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Management of Aquatic Resources in Large Catchments: Recognizing Interactions Between Ecosystem Connectivity and Environmental Disturbance

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Abstract

Management within catchment basins must be approached with an empirically based understanding of the natural connectivity and variability of structural and functional properties of riverine ecosystems. Rivers are four-dimensional environments involving processes that connect upstream-downstream, channel-hyporheic (groundwater), and channel-floodplain (riparian) zones or patches, and these differ temporally. Natural and human disturbances, including biotic feedback (such as predation, parasitism, and other food web dynamics), interact to determine the most probable biophysical state of the catchment ecosystem. Human disturbances can be quantitatively determined by deviations from an observed biophysical state (baseline), but usually this requires long-term ecological data sets. A case history of the Flathead River-Lake system in Montana (USA) and British Columbia (Canada) is summarized to illustrate how disturbances interact at the catchment level of organization. Owing to the natural complexities of catchment ecosystems and the cumulative effects of human disturbances, the rationale and logistics of obtaining long-term data often seem intractable and excessively expensive. The naive alternative is to derive and implement simplistic procedures that are agency specific and often result in management actions that interfere with each other. We argue that integrated management at the catchment level is needed and propose some simple principles, beginning with broader based collegiate training for prospective managers.

Key words. Ecosystem, river, catchment, drainage basin, management, disturbance, natural resources, watershed, Flathead River, Montana.

Introduction

Professor Noel Hynes first synthesized the concept of ecological connectivity in the context of river systems in his Baldi Lecture at the 19th Congress

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of the International Society for Pure and Applied Limnology (Hynes 1975). He eloquently described how rivers are a manifestation of the biogeochemical nature of the valleys they drain, and he proposed that understanding the inherent connectivity between terrestrial and lotic biotopes would lead to important predictions about the future structure and function of river ecosystems.

In the nearly two decades since that seminal lecture, several paradigms (reviewed by Cummins et al. 1984) emerged from scores of studies that examined spatial and temporal aspects of geomorphic, hydrologic, thermal, and riparian influences on biotic attributes (e.g., diversity, zonation, food web associations, bioproduction) of rivers. The river continuum concept (Vannote et al. 1980, Minshall et al. 1985) provided a template for examining how biotic attributes of rivers change within the longitudinal gradient from headwaters to ocean confluence. The serial discontinuity concept (Ward and Stanford 1983*a*) provided a construct for the propensity of rivers to predictably reset biophysical attributes in relation to distance downstream from on-channel impoundments. Comparison of organic matter budgets in streams in different biomes provided the basis for the riparian control concept and demonstrated the extreme importance of allochthonous debris (wood and leaves) in lotic systems (Cummins et al. 1984, Harmon et al. 1986, Webster and Benfield 1986, Ward et al. 1990, Gregory et al. 1991). The nutrient spiraling concept (Webster and Patten 1979, Newbold et al. 1983) led to an understanding of how plant growth nutrients are transformed from dissolved to particulate states during translocation from upstream to downstream reaches. Lastly, the ecotone concept (Naiman and Décamps 1990, Holland et al. 1991) has fostered greater understanding of the extreme importance and potential predictive power related to transformations and fluxes of materials that occur within boundaries between functionally interconnected patches that form the riverine landscape. In many ways the ecotone concept integrates the other paradigms by emphasizing the functional connectivity inherent in all ecosystems.

Studies articulating these paradigms and other syntheses of stream ecology (Lock and Williams 1981, Barnes and Minshall 1983, Dodge 1989, Stanford and Covich 1988, Yount and Niemi 1990), plus a great number of other research projects, have largely verified Hynes's proposition that the streams are tightly coupled with catchment characteristics. Drainage basins or catchments (i.e., the river valley in Hynes's context) may indeed be characterized as ecosystems composed of a mosaic of terrestrial "patches" (Pickett and White 1985) that are connected (drained) by a network of streams. Of course, the lotic environment itself is a smaller scale patchwork or mosaic of habitats in which materials and energy are transferred (connected) through dynamic, biodiverse food webs. In most catchments, on-channel lakes and floodplain aquifers dramatically increase the complexity of the ecosystem, in contrast to the contemporary view of rivers as dynamic channels bounded by a riparian corridor (Sedell et al. 1989).

