairly narrow range of possible site conditions. On one hand, many degraded areas are too unstable to support the vegetation planted during re-vegetation; on the other hand, some sites are capable of prolific natural regrowth, making artificial re-vegetation unnecessary.

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Remote Sensing for Freshwater Conservation

15

Introduction

Because ecoregion conservation by definition requires a large-scale approach to conservation planning, an understanding of the character of the landscape is essential. Specifically, for the purposes of achieving representation we need to know how different habitats are distributed within an ecoregion. To evaluate the intactness of these habitats, we need to know their spatial extent, their configuration, and their proximity to developed or converted areas (e.g., roads, croplands, urban areas). To evaluate future threats, we can assess land-use trends and other measures (such as fire hazard and infrastructure suitability) to project forward in time. In theory, we can derive virtually all of these types of information from remotely sensed images, analyzed with a GIS or image analysis software package.

Remote sensing is the acquisition of data from a distance, such as by satellite imagery or aerial photography. Aerial photos tend to give higher spatial resolution, but for all but the smallest ecoregions it is not feasible to obtain recent photos covering the entire region of analysis. It is easier to obtain satellite imagery covering an entire ecoregion. Imagery must be chosen carefully to ensure that it is of appropriate spectral and spatial resolution and that clouds do not obscure the objective. Remote sensing and GIS can be particularly useful tools for analyzing land-use activities at the catchment scale. For larger catchments, satellite imagery may be sufficient.

There are some promising technologies in development for using satellite imagery to assess freshwater habitats. For example, the Commercial Remote Sensing Program of the U.S. National Aeronautics and Space Administration (NASA) is working with Yellowstone Ecosystem Studies (Y.E.S.) to test and develop the use of hyperspectral imaging to assess stream and riparian habitats (see Box 15.1). These new technologies hold enormous promise for the future, but what can remote sensing and GIS contribute to freshwater ecoregion conservation today?

Unfortunately, most of today's widely available satellite imagery does not have sufficient resolution to capture the majority of rivers or their riparian zones (see Box 15.1, Table 15.1). Even where freshwater habitats do appear, satellite imagery has generally not provided information on habitat characteristics or quality. Assessing actual freshwater habitats generally requires the procurement of aerial photographs or other high-resolution products (see Table 15.2).

Although the tools available for applying remote sensing to assessments of freshwater habitats and their catchments are limited, in the past few years numerous papers have appeared in the literature on the subject. We have compiled the abstracts of nearly 100 of these papers and indexed them by keyword; this document is available upon request from the Conservation Science Program. Johnson and Gage (1997) provide a table summarizing the key literature prior to 1997, which we reproduce here (Table 15.3). The kinds of analyses you can undertake will depend in large part on the imagery that is available for your region, and finding these images may require a bit of investigative work.

Many good sources of information on remote-sensing technologies are available. For an up-to-date introduction to remote sensing, we recommend the NASA tutorial that can be accessed online at http://rst.gsfc.nasa.gov/. Section 14 of the tutorial deals specifically with remote-sensing applications for analyzing hydrologic features. We also offer a list of important satellite imagery sources in Appendix VI.

Table 15.1. Important satellites used as sources of imagery for constructing spatial databases.

Satellite	*Pixel Dimension*	*Total Image Dimension*	*Image Characteristics*	*Source (see below for URLs)*	*Notes/Applications*
Advanced Very High Resolution Radiometry (AVHRR)	1 km	2399 km	Visible & Thermal Infrared	USGS (1)	Global or large regional mapping of vegetation conditions, seasonal changes, and forest fire monitoring
Landsat Thematic Mapper (TM)	30 m	185 km Multispectral	7 Band NASA (3)	USGS (2); remote-sensing satel-	The premier civilian lite. First choice for landscape level remote sensing (e.g., creating a national park map)
Landsat Multi Spectral Scanner (MSS)	80 m	185 km	4 Band Multispectral	USGS (4)	Earlier version of Landsat, no longer operational. Historic imagery allows analysis of landcover change from the early 1970s onwards
SPOT	20 x 20 m or 10 x 10 m	60 km & Color	Panchromatic & NIMA (5)	SPOT Corporation	Expensive for large areas and has data-sharing restrictions, but the released NIMA archive is free
Ikonos	1 to 4 m	Variable but around 10 km	Panchromatic & Color	Spaceimaging (6)	Very high resolution but expensive for large areas and has data-sharing restrictions
RADARSAT, JERS & ERS	10 to 100 m	35-500 km	Radar	Canadian Centre for Remote Sensing (7), Japanese Space Agency (8); European Space Agencies (9)	Synthetic aperture radar imaging; useful for mapping cloudy areas such as tropical forests
Terra & EO-1	Various	Various	Various	NASA (10)	The latest US government civilian satellites

(1) http://edc.usgs.gov/programs/lccp/globallandcover.html
(2) http://www.earthexplorer.com
(3) http://zulu.ssc.nasa.gov/mrsid
(4) http://www.earthexplorer.com
(5) http://geoengine.nima.mil
(6) http://www.spaceimaging.com
(7) http://www.rsi.ca/
(8) http://www.eorc.nasda.go.jp/JERS-1/
(9) http://www.esa.int/esa/progs/eo.html
(10) http://earthobservatory.nasa.gov/MissionControl/

Table 15.2. Digital data available for catchment assessments at various spatial scales. Taken from Johnson and Gage (1997).

Hierarchical Scale	***Digital Data***							
Region/ large catchment	AVHRR	TM/MSS	RADARSAT	SPOT	ERSI photography	Shuttle Elevation	Digital photographs Model	Aerial (fixed wing - high altitude)
River segment	TM/MSS	Radio-meter	Spectro-meter	Digital orthographs	Videography (airborne)	Aerial photographs (fixed wing - medium altitude)	Digital line graph (transporta-tion, hydrography, hypsography)	
Reach	Aerial photographs (helicopter - low altitude)	Video (low altitude, helicopter)						
Pool/ riffle	Aerial photographs (helicopter - low altitude, balloon, tower)	Video (tower)	Radio-meter	Spectro-meter				
Habitat	Photographs (balloon, tripod)	Video (tripod)						

Table 15.3. Applications of remote sensing to aquatic systems. Taken from Johnson and Gage (1997).

Applications	***References***
Detecting physical properties, e.g. temperature, moisture content, 'greenness,' organic and inorganic composition, turbidity, surface texture, drainage patterns; circulation patterns	Finley & Baumgardner 1980; Argialas, Lyon & Mintzer 1988
Vegetation mapping, land use/land cover mapping	Dottavio & Dottavio 1984; Jensen et al. 1986;
Mapping macrophyte distribution	Gross & Klemas 1986; Ackleson & Klemas 1987
Mapping chlorophyll *a* distribution and primary production	Hardisky et al. 1984; Harding, Itsweire & Esaias 1995; Ruiz-Azuara 1995; Rundquist et al. 1996
Mapping turbidity and temperature	Aranuvachapun & Walling 1988; Brakel 1984; Goodin et al. 1993; Bolgrien, Granin & Levin 1995; Liedtke, Roberts & Luternauer 1995
Detecting temporal change, e.g. land use, temperature, macrophyte distribution	Christensen et al. 1988; Jensen et al. 1993; Jensen et al. 1995; Lee & Marsh 1995
Mapping water depth, e.g. mesoscale river habitat	Gilvear, Waters & Milner 1995; Lyon & Hutchinson 1995
Detecting water quality	Lillisand et al. 1983; Khorram & Cheshire 1985; Ormsby, Gervin & Willey 1985; Lathrop & Lillisand 1986, 1989

Box 15.1. Prior remote sensing research on streams and riparian habitats. By Bob Crabtree, Yellowstone Ecosystem Studies.

Since the 1940s, *aerial photography* has been used to document changes in fluvial regions (Reeves et al. 1975). These studies have been able to document both changes in river course (Lewin and Weir 1977; Ferguson and Werrity 1983; Ruth 1988; Schumann 1989) and variations in water depth (Milton et al. 1995). *Multispectral satellite imagery* (e.g., Landsat, SPOT) has enabled researchers to assess fluvial changes over a significantly larger area and on a more frequent basis (Lyzenga 1980; Salo and Kalliola 1986; Jacobberger 1988; Ramasamy et al. 1991; Blasco and Bellan 1992; Stumph 1992; Mertes et al. 1993; Reddy 1993). Unfortunately, only relatively large rivers (e.g., the Mississippi and Amazon Rivers) can be effectively studied with traditional satellite imagery. Indeed, streams and riparian areas have been relatively ignored by the remote sensing community because analysis of these narrow ecological lifelines was not technically feasible with the relatively low spatial and spectral resolution of traditional satellite remote sensing data.

However, several researchers have effectively studied relatively small features on low-order streams with high resolution *airborne multispectral scanner imagery*. For example, Gilvear and Winterbottom (1992) used data from an airborne scanner to map physical features on the River Tay in Scotland during floods. Hardy et al. (1994) used multispectral video imagery to classify relative water depths of mesoscale hydraulic features (e.g., 'shoal,' 'pool,' 'eddy,' and 'run') on Utah's Green River. And Gilvear et al. (1995) used enhanced scanned aerial photos of Faith Creek in Alaska to provide quantitative estimates of water depths and key stream features (runs, glides, and exposed gravel bars), both before and after mining in the watershed. This study documented loss of riffle habitats and reductions in pool depth as a result of sedimentation from mine operations.

Researchers affiliated with Yellowstone Ecosystem Studies have used airborne scanner imagery to study two streams within Yellowstone Park (Colvard 1998; Wright 1998). The goal was to learn whether 1-meter resolution multispectral scanner data could be successfully used to identify field-mapped hydrogeomorphic units. Nine different hydrogeomorphic units and large woody debris were selected for identification. Unfortunately, this experiment was only partially successful because of difficulties with rectification (Colvard 1998; Wright 1998). However, the nine hydrogeomorphic units and large woody debris could be clearly distinguished in the imagery. Project researchers estimate that, without the rectification problems, they could have obtained roughly 75 to 80 percent accuracy when mapping the larger hydrogeomorphic units and woody debris (Marcus and Minshall, pers. comm. 1998).

NASA's AVIRIS hyperspectral scanner previously has been used for stream analysis, primarily for study of stream or streamside contamination (Farrand and Harsanyi 1995; King et al. 1995; Swayze et al. 1996). Recently, Kokaly et al. (1998) attempted to use the AVIRIS scanner to map vegetation cover types in Yellowstone National Park. This effort was successful in discriminating willow and wetland areas along streams. However, all of these AVIRIS studies of streams or stream-related features were hindered by the relatively low spatial resolution (17-20 meters) of the AVIRIS sensor (Swayze, pers. comm. 1998).

This past remote sensing research indicates that, for effective stream and riparian analysis, both fine spatial and high spectral resolution are essential. It strongly suggests that the use of aerial photos and airborne hyperspectral imagery for analysis of stream and riparian areas is not only technically feasible, but has outstanding potential.

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PART IV:

Appendices

Glossary of Ecoregional Conservation Terms

biodiversity vision long-term goals for the ecoregion's biodiversity conservation and actions that identify key sites, populations, thresholds, and ecological processes. The scale of a vision is the entire ecoregion.

biological assessment a record of the distribution of species, communities, and habitats in an ecoregion, of the ecological processes sustaining that biodiversity, and of the current and future threats impinging on it. The scale of an assessment is the entire ecoregion.

biological importance the degree to which a particular area is valuable for maintaining one or more conservation targets.

biome set of ecoregions that (a) experience comparable climatic regimes; (b) have similar vegetation structure; (c) display similar spatial patterns of biodiversity, and (d) contain flora and fauna with similar guild structures and life histories. Also called **major habitat type**.

bioregion a geographically related assemblage of ecoregion complexes that share a similar biogeographic history and thus have strong affinities at higher taxonomic levels (e.g., genera, families).

candidate priority area an area delineated during a biological assessment that is determined to be important for maintaining one or more conservation targets.

conservation landscape a large area determined to be a priority for conservation, and for which a detailed conservation strategy is designed within an ecoregional plan.

conservation plan see **ecoregional plan**.

conservation strategy see **ecoregional plan**.

conservation targets practical targets that guide priority setting and implementation of strategies. These include distinctive units of biodiversity (e.g., endemic species, areas of high richness); larger intact habitats; intact biotas; keystone habitats, species, and phenomena; large-scale ecological phenomena; and species of special concern.

ecological integrity the likelihood that an area's populations, species, and assemblages will endure over time, given considerations of habitat intactness and population/species viability.

ecological processes complex mix of interactions among animals, plants, and their environment that ensure that an ecosystem's full range of biodiversity is adequately maintained. Examples include predator-prey dynamics, pollination and seed dispersal, and nutrient cycling.

ecoregion a large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions. The boundaries of an ecoregion encompass an area within which important ecological and evolutionary processes most strongly interact.

ecoregion complex a contiguous grouping of ecoregions that share biotic and ecological affinities.

ecoregional plan comprehensive strategy for all concerned, implemented by a consortium of WWF and its partners. The scale of a plan depends on the strategy, but it may focus field actions on a small number of local sites within an ecoregion. Also called a **conservation plan** or **conservation strategy**.

focal habitats habitats identified in an ecoregion as being critical for maintaining biodiversity. Examples might include riparian forests, large alluvial river reaches, or rapids.

focal species species whose requirements can be used to set minimum targets for the vision.

freshwater habitat type aquatic systems that are relatively homogeneous with respect to size and thermal, chemical, and hydrological regimes.

Global 200 Ecoregion a large region typically composed of several ecoregions that harbor outstanding biodiversity or representative assemblages and habitats.

habitat intactness a measure of the level of degradation (conservation status) of the habitats in a given area.

integration matrix a tool for assigning priority levels to unique combinations of biological importance and ecological integrity levels.

major habitat type see **biome**.

population viability the likelihood that populations in a particular area will persist over the long term, given considerations of population size, metapopulation dynamics, dispersal ability, and access to required habitats and resources.

priority area a candidate priority area deemed to be critical for achieving long-term conservation goals. Priority areas constitute a subset of all candidate priority areas and may or may not require strict protection.

protected area any place receiving some form of conservation management, from strict protection to sustainable resource use

reconnaissance a quick, multidisciplinary gathering/scoping exercise that informs an assessment of whether and how to proceed. The scale equals the entire ecoregion.

representation the protection of the full range of biodiversity of a given biogeographic unit within a system of protected areas.

site a localized natural habitat containing important biodiversity features.

socioeconomic an understanding of interactions and circumstances that allows for the assessment the determination of present and future pressures and opportunities affecting ecoregions. The scale equals the entire ecoregion, but the assessment may focus on priority areas identified in the biodiversity vision.

stakeholder any person, group, or institution that affects or is affected by, positively or negatively, a particular issue or outcome.

subecoregion see **subregion**.

subregion a biogeographic subunit of an ecoregion, based on the distinctiveness of biotas, habitat types, and ecological processes. Also called a **subecoregion**.

vision statement a concise summary of the key goals of the vision, in the form of a phrase or a succinct paragraph, intended to catalyze interest among target audiences outside WWF and focus conservation efforts on goals of primary importance. The scale equals the entire ecoregion.

Glossary of Biological Terms

Note: This glossary contains terms used in this sourcebook, as well as others that you may encounter when undertaking freshwater ecoregion conservation. We recommend the references listed at the end of this appendix as sources to consult for terms not listed here.

adjunct habitats within the restoration scheme proposed by Frissell (1997), areas that are directly adjacent to and typically downstream from **focal watersheds** or **nodal habitats**. Restoration of these degraded areas would have a relatively high probably of success. See Box 4.2 in main text.

allochthonous originating outside and transported into a given system or area (Lincoln et al. 1982).

allotopic referring to populations or species that occupy different macrohabitats (Lincoln et al. 1982).

alluvial relating to or consisting of any material that has been carried or deposited by running water.

alpha diversity species diversity within a habitat.

amphibian a member of the vertebrate class Amphibia (frogs, toads, and salamanders).

amphipod any of a large group of small crustaceans with a laterally compressed body, belonging to the order Amphipoda.

anadromous diadromous species that spawn in fresh water and migrate to marine habitats to mature (e.g., salmon).

anthropogenic caused or produced through the agency of humans (Lincoln et al. 1982).

aquatic living in water.

Aquatic Diversity Areas (ADAs) potential refuges identified through an approach developed by the American Fisheries Socity, with the intention of protecting evolutionarily distinct biodiversity units. See Box 4.6 in main text.

Aquatic Diversity Management Areas (ADMAs) intermediate targets in the protection of entire catchments, identified through an approach developed by Moyle and Yoshiyama (1994). See Box 4.6 in main text.

aquifer a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs (Maxwell et al. 1995).

arctic referring to all nonforested areas north of the coniferous forests in the Northern Hemisphere (Brown and Gibson 1983).

artesian referring to underground water that moves under pressure and flows to the surface naturally.

autochthonous endogenous materials such as nutrients or organisms fixed or generated within the aquatic system (Armantrout 1998).

baseflow that part of stream discharge not attributable to direct runoff from precipitation, snowmelt, or a spring, but instead coming from groundwater effluent.

base map a map containing geographic features used for locational reference.

basin see **catchment**.

benthic living at, in, or associated with structures on the bottom of a body of water (Brown and Gibson 1983).

beta diversity species diversity between habitats (thus reflecting changes in species assemblages along environmental gradients).

biodiversity (also called biotic or biological diversity) the variety of organisms considered at all levels, from genetic variants belonging to the same species through arrays of species to arrays of genera, families, and still higher taxonomic levels; includes the variety of ecosystems, which comprise both communities of organisms within particular habitats and the physical conditions under which they live (Wilson 1992).

biodiversity conservation the goal of conservation biology, which is to retain indefinitely as much of Earth's biodiversity as possible, with emphasis on those biotic elements most vulnerable to human impacts (Angermeier and Schlosser 1995).

biogeography the study of the geographic distribution of organisms, both past and present (Brown and Gibson 1983).

biohydrologist someone who studies the interactions between the water cycle and plants and animals.

biomonitoring use of biological attributes of a water body to assess its environmental health or condition (Armantrout 1998).

biota the combined flora, fauna, and microorganisms of a given region (Wilson 1992).

biotic biological, especially referring to the characteristics of faunas, floras, and ecosystems (Wilson 1992).

bog wet, spongy land that is usually poorly drained, highly acidic, and nutrient-rich, and is characterized by an accumulation of poorly to moderately decomposed peat and surface vegetation of mosses and shrubs (Armantrout 1998).

brackish describing water with a salinity between that of normal fresh water and normal sea water.

canal an artificially created waterway (Armantrout 1998).

canopy cover percentage of ground or water covered by shade from the outermost perimeter of natural spread of foliage from plants (Armantrout 1998).

catadromous diadromous species that spawn in marine habitats and migrate to freshwater to mature (e.g., eels).

catchment all lands enclosed by a continuous hydrologic-surface drainage divide and lying upslope from a specified point on a stream (Maxwell et al. 1995); or, in the case of closed-basin systems, all lands draining to a lake.

cavernicoles animals that inhabit caves for all or part of their lives.

channel a natural or artificial waterway that periodically or continously contains moving water, has a definite bed, and has banks that serve to confine water at low to moderate streamflows (Armantrout 1998).

channelization the process of straightening a stream, which usually involves lining it with concrete or rock. Channelization is usually undertaken to control flooding and/or to divert water (Doppelt et al. 1993).

cienegas wetland associated with spring and seep systems in isolated arid basins of the American Southwest (Armantrout 1998).

clearcut a logged area where all or virtually all the forest canopy trees have been eliminated.