In this chapter we discuss the catchment in ecosystem terms (Lotspeich 1980, Naiman and Sedell 1981), stressing the ecological coupling that characterizes aquatic components of catchments, and discuss natural and human disturbances that influence biophysical connectivity. We describe how management actions can work at cross purposes when the interactions of natural and human disturbances are not considered from a catchment ecosystem viewpoint, and we discuss the difficulties of assessing cumulative effects of human perturbations. We use the Flathead River (British Columbia, Montana) as an example of a large river ecosystem influenced or partly uncoupled by a myriad of anthropogenic effects and competing management bureaucracies and interests. Finally, we propose an alternative general approach to natural resource management—an approach that begins with revised college curricula for training resource managers as conservators of ecological connectivity in river ecosystems.

Habitat Dimensions, Ecological Connectivity, and Natural Disturbance within River Ecosystems

In the United States, the term *watershed* is often misused in the context of river basin research and management. By proper definition, the watershed is the ridgeline or elevation contour that delimits drainage basins or catchments. The catchment is bounded by the watershed, and since water flows downstream from the watershed through the catchment, thereby integrating influences of natural and human disturbances within the catchment, we use the watershed as the natural ecosystem boundary.

Obviously, in these terms an ecosystem may be very small, such as a first-order catchment (sensu Strahler 1957), or it may be very large, encompassing entire river systems (e.g., the 671,000 km^2 catchment of the Columbia River, USA). Choice of ecosystem dimension (i.e., catchment size) is logically determined by the question being examined or the resource being managed.

The time frame encompassing the research question or management problem is of course also important. In geologic time, as a result of orogeny and erosion, watersheds were bisected and catchments reorganized, clearly having enormous zoogeographic consequences (Stanford and Ward 1986). In a much shorter time frame, engineering projects artificially connected catchments via transwatershed diversions of rivers in many areas (Stanford and Ward 1979, Davies and Walker 1986), allowing differently adapted organisms to commingle (Guiver 1976) or greatly accelerating immigration of