community collection of organisms of different species that co-occur in the same habitat or region and that interact through trophic and spatial relationships (Fielder and Jain 1992).

connectivity involving linkages of habitats, species, communities, and ecological processes across multiple scales; the opposite of fragmentation (Noss 1991, as cited in Federal Interagency Stream Restoration Working Group 1998).

convergence the independent evolution of structural or functional similarity in two or more unrelated or distantly related lineages or forms that is not based on genotypic similarity (Lincoln et al. 1982).

conversion the process of altering natural habitat for another use.

creek the smallest size class of a lotic system, typically associated with headwaters.

critical contributing areas within the restoration scheme proposed by Frissell (1997), portions of the watershed that do not directly support habitat for the species of interest but are important sources of high-quality water and stable watershed conditions for downstream **focal** or **nodal** habitats. See Box 4.2 in main text.

dam a barrier obstructing the flow of water that increases the water surface elevation upstream of the barrier (Armantrout 1998).

degradation the loss of native species and processes resulting from human activities such that only certain components of the original biodiversity still persist, often including significantly altered natural communities.

delta flat plane of alluvial deposits between the branches at the mouth of a river, stream, or creek (Armantrout 1998).

diadromous species that migrate between freshwater and marine habitats while spawning in one habitat and maturing in another (Nyman 1991).

digitizing process and operations for encoding graphic data into some numeric system (e.g., X, Y - coordinates) and storing it on a computer (The Wildlife Socity 1999).

dispersal multi-directional spread, at any time scale, of plants or animals from any point of origin to another, resulting in occupancy of other areas in their geographic range (Armantrout 1998).

distribution occurrence, frequency of occurrence, position, or arrangement of animals and plants within an area (Armantrout 1998).

disturbance any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment (Fielder and Jain 1992).

diversion the removal of water from a water body.

drainage basin see **catchment**.

ecosystem a community of organisms and their physical environment interacting as an ecological unit (Lincoln et al. 1982).

ecosystem service benefit or service provided free by an ecosystem, or by the environment, such as clean water, flood mitigation, or groundwater recharge.

effluent (1) discharge of liquid into a water body or emission of a gas into the environment; (2) used to describe a stream flowing out of a lake or reservoir (Armantrout 1998).

endemic a species or race native to a particular place and found only there (Wilson 1992).

endemism degree to which a geographically circumscribed area, such as an ecoregion or a country, contains species not naturally occurring elsewhere.

endorheic closed basin (no exterior drainage).

ephemeral stream stream where flows are short-lived or transitory and occur from precipitation, snowmelt, or short-term water releases (Armantrout 1998).

epigean pertaining to the biological domain at the ground surface or above it. Includes streams (Jennings 1998).

erosion the wearing away of the land surface by wind, water, ice, or other geologic agents. Erosion occurs naturally from weather or runoff but is often intensified by human land-use practices (Eckhardt 1998).

estuary a deepwater tidal habitat and its adjacent tidal wetlands, which are usually semi-enclosed by land but have open, partly obstructed, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted from freshwater runoff from the land (Maxwell et al. 1995).

eutrophication overenrichment of a water body with nutrients, resulting in excessive growth of organisms and depletion of oxygen concentration (Lincoln et al. 1982).

exotic species a species that is not native to an area and has been introduced intentionally or unintentionally by humans; not all exotics become successfully established.

extinct describes a species or population (or any lineage) with no surviving individuals.

extinction the termination of any lineage of organisms, from subspecies to species and higher taxonomic categories from genera to phyla. Extinction can be local, in which one or more populations of a species or other unit vanish but others survive elsewhere, or total (global), in which all the populations vanish (Wilson 1992).

extirpated status of a species or population that has completely vanished from a given area but that continues to exist in some other location.

extirpation process by which an individual, population, or species is totally destroyed (Fielder and Jain 1992).

falls free-falling water with vertical or nearly vertical drops as it falls over an obstruction (Armantrout 1998). Also known as waterfalls.

family in the hierarchical classification of organisms, a group of species of common descent higher than the genus and lower than the order; a group of genera (Wilson 1992).

fauna all the animals found in a particular place.

fen low-lying peatland that is partially covered with relatively fast moving, nutrient-rich, neutral to basic water that is rich in calcium. Fens are often dominated by sedges and rushes that form peat when they die and decay (Armantrout 1998).

flood (1) rising and overflowing of a water body onto normally dry land; (2) any flow that exceeds the bankfull capacity of a stream or channel and flows onto the floodplain (Armantrout 1998).

floodplains areas that are periodically inundated by the lateral overflow of rivers or lakes, and/or by direct precipitation or groundwater; the resulting physicochemical environment causes the biota to respond by morphological, anatomical, physiological, phenological, and/or ethological adaptations, and produce characteristic community structures (Junk et al. 1989).

flood pulse periodic increase in riverine productivity that occurs when rivers inundate floodplains (Armantrout 1998).

flora all the plants found in a particular place.

flow (1) movement of water and other mobile substances from one location to another; (2) volume of water passing a given point per unit of time (Armantrout 1998).

fluvial pertaining to or living in streams or rivers, or produced by the action of flowing water (Armantrout 1998).

focal watershed within the restoration scheme proposed by Frissell (1997), a drainage basin that remains hydrologically and biotically unimpaired by human landscape alteration or aquatic species introductions and is a high priority for protection. See Box 4.2 in main text.

fragmentation process by which habitats are increasingly subdivided into smaller units (Fielder and Jain 1992).

free-flowing stream or stream reach that flows unconfined and naturally without impoundment, diversion, straightening, rip-rapping, or other modification of the waterway (Armantrout 1998).

freshet a great rise or overflowing of a stream caused by heavy rains or melted snow.

freshwater in the strictest sense, water that has less than 0.5‰ of salt concentration (Brown and Gibson 1983); in the context of ecoregion conservation, refers to rivers, streams, creeks, springs, and lakes.

freshwater marsh area with continuously waterlogged soil that is dominated by emergent herbaceous plants but without a surface accumulation of peat (Armantrout 1998).

gaging station particular location on a stream, canal, lake, or reservoir where systematic measurements of streamflow or quantity of water are made (Armantrout 1998).

genera the plural of genus.

genetic drift the occurrence of random changes in the gene frequencies of small isolated populations, not the result of selection, mutation, or immigration (Lincoln et al. 1982).

genus a group of similar species with common descent, ranked below the family (Wilson 1992).

geomorphology geological study of the configuration, characteristics, origin, and evolution of land forms and earth features.

glochidia (singular: glochidium) the intermediate larval stage of freshwater mussels. In the spring or summer, glochidia are expelled from a female mussel's gills into the water. The glochidia then attach to an appropriate host, usually a fish, and form numerous cysts.

grazing the act of feeding by livestock on vegetation of pastures and ranges.

groundwater water in the ground that is in the zone of saturation, from which wells and springs and groundwater runoff are supplied (Maxwell et al. 1995).

grubstake habitats within the restoration scheme proposed by Frissell (1997), habitats tending to occur in low-elevation, heavily disturbed portions of the drainage basin, generally associated with lowland floodplain rivers. Restoration costs are high, but the potential payoff could be large. See Box 4.2 in main text.

guild group of organisms, not necessarily taxonomically related, that are ecologically similar in characteristics such as diet, behavior, or microhabitat preference, or with respect to their ecological role in general.

habitat an environment of a particular kind, often used to describe the environmental requirements of a certain species or community (Wilson 1992).

headspring a spring that is the source of a stream.

headwaters (1) upper reaches of tributaries in a drainage basin; (2) the point on a nontidal stream above which the average annual flow is less than five cubic feet per second (Armantrout 1998).

herpetofauna all the species of amphibians and reptiles inhabiting a specified region.

hydrograph a graphic representation showing changes in the flow of water or in the elevation of water level plotted against time.

hydrography the study, description, and mapping of oceans, lakes, and rivers, especially with reference to their navigational and commercial uses (Nevada Division of Water Planning 1998).

hydrologic regime water movement in a given area that is a function of the input from precipitation, surface, and groundwater and the output from evaporation into the atmosphere or transpiration from plants (Armantrout 1998).

hydrology the science of waters of the earth; their occurrence, distribution, and circulation; their physical and chemical properties; and their reaction with the environment, including living beings (Nevada Division of Water Planning 1998).

hydroperiod the typical cycle for ponds and other waterbodies describing the length of time during which they have water.

hydrophyte any plant adapted to live in water or very wet habitats (Lincoln et al. 1982).

hydropower electrical energy produced by falling water.

hyperspectral the use of many narrow sections of the electromagnetic spectrum in remote sensing (The Wildlife Society 1999).

hypogean pertaining to below-surface environments.

hyporheic zone the transition zone between groundwater and streams.

ichthyofauna all the species of fishes inhabiting a specified region (Brown and Gibson 1983).

impoundment a body of water such as a pond, confined by a dam, dike, floodgate, or other barrier. It is used to collect and store water for future use (Eckhardt 1998).

indigenous native to an area.

intact habitat relatively undisturbed areas characterized by the maintenance of most original ecological processes and by communities with most of their original native species still present.

interbasin water transfer a project that moves water between hydrologically unconnected catchments.

introduced species see **exotic species**.

invasive species exotic species (i.e., alien or introduced) that rapidly establish themselves and spread through the natural communities into which they are introduced.

invertebrate any animal lacking a backbone or bony segment that encloses the central nerve cord (Wilson 1992).

irrigation movement of water through ditches, canals, pipes, sprinklers, or other devices from the surface or groundwater for providing water to vegetation (Armantrout 1998).

isopod a member of the crustacean order Isopoda, a diverse group of flattened and segmented invertebrates. Pillbugs are an example.

IUCN acronym for The World Conservation Union.

karst applies to areas underlain by gypsum, anhydrite, rock salt, dolomite, quarzite (in tropical moist areas), and limestone (Hobbs 1992).

keystone species species that are critically important for maintaining ecological processes or the diversity of their ecosystems.

lacustrine pertaining to lakes, reservoirs, wetlands, or any standing water body of considerable size (Armantrout 1998).

lake an inland body of water fresh or salt of considerable size occupying a basin or hollow on the earth's surface, and which may or may not have a current or single direction of flow (U.S. Dept. of Agriculture 1995).

landform the physical shape of the land reflecting geologic structure and processes of geomorphology that have sculptured the structure (Hunt 1974).

landsat satellite system that provides imagery used for remote sensing inventory and analysis. Also refers to a series of earth-orbiting satellites gathering multispectral scanner or thematic mapper imagery (Armantrout 1998).

landscape an aggregate of landforms, together with its biological communities (Lotspeich and Platts 1982).

landscape ecology branch of ecology concerned with the relationship between landscape-level features, patterns, and processes and the conservation and maintenance of ecological processes and biodiversity in entire ecosystems.

lentic referring to standing freshwater habitats, such as ponds and lakes (Brown and Gibson 1983).

levee a natural or man-made earthen obstruction along the edge of a stream, lake, or river. Usually used to restrain the flow of water out of a river bank (Eckhardt 1998).

life cycle the entire lifespan of an organism from the moment it is conceived to the time it reproduces (Wilson 1992).

lotic referring to running freshwater habitats, such as springs and streams (Brown and Gibson 1983).

macroinvertebrates invertebrates large enough to be seen with the naked eye (e.g., most aquatic insects, snails, and amphipods) (Maxwell et al. 1995).

macrophyte a plant that can be seen without the aid of optics (Armantrout 1998).

main channel primary watercourse containing the major streamflow. Also referred to as **main stem** (Armantrout 1998).

main stem see **main channel**.

map projection a method of representing the earth's three-dimensional surface as a flat, two-dimensional surface.

marine living in saltwater (Brown and Gibson 1983).

metapopulation a group of two or more separated populations of the same species that regularly exchange genes.

minimal viable population the smallest population size necessary for a species' long-term survival, given foreseeable impacts (Quammen 1996; Peck 1998).

mollusk or **mollusc** an animal belonging to the phylum Mollusca, such as a snail or clam (Wilson 1992).

morphology the form and structure of an organism, with special emphasis on external features (Lincoln et al. 1982).

multispectral imagery satellite imagery with data recorded in two or more bands (Armantrout 1998).

nodal habitats within the restoration scheme proposed by Frissell (1997), areas that are spatially dissociated from refuge habitats, but serve critical life history functions for individual organisms that originate from populations and species in refuge habitats throughout a basin. See Box 4.2 in main text.

non-indigenous species see **exotic species**.

nonpoint source a diffuse form of water quality degradation in which wastes are not released at one specific, identifiable point but from a number of points that are spread out and difficult to identify and control (Eckhardt 1998).

non-native species see **exotic species**.

nutrient element or compound essential for growth, development, and life for living organisms such as oxygen, nitrogen, phosphorus, and potassium (Armantrout 1998).

nutrient cycling circulation of nutrient elements and compounds in and among the atmosphere, soil, parent rock, flora, and fauna in a given area such as a water body (Armantrout 1998).

obligate species a species that must have access to a particular habitat type to persist.

oligotrophic having a low supply of plant nutrients (Eckhardt 1998).

overexploitation refers to levels of collection, hunting, or fishing that are not ecologically sustainable. Also called **overharvest**.

overharvest see **overexploitation**.

Pearson correlation a measure of linear association between two variables. Values of the correlation coefficient range from -1 to 1. The absolute value of the correlation coefficient indicates the strength of the linear relationship between the variables, with larger absolute values indicating stronger relationships. The sign of the coefficient indicates the direction of the relationship.

peat bog bog with a dominant underlying material of peat (Armantrout 1998).

pelagic (1) open water areas of lakes, reservoirs, or seas away from the shore; (2) refers to organisms at or near the surface in water away from the shore (Armantrout 1998).

perennial stream, lake, or other water body with water present continuously during a normal water year (Armantrout 1998).

physiography the study of the natural features of the earth's surface, especially in its current aspects, including land formation, climate, currents, and distribution of flora and fauna.

plankton small plants and animals, generally smaller than 2 mm and without strong locomotive ability, that are suspended in the water column and carried by currents or waves and that may make daily or seasonal movements in the water column (Armantrout 1998).

pluvial lake a former lake that existed under a different climate in areas that are now dry (Armantrout 1998).

polymorphism the co-occurrence of several difference forms (Lincoln et al. 1982).

point source source of pollution that involves discharge of wastes from an identifiable point, such as a smokestack or sewage treatment plant (Eckhardt 1998).

population in biology, any group of organisms belonging to the same species at the same time and place (Wilson 1992).

potamodromous life-cycle strategy of a fish that includes migrations, spawning, and feeding entirely in freshwater (Armantrout 1998).

radiation the diversification of a group of organisms into multiple species, because of intense isolating mechanisms or opportunities to exploit diverse resources.

rarity seldom occurring either in absolute number of individuals or in space (Fielder and Jain 1992).

raster data data that are organized in a grid of columns and rows and usually represent a planar graph or geographic area (Armantrout 1998).

recharge refers to water entering an underground aquifer through faults, fractures, or direct absorption (Eckhardt 1998).

refugia habitats or environmental factors that convey spatial and temporal resistance and/or resilience to biotic communities affected by biophysical disturbances (Sedell et al. 1994).

rehabilitation (1) action taken to return a landform, vegetation, or water body to as near its original condition as practical; (2) term implies making land and water resources useful again (primarily for humans) after natural or anthropogenic disturbances (Armantrout 1998).

relictual taxa a species or group of organisms largely characteristic of a past environment or ancient biota.

remote sensing the science of deriving information about the earth's land and water areas from images acquired at a distance. It usually relies upon measurement of electromagnetic energy reflected or emitted from the features of interest (The Wildlife Society 1999).

re-operation see **re-regulation**.

re-regulation changing the duration and timing of flow releases of a dam to mimic the natural hydrograph. Also called **re-operation**.

reservoir a pond, lake, tank, or basin (natural or human made) where water is collected and used for storage. Large bodies of groundwater are called reservoirs of water (Eckhardt 1998).

resident species organisms normally found in a single habitat, ecosystem, or area (Armantrout 1998).

resilience the speed at which a habitat, population, or community is able to return to equilibrium following a perturbation (Pimm 1986).

restoration management of a disturbed and/or degraded habitat that results in recovery of its original state (Wilson 1992).

riparian referring to the interface between freshwater habitats (normally flowing waters) and the terrestrial landscape (Gregory et al. 1991).

riparian buffer zone a riparian area that is afforded some degree of protection (Wenger 1999).

riprap hard materials, such as logs, rock, or boulders (often fastened together) used to protect a bank or another important feature of a stream, lake, reservoir, or other water body (Armantrout 1998).

river a natural stream of water of considerable volume, larger than a brook or creek.

runoff surface water entering rivers, freshwater lakes, or reservoirs (Eckhardt 1998).

saline salty.

salinity the amount of dissolved salts in a solution.

satellite imagery passive images of natural radiation detected in visual or infrared wavelengths (Armantrout 1998).

sediment soil particles, sand, and minerals washed from the land into aquatic systems as a result of natural and human activities (Eckhardt 1998).

sedimentation (1) action or process of forming and depositing sediments; (2) deposition of suspended matter by gravity when water velocity cannot transport the bed load (Armantrout 1998).

semi-aquatic living partly in or adjacent to water (Brown and Gibson 1983).

Shannon-Weaver Index a measurement of diversity that takes into account species richness and the proportion of each species within the local community. Can also be used for measuring the diversity of elements other than species. Also known as the Shannon-Weiner Index.

siltation the deposition of finely divided soil and rock particles upon the bottom of stream and river beds and reservoirs (Eckhardt 1998).

sinkholes depressions or cavities created by dissolution of limestone bedrock or collapse of caves. Typically found in karst landscapes.

sinuosity for streams, the ratio of channel length between two points on a channel to the straight line distance between the same two points.

speciation the process of species formation, in which one species evolves into two or more species (Quammen 1996).

species the basic unit of biological classification, consisting of a population or series of populations of closely related and similar organisms (Wilson 1992).

species adaptation particular part of the anatomy, a physiological process, or behavior pattern of a particular species that increases its chances of survival or ability to reproduce (Wilson 1992).

species assemblage the combination of particular species that occur together in a specific location and have a reasonable opportunity to interact with one another (Matthews 1998).

species radiation refers to the evolution of a single species into several different species within the same geographical range (Wilson 1992). Also referred to as adaptive radiation.

species richness a simple measure of species diversity calculated as the total number of species in a habitat or community (Fielder and Jain 1992).

spring a natural discharge of water as leakage or overflow from an aquifer through a natural opening in the soil/rock onto the land surface or into a body of water (Hobbs 1992).

stenothermic tolerant of a narrow range of environmental temperatures (Lincoln et al. 1982).

stenotopic able to exist only in a narrow range of habitats.

stream a general term for a body of flowing water (Maxwell et al. 1995); often used to describe a mid-sized tributary (as opposed to a river or creek).

stream order hierarchical ordering of streams based on the degree of branching. A first-order stream is an unforked or unbranched stream. Two first-order streams flow together to form a second-order stream, two second orders combine to make a third-order stream, etc. (Armantrout 1998).

stochastic random.

stock a race, stem, or lineage (Lincoln et al. 1982).

subcatchment a smaller catchment (e.g., one draining a headwater stream) within a larger catchment

subspecies subdivision of a species. Usually defined as a population or series of populations occupying a discrete range and differing genetically from other geographical races of the same species (Wilson 1992).

subterranean underground.

subtropical an area in which the mean annual temperature ranges from 13°C to 20°C (Brown and Gibson 1983).

surface water all waters whose surface is naturally exposed to the atmosphere, for example, rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc., and all springs, wells, or other collectors directly influenced by surface water (Nevada Division of Water Planning1998).