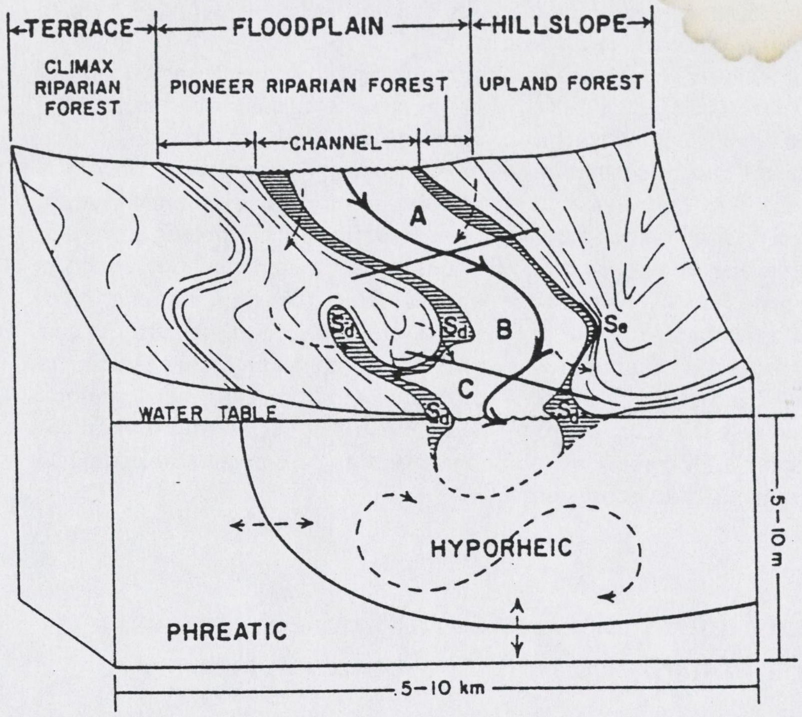
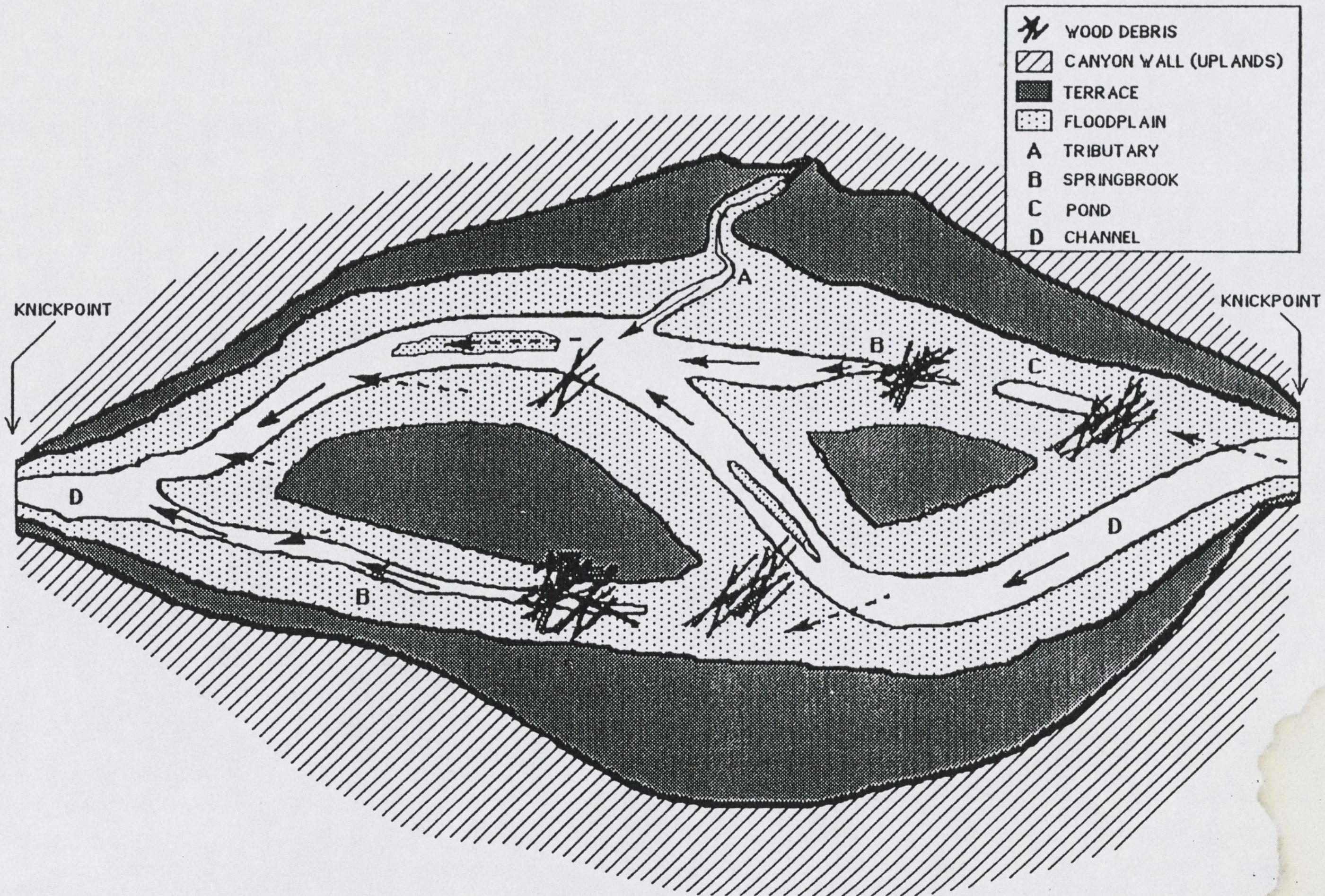


FIGURE 5.1. Major landscape features of the Kalispell Valley of the Flathead River, Montana, USA, showing the three primary spatial dimensions (lateral, longitudinal or altitudinal, and vertical) which are dynamically molded through time (the fourth dimension) by fluvial processes. Biota may reside in all three spatial dimensions: riparos (streamside or riparian), benthos (channel), hyporheos (river-influenced groundwater), and phreatos (true groundwater). The hatched area is the varial zone, or the area of the channel that is periodically dewatered as a consequence of the average amplitude of the discharge regime. Major channel features include a run (A), riffle (B), and pool (C); Sd refers to sites of sediment deposition and Se refers to a major site of bank erosion. The heavy solid line is the thalweg, and broken lines conceptualize circulation of water between benthic, hyporheic, and phreatic habitats.

nonnative biota introduced by other means (Stanford and Ward 1986, Mooney and Drake 1986).