swamp tree- or tall shrub-dominated wetlands that are characterized by periodic flooding and nearly permanent subsurface water flow through mixtures of mineral sediments and organic materials without peat-like accumulation (Armantrout 1998).

systematics the classification of living organisms into hierarchical series of groups emphasizing their phylogenetic interrelationships; often used as equivalent to taxonomy (Lincoln et al. 1982).

taxon (pl. taxa) a general term for any taxonomic category, e.g., a species, genus, family, or order (Brown and Gibson 1983).

temperate an area in which the mean annual temperature ranges from 10°C to 13°C.

terra firma dry land.

terrestrial living or occurring on land.

tributary a stream or river that flows into a larger stream, river, or lake, feeding it water.

troglobites obligate cave species (Hobbs 1992).

troglophiles facultative cave species (Hobbs 1992).

trophic related to the processes of energy and nutrient transfer (i.e. productivity) from one level of organisms to another in an ecosystem (Armantrout 1998).

turbidity refers to the extent to which light penetrates a body of water. Turbid waters are those that do not generally support net growth of photosynthetic organisms (Jeffries and Mills 1990).

upland an area of land lying above the level where water flows or where flooding occurs.

vagile able to be transported or to move actively from one place to another (Brown and Gibson 1983).

vector data data that represent physical elements such as points, lines, and polygons (Armantrout 1998).

xeric describes dryland or desert areas.

waterfalls see **falls**.

watershed see **catchment**.

water table depth below which the ground is saturated with water (Armantrout 1998).

wetlands lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. These areas are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions (Maxwell et al. 1995).

woody debris any woody material in an aquatic system, often providing habitat and nutrients.

zoogeography the study of the distributions of animals (Brown and Gibson 1983).

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GIS Needs and Decentralization of GIS in the WWF Network

III

Introduction

GIS is an essential tool for ecoregion conservation. A GIS system is a powerful means of:

1. Providing base maps for conducting a biological assessment
2. Synthesizing expert opinion to determine and locate priority areas
3. Analyzing minimum habitat requirements for focal species and ecological processes
4. Identifying potential habitat
5. Representing the relationship between physical, biological, and socioeconomic data

In the past, functional GIS analyses could be conducted only by using expensive computer hardware and software. The high cost of the equipment limited the number of WWF offices and programs that could afford a full-fledged GIS lab. This constraint has virtually disappeared over the past few years. Computers have become more powerful and less expensive, and today more offices are able to afford a computer system that can handle GIS analyses. The Conservation Science Program (CSP) at WWF-US has been working to bolster the use of GIS within the WWF network by helping to decentralize its use.

The purpose of this appendix is to provide information about the data, software, and hardware requirements for using GIS to conduct biological assessments. The appendix includes information on how CSP can help by providing training and data. Because computer technologies evolve quickly, you may want to consult with CSP or other centers of GIS expertise before assembling your lab or data.

Software

The purchase of a computer does not automatically create a GIS lab. You will also need data, software, and personnel with GIS training. To this end, WWF has developed an agreement with ESRI, the maker of ArcView, one of the leading GIS software packages. This agreement allows for the purchase of ArcView, along with Spatial Analyst (a module that allows for conservation analyses relevant to ecoregion conservation), at an extremely reduced rate of US$350 compared with a list price of US$4,000. This agreement also allows CSP to purchase other ESRI software, such as PC ArcInfo and add-ons for ArcView.

ESRI GIS software is by no means the only GIS software available, but it is the most widely used by conservation planners. Because of its worldwide availability and CSP's arrangement to offer the software at reduced prices, it is the software we recommend you use in your "home" GIS lab (the lab in your main WWF office). It is also the software used at CSP. There are several different versions of the software, and these vary greatly in price. The top-of-the-line software is called ArcInfo.

The ArcInfo software runs on either UNIX or Windows NT computers. ArcInfo is very powerful but it is also very expensive and complicated to use. CSP does not receive any discounts on ArcInfo, although ESRI sometimes provides discounts on a case-by-case basis. Thus, we recommend ArcInfo only for large, centrally located labs with full-time staff trained in use of the software.

ESRI's intermediate-level software package is PC-ArcInfo. This software runs on computers running Windows 95 or higher. It is not as powerful as ArcInfo but has a few more features than ArcView, the most widely used software. The key feature that ArcInfo and PC-ArcInfo provide that ArcView lacks is easy digitizing. ArcView can be used for digitizing but it is slow and awkward. Because of this limitation, ArcView is not recommended as the software package to use during an assessment workshop. Except for digitizing, ArcView handles almost all other assessment requirements as well as or better than ArcInfo and PC-ArcInfo, and is therefore recommended for the home GIS lab. ArcView can run on almost any computer that can run Windows 95 or higher, and it is easy to learn.

Hardware requirements

ArcView and PC-ArcInfo will work on most PCs. Both programs are memory- and hardware-intensive, so the faster and better your computer the quicker and more efficiently you will be able to complete your work. The minimum requirements and the suggested requirements are listed below. Only use the minimum requirements if your budget precludes purchase of the ideal package. The extra money that you spend today will quickly be recouped by increased productivity, so try to spend as much as you can afford to get a faster quality system at the onset.

Printers

Many different types of printers are available. Based on our experience, the major brands (HP, Epson, and Canon) perform similarly among equally priced printers. These printers range in price from US$150 to US$500. The more expensive models print faster with a higher resolution. When buying a printer for GIS remember that most maps need to be larger than 81/2 by 11 inches (or A4), so look for printers that can print on larger sheets of paper (these will range in price up to US$1000). There are reasonably priced printers that can print up to 13 by 22 inches (about 33 by 56 cm). Plotters are large printers that can print on rolls of paper. They allow for maps that are up to 36 inches wide and 52 inches long (about 91 by 132 cm). They are quite expensive; low-end models start at $5000 and high-end models cost around US$12,000, but they are essential for producing base maps used in ecoregional planning exercises.

Additional hardware

Scanners allow you to add pictures and graphics to maps, and they cost about US$120 – US$400. ZIP drives are similar to floppy disk drives, and they are popular for exchanging large data files. They hold between 100MB (US$70) and 250MB (US$140). A ZIP drive is a good purchase only if you are exchanging data with others who also have one, so check with your colleagues before purchasing.

Computer Requirements*

Hardware Component	***"Ideal" Cost Estimate - US$3,000***	***Minimum Cost Estimate - US$1,700***
CPU	Pentium 4 1.8 GHz or better	Pentium III 900MHz or better
CD-ROM	CD-Recorder (CD-R). These allow you to save your data on CDs. This is a nice feature for exchanging data.	CD-ROM required
Hard Drive	Two hard drives with a total of 60GBs or higher. GIS datasets can be very large.	20GBs or larger
RAM	512 MB or more. The more RAM, the quicker your computer will run.	128MB or more
Operating System	Windows XP or Windows 2000	Windows XP or Windows 2000
Monitor	17-21 inches. Large monitors will improve work performance.	15 - 17 inches
Mouse	Required	Required
Printer	See text	Inkjet color printer
Tape Backup Device	1GB of capacity minimum. There are many different types. Our suggestion is to find a type that others in the area also use so that you can also use the tapes to exchange data.	Not required but a good investment to ensure data protection.

* Computer prices and equipment are rapidly changing. This list is shown as an example of different systems. These configurations and prices are current as of January 1, 2002.

Workshop GIS lab requirements

During an assessment workshop the GIS requirements are heightened, because there is time pressure to convert hard copy maps to digital data layers, synthesize the layers, and produce new hard copy maps that participants can review and use for further analyses. Because of the quick turnaround time, it is often important for the primary GIS analyst to have one or two assistants. Universities often have students interested in helping and who will work for reduced rates. When hiring assistants for the workshop, make sure that they have experience with the GIS software you are using and that there are no language obstacles.

The workshop lab should have one or two digitizing tablets. These tablets are the means of converting information from hard copy maps into digital data. Depending on the number of assistants, there should be several workstations (computer terminals) available at all times during the day. The workshop lab also needs a large size plotter for printing large maps.

Decentralization of GIS and related technologies

CSP works to assist WWF programs in acquiring the right tools, skills, and data to conduct assessment workshops, develop biodiversity visions, and design ecoregional plans. This assistance takes a variety of forms, from actually conducting workshops, to facilitating the acquisition of hardware, software, and satellite imagery, to providing technical support and training for field staff. Once field offices have acquired the necessary equipment and expertise, they will also be able to conduct workshops independently, collect their own data, and conduct analyses. By decentralizing data and transferring the skills needed to produce maps, WWF will be able to communicate its messages to a broader audience in a more timely and efficient manner.

We envision a three-tiered GIS network. The field offices make up the first tier. At these offices, ecoregional plans will be designed and implemented and people with a wealth of local knowledge will collect and analyze data. The second tier will be a system of regional hubs. At these centrally located hubs, field personnel will be able to use larger, more powerful computers to perform data-intensive analyses and they will have access to more expensive equipment such as large digitizers and plotters. The second-tier labs will also have the personnel and equipment for use in assessment workshops. The third tier will consist of one or two major labs, such as that at CSP, that can provide software and training to both the first and second tiers.

Data requirements

The data that you collect is an integral part of the ecoregional planning process. If you collect inaccurate data you will produce inaccurate results. Other people outside of your office will generate most of the data, which will either be for sale or available for free. It is important to ensure that the data are compatible with your system and that the quality of the data meets your needs. The following list describes a brief set of guidelines to ensure that you are obtaining the most appropriate and useful data.

1. Obtain the information in a digital format. Although the ultimate product of your assessment may be hard copy maps, try to obtain digital copies of all the data layers you will need (e.g., soil, land use, vegetation, towns, state/provincial/country boundaries, topography, etc.). Obtaining the data in digital format will save you the trouble of digitizing the data into the computer.

2. Obtain background information (metadata) about each digital data layer. This should include, at a minimum:

   A. Scale: For each digital data layer, you should know the scale of the original data, because this determines the scale of the digital version. The boundaries of any country will look completely different when viewing a map produced at the scale of 1:25,000 versus a map scale of 1:1,000,000. The accuracy of a map increases as the second number in these ratios decreases, so that a 1:25,000 map is much more accurate than a 1:1,000,000 map, but it will also cover a much smaller area and take up more computer memory.

   B. Projection: The earth is round, but most maps are flat. Therefore, representing a round earth on a flat map produces some distortion, and different ways of projecting the earth on flat maps are better for different parts of the world. It is important to know the projection of the digital map. Common projections include Lambert, UTM, Geographic, Conical, and Albers. Geographic is generally the standard and oftentimes most useful projection. Additional information termed "projection parameters" usually accompanies each projection. These parameters are as important as the projection name, so be sure to ask for them when obtaining data. Different projections have different parameters. Some examples of parameters include datum, central meridian, zone, false northing, false easting, spheroid, and units.

C. Source data: For each data layer try to obtain information about the source of the digital data. If the layer represents the results of an analysis, you will need information on the data used in the analysis. For example, who created the data (government organization, NGO, military, etc.), and what year was the original map or digital data produced? This information is particularly important for land-use or vegetation data, which are constantly changing with time. When dealing with vegetation data be sure to get the origin of the data, e.g., hard copy map, satellite image, aerial photo. If it is from a satellite image, the type of classification (supervised or unsupervised) and the type of sensor it was derived from (TM, MSS, radar, SPOT, etc.) are critical to any mapping work and analysis.

3. Obtain digital data that are compatible with ArcView or ArcInfo, if possible. As noted above, ArcView and ArcInfo are two GIS software packages made by ESRI that are compatible and interchangeable. CSP uses these programs almost exclusively, as do a large majority of other organizations throughout the world. Obtaining digital information compatible with these formats will facilitate exchanging and sharing various GIS data layers. Other GIS software programs include Mapinfo, IDRISI, ErMapper, and ERDAS, and you may receive data in these formats.

4. Keep a contact name, address, and phone number. If you have difficulty interpreting the data, there are errors with it, or you need additional maps or digital layers, having contact information will help you to resolve the problems more quickly.

Some Suggestions for Conducting Successful Expert Assessment Workshops

IV

Working with colleagues throughout the WWF Network, the Conservation Science Program of WWF-US has carried out a number of expert assessment workshops for continental and ecoregion-scale conservation analyses. Here we offer some suggestions about logistics, agendas, protocols, and other workshop details that we believe can contribute to a successful meeting. Every workshop is a learning process, teaching as much from mistakes as from successes.

In any workshop there will be a tension between being responsive to participants and maintaining control of the process. Some general suggestions to keep in mind are:

1. Be flexible and adaptive during workshops while keeping the broad goals in mind.
2. Try to think about your minimum information needs and focus on these.
3. Regularly consult with the participants during the workshop to ensure that the approach and synthesized information are deemed robust and useful for conservation planning at this scale.
4. Treat the comments and critiques of workshop participants with the utmost respect. Allow people to vocalize their opinions and ideas but gently steer the workshop along to reach its overall goals.

In Chapters 6, 7, and 8 we offer recommendations related to particular aspects of assessment workshops. We provide additional suggestions here.

Before the workshop

Participants

We have found that workshop participants who have knowledge of patterns of biodiversity and conservation issues for a variety of taxa and ecosystems across whole ecoregions contribute a great deal to these analyses. We have often scheduled workshops around the availability of such key experts. It is also important that the collective group of invited experts be able to cover a wide range of taxa, subregions, and threats to help develop a broad, long-term perspective on the conservation vision for an ecoregion. Finally, the presence of one or two well-regarded experts who will champion the ecoregion conservation process is essential — these individuals can rally their colleagues at critical moments when the process hits a stumbling block.

Preliminary information packets

We recommend sending two sets of information to experts prior to a workshop. The first, which would accompany an invitation, would describe the fundamental idea of ecoregion conservation, the goals of the workshop, and basic logistical information regarding dates, location, and the costs you will cover. Give a fair description of the ecoregion conservation process, so that those who feel they are unqualified to participate or who disagree with the approach can decline the invitation. In other words, include a "truth in advertising" clause informing potential participants that, for example, they will be asked to set priorities based on existing biodiversity information, they will need to think at large scales, and they should expect to work hard over the duration of the meeting (to discourage those hoping for a holiday). The description of the approach should be as brief as possible; have additional information ready in case any invitees request it before deciding whether or not to participate (check the Conservation Strategies Unit intranet site for possible summary documents).

Along with the invitation you might also consider a form for experts to return that will help you to arrange their travel and accommodations. If visas are required, these should be arranged as early as possible. Also alert participants to vaccinations or prophylactics they should consider, as well as any other special preparations that will be required.

Several weeks or more before the workshop, we suggest sending a second packet of information to participants. Although most experts will look at their packets for the first time as they travel to the meeting, it is important to send the packets out well in advance because the mail can be slow and experts will often be travelling or in the field. If you are asking experts to do anything in preparation for the meeting — such as pulling together any data or literature that they will need — you should draw special attention to these preparations. To help experts understand the type of data they will be using and whether they should augment that information with their own, it is helpful to include a list of the references and data sources that you have collected and will be bringing to the workshop.

The second packet might also present a more detailed description of the workshop goals and the level of biogeographic resolution, as well as a proposed agenda. Again, identify what information is essential to convey to the participants, and consider that a large volume of text might overwhelm them and consequently cause them to read none of it. Even if you include ample background information on the workshop process, you will nonetheless have to present it again during the workshop, because you cannot be certain that all participants will have read and understood it. To minimize the amount of text, consider outlining the questions that will drive each of the assessment steps, as a way to encourage experts to begin thinking about how they would answer them.

Experts may be more likely to look at desk studies, as well as maps showing the region of analysis, proposed biogeographic subdivisions, and any synthesized information on biodiversity or threats. It is difficult for participants to digest all synthesized data during a workshop, so their exposure to these products prior to the workshop can allow them to formulate their responses more thoughtfully. Consider collecting all desk studies within a single document or on a CD, and putting the maps on a CD as well.

Finally, include clear logistical information, including the location of the hotel and workshop, directions to each place and recommended transport options, general information on the workshop location and anticipated climate, descriptions of any planned field trips, explanations of which costs will be covered and how, and contact information for the workshop organizers and the hotel.

Workshop agenda

In our experience, experts become very impatient during presentations that last more than 15 or 20 minutes. At the beginning of each new task, and particularly at the beginning of the workshop, you may believe that there is too much important information to convey in that short a period of time. Think about creative ways of communicating the information outside of formal presentations to the entire group. A professional facilitator should have ideas about how to structure various activities or organize the group. Additionally, when designing the agenda build in coffee breaks, as experts will become distressed if the agenda appears to be unrelenting. Since there is seldom time for experts to make presentations of their work to the group, consider reserving time in the evenings for optional talks or seminars.

During the workshop

Room configuration and table setup

Once you have a good idea of the number and composition of participants at the workshop, begin to design the room configuration. Secure a room that has ample space to accommodate multiple working groups, each seated around a large square or rectangular table and at enough distance from other groups to allow free movement and to minimize noise distractions. There should also be space at the front of the room for the facilitator and presenters to speak to the group as a whole. If the freshwater assessment is part of a larger terrestrial exercise, we recommend securing a separate room to accommodate the freshwater group because the two groups will probably follow different timetables and engage in different tasks. (In this case, the main room must be large enough to accommodate all participants for plenary activities.)

Anticipate your equipment needs well in advance, and arrange for small tables to hold the various pieces. An overhead projector (with extra light bulbs) and flipchart will probably be essential; also consider if you will need an LCD projector, a slide projector, or a microphone. You will also need tables for resource materials, basic supplies (pens/markers/paper/mylar), drinks and glasses, food (if snacks will be in the room), and possibly simultaneous translation equipment. If electrical outlets are in short supply and you anticipate the use of many laptop computers, have extension cords and/or outlet strips available. If there is the possibility that the room ventilation or air conditioning will not be sufficient, bring stand-up fans.

As for the working group tables, these should be bare, with no tablecloths (for ease of drawing on maps). Tape up cracks in tables so that drawing on the maps does not tear them. Do not permit drink glasses on the table, as the ink on most maps runs if it gets wet.

Introductions

We typically try to keep the introductions brief, with participants stating their name and affiliation only — anything more than this takes too much time, except for small workshop groups. In one past workshop, the facilitator simply read the names and affiliations, and each participant stood up in turn.

For a more dynamic beginning to the workshop, consider using a creative exercise that is quick and engaging. For example, to give a sense of the composition of participants, the facilitator could go through a series of "commands" that ask participants to stand up or sit down depending on if they met certain criteria. For example: "Stand up if you are an ichthyologist." "Stand up if this is your first priority-setting workshop." "Stand up if you work at a museum." "Stand up if you have more than 30 years of experience working in this region." You can design the questions to add a bit of humor and to recognize those individuals who have exceptional experience to contribute to the process. You can also use the exercise to obtain information that will help you to run a better workshop. You can end the exercise with a series of questions that brings the entire group to its feet, or that causes everyone to sit down. This is only one example of a possible introductory exercise; professional facilitators will have additional ideas.

Priority setting

In the introductory materials you may have already alerted participants to the fact that they will be expected to set priorities, or at least produce information that will be used to set priorities. It is probably worth repeating this notice at the beginning of the workshop. Emphasize to the experts that it is far better for them to weigh in on priorities than to leave priority setting to politicians, bureaucrats, non-specialists, or others less familiar with the region and its biology. Remind the experts that they will have ample opportunities to review and comment on the reports and maps before any priorities are finalized.