Given that catchments may be referred to as ecosystems and that the ecosystem is dynamic in time and space as well as in its relation to environmental problem solving, it is fundamentally important to recognize the major structural features and dimensions of river ecosystems (Figure 5.1). Ecologists have appreciated for many years the importance of microhabitats encompassed by the run-riffle-pool sequence as influencing the distribution and abundance of biota within the river channel. Zonation of biota within the longitudinal continuum has long been recognized as a fundamental feature of the lotic environment (Hynes 1970), although explanations of specific distribution patterns often remain contentious (Alstad 1982, 1986; Thorp et al. 1986). Within the last decade, the connection between riparian zones, including the surficial floodplain dynamics, and ecological structure and function has been clearly demonstrated (see reviews in Décamps and Naiman 1989, Dodge 1989, Gregory et al. 1991). The importance of microbial transformation and transport of solutes in groundwaters has been shown in relation to plant growth nutrients for channel biotopes in streams (Stanford and Ward 1988, Ford and Naiman 1989, Dahm et al. 1991, Stream Solute Workshop 1990, Grimm et al. 1991, Valett et al. 1991); and penetration of groundwaters (i.e., the hyporheic zone, Figure 5.1) by amphibiotic stream biota has been documented (Schwoerbel 1967, Stanford and Gaufin 1974, Williams and Hynes 1974, Bretschko 1981, Danielopol 1984, Pugsley and Hynes 1986, Stanford and Ward 1988). But the presence of large-scale hyporheic zones, and the critical importance of groundwater – surface water interchange as a major landscape feature of catchments, have only recently been demonstrated (Stanford and Ward 1988, Danielopol 1989, Gibert et al. 1990).

River floodplains are often, if not always, penetrated by interstitial, subterranean flow (Figure 5.2). Water penetrates (downwells) at the upstream end of the floodplain, flows through unconfined aquifers at rates determined by the porosity of the substrata and the slope of the floodplain, and eventually upwells to the surface some distance downslope. Location of aquifer discharge is often related to bedrock outcrops or encroaching canyon walls (knickpoints in Figure 5.2). Effluent groundwaters may enter the channel directly or emerge as floodplain springbrooks that exhibit seasonally dynamic hydrology controlled by flow entering the floodplain from the river and from tributaries. These springbrooks usually occur in abandoned meander channels blocked at the upstream end by natural deposition of alluvium and woody debris. They have been referred to as wall-base channels in locations where they erupt from the substratum of old channels originally constrained by contact with the terrace or canyon walls (Peterson and Reid 1984). However, variations on this general theme may occur, depending on floodplain geomorphology and catchment hydrology (Amoros et al. 1982). Since spates frequently may overflow these springbrooks (in the Flathead River, Montana, these systems are flooded on about a ten-year return frequency; J. Stanford et al., unpublished), woody debris often accumulates, providing structurally complex lotic habitat. Moreover, relative to the main river channel, these springbrooks are characterized by fairly stable flows, moderated temperature regimes, high water clarity, and elevated concentrations of plant growth nutrients, particularly nitrate and soluble reactive phosphorus. As a result, standing crops of attached algae and zoobenthos can exceed biomass in the channel by several orders of magnitude. Juveniles of native cutthroat trout (*Oncorhynchus clarkii*) are abundant (J. Stanford et al., unpublished).


WOOD DEBRIS
CANYON WALL (UPLANDS)
TERRACE
FLOODPLAIN
A TRIBUTARY
B SPRINGBROOK
C POND
D CHANNEL
KNICKPOINT
KNICKPOINT
A
B
C
D
D
B

Therefore, it appears that these springbrooks are "hot spots" of bioproduction, although this relation has yet to be thoroughly documented.

Wall-base streams are known to be critically important as spawning and rearing habitats for salmonids in Pacific Northwest streams (Peterson and Reid 1984); and recent analyses suggest that aggraded floodplains and upwelling groundwaters historically were key production areas for anadromous salmonids (*Oncorhynchus* spp.) and resident bull charr (*Salvelinus confluentus*) in the Columbia River system (James Sedell, U.S. Forest Service, pers. comm.). In the Flathead River, Montana, native bull charr adults migrate upstream from Flathead Lake to spawn in specific habitats of fourth-order tributaries (Figure 5.3; see also Fraley and Shepard 1989). Juveniles remain in riverine habitats for two or three years before migrating downstream to Flathead Lake, where they mature. This phenology is termed *adfluvial*. Primary bull charr spawning sites are the groundwater upwelling zones of aggraded floodplain segments, which usually occur downstream from major altitudinal transitions (knickpoints) in the river continuum. Bull charr select only fourth-order streams that are not regulated by on-channel lakes, apparently in response to temperature criteria (J. Stanford, unpublished).