Map guidelines

We ask experts to draw very carefully on the base maps since their lines will be faithfully reproduced on the finished products. All polygons (areas) should be closed — that is, except for linear priorities, there should be no dangling lines. It is critical that experts identify each line or polygon with an identification code placed directly on the map; for disjunct areas, all pieces should be marked and coded identically. The codes and names of all areas should be written on corresponding data sheets, but it is also a good idea to maintain a map key, if possible. We ask experts not to fold template maps, as folded maps are difficult to digitize into a GIS. In many workshops, we use mylar (clear plastic) overlain on template maps. Ensuring that the mylar and template maps stay aligned is very important (we use registration points). Although it is useful and highly recommended to have GIS products produced overnight, this is not necessary and can present a big challenge for tired workshop staff. In Chapter 6 we discuss workshop maps in greater detail.

Data sheets

All information describing priority areas must be captured on data sheets. In their most basic format, data sheets may be printouts of Word files, with space for experts to fill in required information. At the other extreme, you could design input forms in a database program such as Access, with a structure that would automatically combine information from various tasks for each priority area. In Appendix V we offer examples of data sheets designed in Access; if direct data entry into a computer is impossible, experts can still write on hard copy printouts of these Access data sheets. Be sure to have plenty of extra data sheets on hand, so that the process can proceed without any delays.

Be explicit about what kind of information you want on each data sheet and the standard format for its input. For example, data sheets for each candidate priority area should have information on the precise location of the area and the reasons for its nomination within the context of a standardized set of biodiversity features. Prior to filling in data sheets, experts should agree upon biodiversity features and valuations and use a standardized approach to record descriptors for each area. We have found that this works best if the data sheets themselves have specific fields for different features and levels, otherwise the types of answers may differ so much as to make them incomparable. Insist that the experts writing each description put their names on the data sheet, write legibly, and provide specific locality information for each area. Experts will often give literature references in lieu of providing actual information. It is very important to get the full citations of references, or preferably full copies, at the time of the workshop.

We usually assign a person in each working group to be responsible for collecting the fully completed data sheets. We recommend making photocopies of the full set of data sheets immediately, in case any are misplaced. If possible, we also suggest transferring information from the data sheets to a computer at the end of each day, so that if any entries are illegible you can work with the authors to clear up any confusion before the workshop is over.

Field trips

Participants work extremely hard in gathering biodiversity information and developing a biodiversity vision. In appreciation, we have tried to offer some form of field trip to experience native habitats around the workshop location.

Information exchange

Experts will often request copies of maps and databases and will be curious to know the schedule for completing the reports. The workshop team should consider these issues in advance as well as the best format and mechanism for disseminating data and maps.

After the workshop

Thank-you letters

We try to send thank-you letters to all participants within two weeks after the workshop. If possible, include an estimated schedule for providing draft reports and maps to participants.

Draft report and maps

Draft reports and maps typically go out from three to five months after each workshop. We ask that experts review these and send comments to us within a month.

Final report and maps, and data dissemination

Prior to the workshop, the assessment team should consider what the final products will be, in what format they will be presented, what media will be used (CD, paper copy, etc.), any restrictions on their dissemination, charges (if any), and the persons responsible for the dissemination. These products will not only include written documents but also databases and maps. The intended audience and the available budget will in large part determine these decisions. Because experts at the workshop will almost certainly ask about data availability, it is important to make these decisions in advance.

Samples of Data Sheets for Assessment Workshops

V

Candidate Priority Areas

Authors:

Subregion name:

Candidate Area Number:

Please specify a unique number for each candidate area. Precede the number with the letter assigned to your subregion. Example: Subregion W=W1,W2

Area Name:

Component taxon areas from Day 1 (list area numbers):

General description of candidate area locations (nearest village/town, administrative districts, river basin, etc.)

General description of candidate area features, including habitat type (s)

I. Primary Reasons for Selection
Please check 1-3 reasons for selection of this cadidate area. Use information from Day 1 nomination forms as needed.

Richness: ☐ **Ecological phenomena:** ☐ **Habitat representation:** ☐ **Other:** ☐ **(Specify below)**

Endemism: ☐ **Evolutionary phenomena:** ☐ **(Specify habitat type)**

Rare habitat: ☐ **Intact catchment or biotas:** ☐

Species of special concern: ☐

Maintenance of physical processes: ☐

Please give supporting information for reasons checked above. Include specific biodiversity features particularly taxa for richness or endemism criteria.

Candidate Priority Areas (contd.)

II. Ranking of candidate areas based on biological distinctiveness

The workshop group will develop a ranking system based on bioloigical importance. A possible example follows:

Highest biological importance: Area has high representation of endemic taxa, high richness for multiple taxa, unique phenomena, rare habitats, and/or has an intact catchment.

High biological importance: Area has moderate degree of endemism, high richness in one or more taxa, rare habitats, and/or is important for the maintenance of physical processes.

Moderate biological importance: Area has low degree of endemism and moderate richness, or supports species of special concern or other targets.

Relative ranking of candidate area (mark one):

Highest biological importance
High biological importance
Moderate biological importance

Ranking notes:

III. Information Quality

Level of Scientific understanding:

High
Medium
Low
Not known by group

Information gaps/additional notes:

IV. Bibliography/Information Sources (including experts)

V. Contact Information for Conservation Partners for the Area (including e-mail addresses)

Ecological Integrity Assessment - Freshwater

Authors:

Candidate Area Number:

Area Name:

Ecological Integrity

Please categorize each candidate important area within a "ecological integrity" level. Consider which set of landscape and biological features the area most closely matches.

Highest The land draining to the area is undisturbed by human activity. Water quality is high and hydrographic integrity is unaltered. Exotic species are absent. Aquatic habitat is intact, unfragmented, and connected with other habitats. Intact species assemblages and the full suite of ecological processes occur. Species are protected from unsustainable exploitation.

High Upland land uses such as grazing, logging, or agriculture are limited or well-managed. Habitats are relatively undistributed by altered hydrographic integrity, pollution, fragmentation, or other forces. Habitat is largely unfragmented, and isolated habitats may be reconnected with other areas. Few exotic species are established, and native species face low exploitation pressures. Although large aquatic herbivores and predators may presently be absent from some habitats, such areas sustain many native species and associated ecological processes.

Moderate Habitat is altered but potentially restorable. Human disturbance has extirpated many sensitive species, but some habitat remains suitable for most native species. Species composition and community structure are altered, but native species are likely to return with improved habitat and connections to source pools. Isolated habitats may be re-connected with other areas. Riparian areas can be restored. Hydrographic integrity and linked ecological processes may be restorable. Exotic species may be potentially be managed.

Low Habitat is almost completed altered. Many species are extirpated or extinct. Any intact habitat is isolated. Surrounding land development, the presence of large permanent structures altering hydrogrphic integrity, established exotic species, and/or consistently poor water quality make recovery of original habitat, species, and processes unlikely.

Based on the approach developed, please choose a level of ecological integrity for this candidate area.

Ecological integrity level (mark one):

Highest
High
Moderate
Low

Ecological Integrity notes:

Important Global Maps, GIS, and Satellite Data

VI

Please note: The following information, URLs, and lists of data sources are neither meant to indicate an order of importance nor to be complete. They give an overview of what is available and provide suitable starting points for further searches.

Paper Topographic Maps

Name of dataset: GNC, JNC, TPC & JOG Charts
Producer/publisher of dataset: National Imagery and Mapping Agency (NIMA)
Geographic coverage of dataset: Global Coverage. Some charts available as digital scanned rasters.
How to obtain dataset (URL): http:///www.nima.mil
Brief description of dataset: http://geoengine.nima.mil/geoEngine/help/doi_pub.htm
Limitations of dataset: The Global Joint Operation Graphics 1:250,000 scale series is the highest scale Western military map series available with full global coverage. Central American countries were scanned into a mosaic and released to the public as part of the relief effort after Hurricane Mitch by the Center for Integration of Natural Disaster Information http://cindi.usgs.gov. Other regions may or may not be released directly to the public depending on international data-sharing agreements. However, the National Archives and the Library of Congress Map Library allow public access (http://www.nara.gov/research/bymedia/cart_int.html & http://lcweb.loc.gov/rr/geogmap/) and are also excellent sources for older Defense Mapping Agency/U.S. Army topographic maps and photo mosaics, especially Southeast Asia (Vietnam, Laos, etc), at various scales (1:50K & 1:100K).

Some maps are also available from commercial vendors (e.g., Omnimap http://www.omnimap.com)
Example: "Laos 1:50,000 Topographic Map Series. NIMA. There are 275 sheets available from NIMA and another 128 sheets (all border sheets) available from the Vietnamese or Laotians. The yellow sheets are from NIMA and are $15 per sheet; the blue sheets are Vietnamese/Laotian issue and are $20 per sheet. 65-8050-A NIMA issue, specify sheet number. Set of 403 sheets: $4,670.00."

Name of dataset: Russian Topographic Maps Various Scales
Producer/publisher of dataset: Russian Military
Geographic coverage of dataset: Global Coverage. Some areas available digitally.
How to obtain dataset (URL): http://www.omnimap.com & http://www.missingmaps.com
Quovadis in Germany also sells scanned Russian maps on CD-ROM http://www.qvnav.com/index_e.htm
Brief description of dataset: The Russians make excellent maps and the artwork is in general superior to Western military maps for raster to vector conversion (the "Mapscan" software package from the UN Populations Division is a good tool for this task http://www.un.org/depts/unsd/softproj/index.htm). Unfortunately the projection used ("Pulkov 1942 datum") is a little hard to handle and all place names are in Cyrillic.

Example from Quovadis website:
"Africa 1:500,000 Topographic Maps CD-ROM. This three CD-ROM set contains all of the Soviet military 1:500,000 topographic maps for Africa as georeferenced color raster images. The CD-ROM also contains a viewer interface, place-name search, latitude/longitude search, image export facility, and printing capabilities. The 'Moving Map' function tracks your progress as you drive. Fully interactive with GPS units (Garmin and Magellan, plus others). Available as a three-CD-ROM set or as individual CD-ROMs for eastern, western, or southern Africa. Set of three CD-ROMs $259."