These observations emphasize that the riverine ecosystems are truly four dimensional, with longitudinal (upstream-downstream), lateral (floodplain-uplands), and vertical (hyporheic-phreatic) dimensions (Figure 5.1); since these spatial dimensions are transient or dynamic over time as a consequence of relativity, temporality is the fourth dimension (Ward 1989). Within a given stream reach, distribution and abundance of organisms form a multivariate function of the structural and functional attributes of channel (fluvial), riparian (floodplain, shoreline), and hyporheic (groundwater) habitats as they interact within time and space with the geomorphology and hydrology of the catchment. Clearly, catchments may be characterized as patch-dynamic systems (Pringle et al. 1988, Townsend 1989), and ecological connectivity of patches is a fundamental feature.

Many riverine organisms may traverse all three spatial dimensions in the process of completing life cycles (high connectivity), whereas others may be relatively stationary (low connectivity). For example, in the Flathead River, Montana, a gravel-bottom system with expansive intermontane floodplains characterized by substantial interstitial flow (Figure 5.2), certain specialized stoneflies (Insecta: Plecoptera) reside within floodplain groundwaters during the entire larval stage. Indeed, hundreds of these crepuscular stoneflies have been collected in single samples taken from groundwater monitoring wells 2–3 km from the river channel, demonstrating the enormous volume of the

FIGURE 5.2. Simplified plan view of an intermontane floodplain of a gravel-bed river on the Middle Fork of the Flathead River, Montana, USA. The floodplain is formed on the aggraded slope between bedrock constrictions (knickpoints) of the river channel. Riparian forests are well developed (mature) on the terrace, intergrade into upland forests, and are in various successional stages on the floodplain.

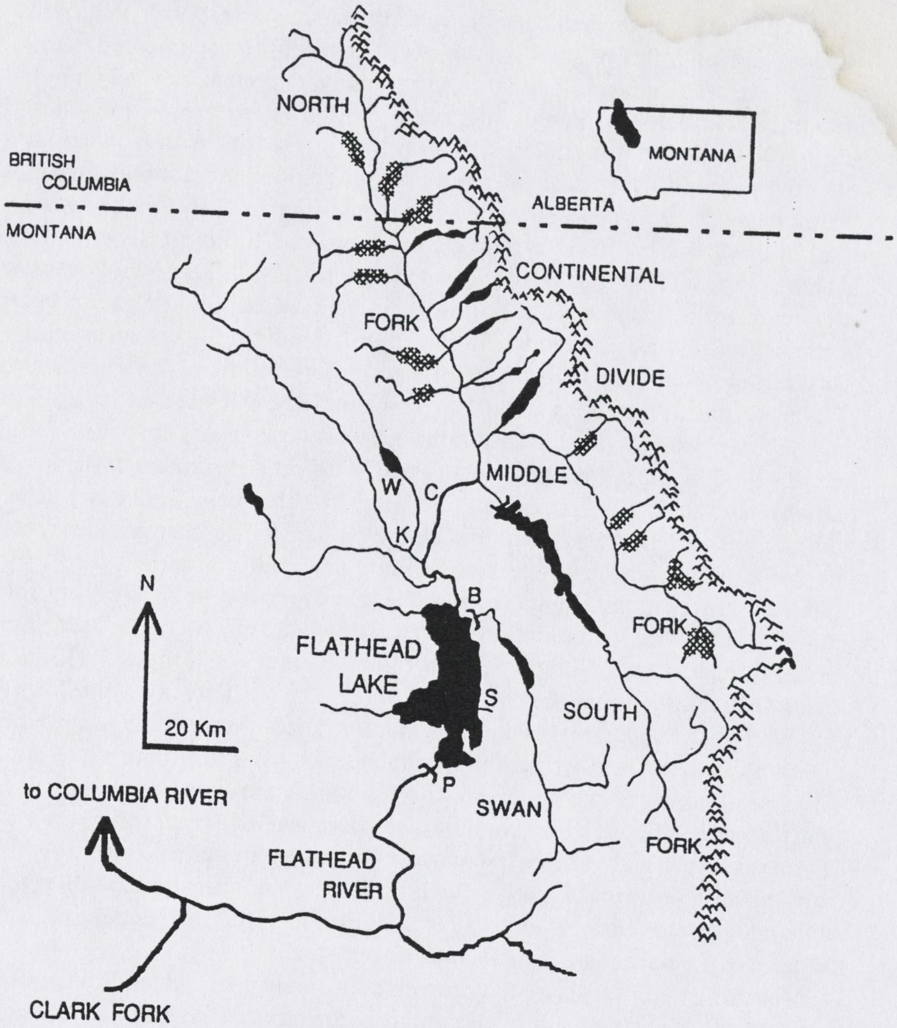


FIGURE 5.3. The Flathead River catchment basin in Montana, USA, and British Columbia, Canada. Primary spawning sites for adfluvial bull charr (*Salvelinus confluentus*) from Flathead Lake are shown on tributary creeks of the North and Middle Forks by cross hatching. Towns include Kalispell (K), Whitefish (W), Columbia Falls (C), Bigfork (B), and Polson (P). The Flathead Lake Biological Station (S) is on the east shore of the lake. The hydroelectric dam on the Swan River near Bigfork is a small run-of-the-river facility, whereas the other two dams in the system are much larger. See text for further explanation.

hyporheic zone in this river. They are the top consumers in a speciose (80+ species) groundwater food web. Yet these stoneflies emerge as winged adults from the river channel and fly into the riparian vegetation to mate and produce eggs. The eggs are deposited in the river channel, followed by larval immigration into the hyporheic zone (Stanford and Ward 1988). Many other riverine insects, which commonly characterize the rhithron (cold, swift-flowing, gravel-cobble substratum) habitat of western USA rivers, also depend on riparian vegetation during the flight period, but the larval stage is completed within the channel. Most noninsect zoobenthos and periphyton (attached algae) are essentially obligate channel inhabitants, although they, like most fish species and insect larvae, are often distinctly segregated by temperature, flow, substratum, or behavioral criteria within the altitudinal gradient of the stream continuum (e.g., bull charr distribution in Figure 5.3; see also Resh and Rosenberg 1984, Matthews and Heins 1987).

Biodiversity and bioproduction in rivers are related to a plethora of factors that interact bioenergetically (Figure 5.4) to determine reproductive success of individuals (e.g., the P and C compartments of Figure 5.4) attempting to coexist. Phenologies (life histories) are highly evolved and sensitive to environmental change. Consequently, disturbance events (e.g., floods, droughts, fires, disease epidemics, invasions by exotic species) reduce reproductive success and, hence, bioproduction; thus connectivity of lotic food webs is naturally decreased (Figure 5.5). Our main point is that for a particular species to survive, either as a resident of the catchment or as an immigrant, enough individuals must realize a net energy gain to meet phenological requirements which permit conservation of the gene pool (i.e., net positive contribution to riverine bioproduction). Bioproduction at the ecosystem level of organization is controlled by the same plethora of environmental factors; although in the case of riverine fishes, especially anadromous species, harvest by humans often is more pervasive than other environmental disturbances.

The degree of structural (Figures 5.1 and 5.2) and functional (e.g., flux of organic and inorganic materials and energy between consumer groups, Figure 5.4) connectivity determines the most probable biophysical state of the ecosystem at any given time. For many scientists this implies that tightly coupled ecosystems are highly evolved, undisturbed, and essentially in equilibrium. However, circumspection of equilibrium concepts is waning in contemporary ecology (Murdoch 1991), owing to the realization that natural and anthropogenic disturbances occur too frequently in most catchments to allow equilibrium models at any level of organization to be realistic (Resh et al. 1988; Naiman et al., this volume). Disturbance events alter structural and functional connectivity (Figure 5.5); the instantaneous biophysical status of ecosystems is usually more analogous to a quasi-equilibrium (sensu Schumm and Lichty 1956; see also Huston 1979).