Digital GIS Data

Name of dataset: VMAP1 Vector data & VMAP0 Vector data "The Digital Chart of the World" (DCW)
Producer/publisher of dataset: National Imagery and Mapping Agency
Geographic coverage of dataset: Extensive global coverage (but not complete for VMAP1)
How to obtain dataset (URL): http://geoengine.nima.mil; http://ortelius.maproom.psu.edu/dcw/
Brief description of dataset: The DCW is the standard 1:1 million global vector dataset http://164.214.2.59/vpf-proto/index.htm. VMAP1 is an improved version but has not yet been released for all areas.

Name of dataset: GeoCover-Land Cover (LC)
Producer/publisher of dataset: National Imagery and Mapping Agency & EarthSat Corporation
Geographic coverage of dataset: Complete global coverage becoming available in next two years.
How to obtain dataset (URL): http://www.crsp.ssc.nasa.gov/databuy/dbmain.htm; http://www.earthsat.com
Brief description of dataset: Landsat Derived Landcover: "GeoCover-Land Cover (LC) is a NIMA Omnibus project under which EarthSat will produce a Global Land Cover Database consisting of the following NIMA specified classifications: Deciduous Forest, Barren/Sparse Vegetation, Water, Evergreen Forest, Agriculture-Rice, Ice/SnowScrub/Shrub, Agriculture-Other, No Data/Cloud Shadow, Grassland, Wetlands-Herbaceous, Urban/Built Up, Wetlands-Mangrove. Classifications will be derived from 7600 Orthorectified Landsat scenes produced by EarthSat for NASA under the Earth Sciences Enterprise program."

Name of dataset: 1km AVHRR Global Derived Landcover
Geographic coverage of dataset: Complete global coverage
How to obtain dataset (URL): http://edc.usgs.gov/programs/lccp/globallandcover.html. More recent attempts at global maps are at the University of Maryland Global Land Cover Facility http://gaia.umiacs.umd.edu:8811/landcover/index.html and Continuous Fields Tree Cover Project http://glcf.umiacs.umd.edu/documents/treecover.html
Brief description of dataset: Quite a few regional descriptions are available. A good example is the "1-km land cover database of Asia" from the Land Cover Working Group (LCWG) of the Asian Association on Remote Sensing (AARS): http://asiaserv.cr.chiba-u.ac.jp/cd/index.htm

Name of dataset: Digital Terrain Elevation Data. DTED Levels 0,1 & 2, Shuttle Radar Topography Mission
Producer/publisher of dataset: National Imagery and Mapping Agency, NASA, United States Geological Survey (USGS)
Geographic coverage of dataset: Almost complete global coverage. http://www.jpl.nasa.gov/srtm/ & http://edcwww.cr.usgs.gov/srtm/ DTED Level 0 (GTOPO30) from either http://geoengine.nima.mil or http://edcdaac.usgs.gov/gtopo30/gtopo30.html. HYDRO 1K Elevation Derivative Database is at http://edcdaac.usgs.gov/gtopo30/hydro/index.html
Brief description of dataset: For a complete guide to elevation data, see Bruce Gittings' Digital Elevation Data Catalogue http://www.geo.ed.ac.uk/home/ded.html

Name of dataset: Administration Boundaries, Environment, Soils, Vegetation, Population, Refugees, etc
Producer/publisher of dataset: Various
Geographic coverage of dataset: Various
How to obtain dataset (URL): Center for International Earth Science Information: http://www.ciesin.org
Socioeconomic data and applications center: http://sedac.ciesin.org
The Geography Network: http://www.geographynetwork.com
USGS EROS Data Center International Program: http://edcsnw3.cr.usgs.gov/ip/ip.html
United Nations Environmental Program GRID: http://www.grid.unep.ch
UN GRID North America Node: http://grid.cr.usgs.gov/
UN Reliefweb: http://www.reliefweb.int & http://www.unhcr.ch/refworld/maps/maps.htm
Food and Agriculture Organization: http://www.fao.org/
Global Names Information System from NIMA: http://164.214.2.59/gns/html/index.html
The GeoCommunity, GIS information and the GIS Data Depot: http://www.geocomm.com/; http://www.gis-datadepot.com/
Center for Sustainability and the Global Environment (SAGE), University of Wisconsin: http://sage.meteor.wisc.edu/index.html and their Atlas of the Biosphere: http://atlas.sage.wisc.edu/
The International Land Surface Climatology Project (ISLSCP) Initiative II, NASA, Goddard, DAAC, gridded 0.5 degree maps of global coverage: http://islscp2.gsfc.nasa.gov/islscp-2_home.html
Center for Environmental Systems Research, University of Kassel, gridded global irrigation and wetlands/lakes map: http://www.usf.uni-kassel.de/usf/archiv/daten.en.htm

Satellite Imagery

(Check http://earthobservatory.nasa.gov/MissionControl/ for latest satellite information)

Name of dataset: Landsat TM & MS
Producer/publisher of dataset: United States Geological Survey/NASA/Various commercial companies
Geographic coverage of dataset: Global coverage, complete free global coverage becoming available in next two years through NASA Databuy program
How to obtain dataset (URL): NASA Databuy http://zulu.ssc.nasa.gov/mrsid/
LANDSAT 7 Browse Image Viewer http://edclxs2.cr.usgs.gov/L7ImgViewer.shtml
UMD Global Land Cover Facility Landsat Archive http://gaia.umiacs.umd.edu:8811/GLCFadminReports/landsat.jsp
Tropical forests http://www.bsrsi.msu.edu/trfic/home.html
Purchase from USGS http://www.earthexplorer.com
Brief description of dataset: Medium resolution. The premier civilian remote-sensing satellite program. LandSat satellites have been flying for 30 years and provide the best source of landscape level imagery. The continuity of the dataset also allows an unmatched ability to document land-use changes.

Name of dataset: The Controlled Image Base 10m Georectified Spot Imagery (DOI 10)
Producer/publisher of dataset: National Imagery and Mapping Agency
Geographic coverage of dataset: Extensive global coverage (but not complete)
How to obtain dataset (URL): http://geoengine.nima.mil
Brief description of dataset: Free fully georectified 10-meter resolution imagery http://geoengine.nima.mil/geoEngine/help/doi_pub.htm. Grey-scale with poor contrast in some regions and unknown imagery dates.

Name of dataset: ASTER - Advanced Spaceborne Thermal Emmission and Refelection Radiometer
Producer/publisher of dataset: NASA, Japanese Ministry of Economy, Trade and Industry (METI), USGS
Geographic coverage of dataset: global, see below
How to obtain dataset (URL): http://asterweb.jpl.nasa.gov/ & http://imsweb.aster.ersdac.or.jp/; data order catalog at http://edcimswww.cr.usgs.gov/pub/imswelcome/
Brief description of dataset: Areas of ASTER science investigation include: land surface climatology, vegetation and ecosystem dynamics, monitoring volcanoes, hazard monitoring (volcanoes, wildfires, floods, landslides), carbon cycle in the marine ecosystem, geology and soils, land surface and land-cover change, aerosols and clouds, elevation models, hydrology. Aster obtains high-resolution (15 to 90 m) image data in 14 channels (band 2, 3, 4 similar to Landsat TM). ASTER is an on-demand instrument. This means that data will only be acquired over a location if a request has been submitted to observe that area. Any data that ASTER has already acquired are available for free by ordering those data at given URL (data can be ordered as raw or processed/corrected images - within an hour you receive an email with an ftp-address where the data are prepared for download; also possible to order CDs). To request that ASTER acquires new data or data are processed (e.g. for elevation models) see above URLs.

Name of dataset: Radar Satellites
Producer/publisher of dataset: Canadian, European, Japanese Space Agencies
Geographic coverage of dataset: Complete global coverage
How to obtain dataset (URL): European INSAR images http://earth1.esrin.esa.it/INSI/
Online CD-ROMs at the Earth Observation Research Center of the Japanese Space Agency:
http://www.eorc.nasda.go.jp/EORC/DataLibrary/Index_JERS_1.htm
Deutsches Fernerkundungsdatenzentrum (DFD) http://isis.dlr.de/ has good browse archive
Brief description of dataset: Radar satellites are very useful in areas of high cloud coverage (tropical forests) and for other specialized applications (marine oil spills, flood monitoring, elevation modeling, etc.)

Name of dataset: IKONOS Carterra, the Spaceimaging Ikonos
Geographic coverage of dataset: Complete global coverage
How to obtain dataset (URL): browse image archive http://map2.spaceimaging.com/ (sometimes has problems)
Brief description of dataset: High-resolution (1 meter grey 4 meters color) image but expensive (about $2000 for 8km by 8km) and tough data sharing restrictions.

Finding Other Data Sources and Information

A. Use search-engines such as http://www.google.com or http://www.altavista.com with suitable keywords, e.g. “Dataset, Vegetation, Wetlands, Congo, GIS, Landsat, ArcView” etc.

B. Write down and search for the names of people, organizations, papers, projects, etc., working in the area of interest

C. Search email archives ESRI-L http://www.esri.com/site/search.work.html and the ESRI website http://gopher.gis.umn.edu:70/7c/rsgis/lists/esri-l/.cache

Browse through links on homepages of international or local geography departments at universities or other institutions, e.g. the University of Edinburgh GIS WWW Resource List
http://www.geo.ed.ac.uk/home/giswww.html

You might also be able to use something from the Perry-Castañeda Library Map Collection
http://www.lib.utexas.edu/Libs/PCL/Map_collection/Map_collection.html
Or start browsing through Sol Katz’s WWW Mapping/Metadata Resource List http://www.blm.gov/gis/nsdi.html

Various aerial, satellite photographs, and scanned topographic maps are also available from:
Microsoft’s Terraserver site: http://terraserver.homeadvisor.msn.com/advfind.asp?W=0
Ermapper’s site: http://www.EarthEtc.com

Contact Information for Select WWF Freshwater Staff

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