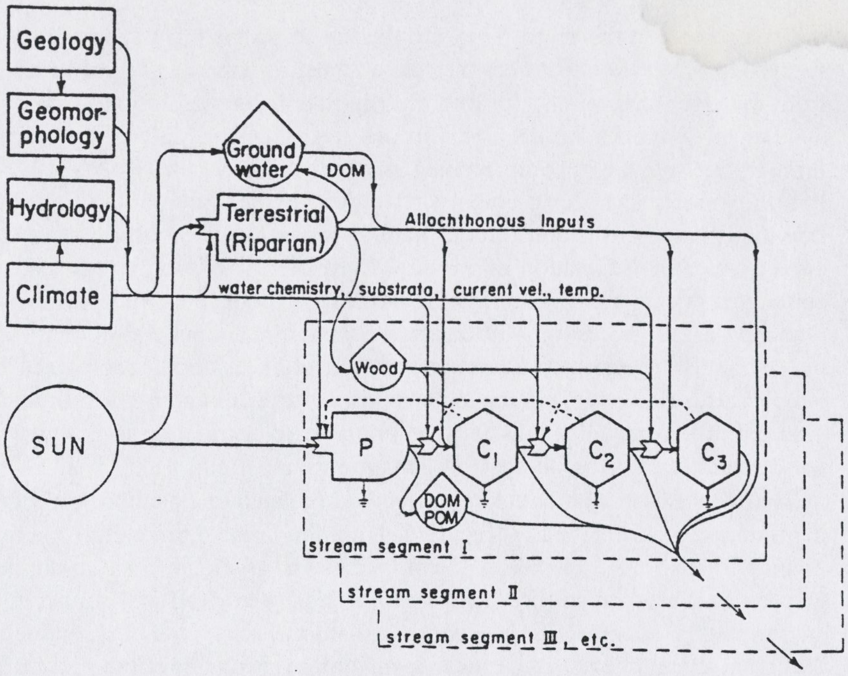


FIGURE 5.4. Energetics of successive segments of a stream ecosystem (from Benke et al. 1988). Solar energy provides energy for primary production in both the terrestrial ecosystem and the stream. Climate, geology, geomorphology, and hydrology have interdependencies, and all directly affect both the terrestrial and stream systems. The terrestrial system, with indirect input through the groundwater, provides allochthonous resources for the stream consumers, including important substrata (wood) and food (leaf litter, DOM, organisms). P = primary producer module. C_1, C_2, C_3 = consumer modules. Symbols after Odum (1983). Solid arrows are energy flows or energy regulators. Dashed lines are biotic feedback regulators.

Human Disturbances and Loss of Ecological Connectivity

How much disturbance can occur in a catchment before ecosystem resilience (i.e., the ability to recover from disturbance, Odum et al. 1979) is exceeded and ecosystem structure and function are permanently altered (Yount and Niemi 1990)? How much is attributable to natural interannual variation? That such questions were articulated years ago but remain largely unanswered is, of course, problematic for researchers and especially for managers attempting cumulative impact assessments at the catchment level.

We have argued (Ward and Stanford 1983*b*) that natural interannual variation in catchments is encompassed by Connell's (1978) intermediate disturbance hypothesis. Connell suggested that biodiversity is maximized by

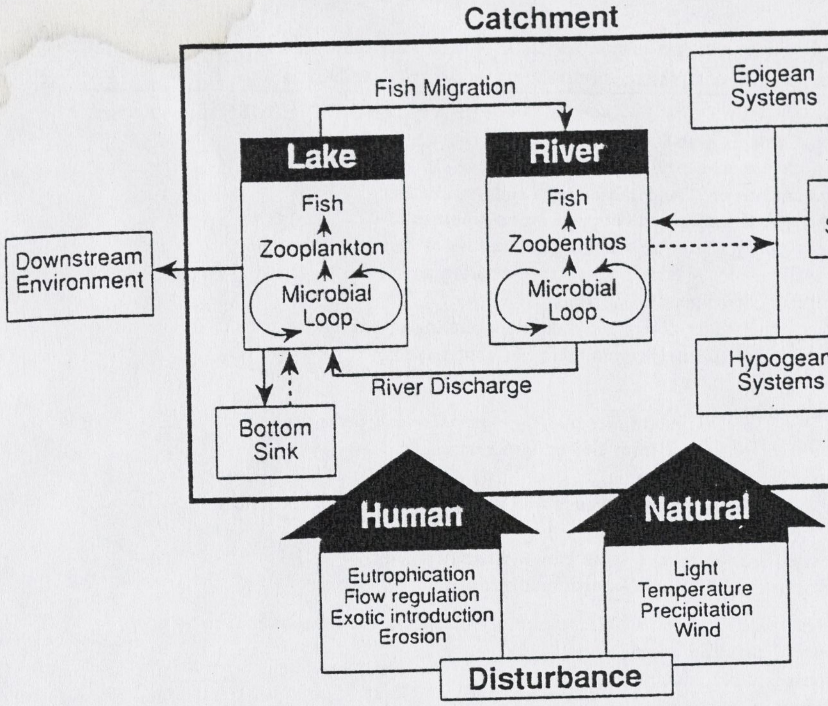


FIGURE 5.5. Ecological connectivity of the Flathead River-Lake ecosystem.

ecosystems that are "adapted" to disturbance events of intermediate intensity and duration. Intermediate might be loosely quantified in catchment terms as less than a 100 year flood event and more dynamic than constant flow, for example, from a spring or a storage reservoir. In other words, it is intuitive that a most probable state of quasi-equilibrium can be maintained by natural, intermediate disturbances until the occurrence of a major disturbance event on the scale of a volcanic eruption or hurricane. Events of that magnitude can completely restructure ecosystems. However, recovery is more rapid than once thought (e.g., recovery of streams following the 1980 eruption of Mount St. Helens in the Cascade Range, USA, is occurring decades sooner than expected).

In many ways the idea of natural disturbance controls on stream ecosystem structure and function—however intuitive—remains hypothetical for lack of long-term data to test inferences. Indeed, the National Science Foundation decided nearly a decade ago to support long-term ecological research (LTER) at a variety of sites in different biomes so that accurate data describing interannual variation and ecosystem responses to environmental change could be evaluated quantitatively. The objective was to initiate work on hypotheses requiring data sets of five years or more and, at the same time, set up a

Table 5.1. Some pervasive human disturbances that uncouple important ecological processes linking ecosystem components in large river basins.

STREAM REGULATION BY DAMS, DIVERSIONS, AND REVETMENTS: *uncouples longitudinal, lateral, and vertical dimensions*	
Lotic reaches replaced by reservoirs:	loss of up-downstream continuity, migration barrier, flood and nutrient sink, stimulates biophysical constancy in downstream environments
Channel reconfiguration and simplification:	loss of lateral connections, removal of woody debris, isolation of riparian and hyporheic components of floodplains
Transcatchment water diversion:	abnormal coupling of catchments, dewatering of channels, immigration of exotic species, import of pollutants
WATER POLLUTION: *alters flux rates of materials, uncouples food webs*	
Deposition of pollutants from airshed into catchment:	eutrophication, acidification
Direct and diffuse sources of waterborne waste materials from catchment:	toxic responses, eutrophication
Accelerated erosion related to deforestation and roading:	sedimentation of stream bottoms, eutrophication
FOOD WEB MANIPULATIONS: *induces strong interactions that alter food webs*	
Harvest of fishes and invertebrates:	biomass and bioproduction shifts
Introduction of exotic species:	cascading trophic effects

network of sites where basic biophysical data would be systematically gathered for decades (Likens 1989, Franklin et al. 1990). These studies have already greatly contributed to understanding ecosystem connectivity, although data are not yet of sufficient scope to resolve many of the landscape- and patch- specific hypotheses proposed in the LTER program (Swanson and Sparks 1990). Moreover, these data are very site specific and tied to falsification of hypotheses that are clearly of great scientific importance but may be rather narrow in scope from the point of view of many managers.

Even though the scientific community has a long way to go before ecosystem response to natural environmental changes is fully understood, the human disturbances of catchments are often more extreme than natural events in frequency, intensity, and duration. In case after case, ecosystems in the catchment sense presented herein have been essentially uncoupled by the cumulative impacts and interactions of human disturbances (Table 5.1) (see also Ward and Stanford 1989). Perhaps the most pervasive disturbance is encompassed by the combined effects of channelization, revetment, and harvest of riparian timber within major river corridors. It has often been written that we may never know the true nature of channel-floodplain connectivity of large (> eighth order) rivers in the temperate latitudes because cultural development of the industrial nations was so dependent on these rivers as commercial waterways and because the attendant effects were so ecologically devastating (cf. Regier et al. 1989). In most, if not all cases, precious little information about the connectivity of these large rivers was recorded before major human disturbances took place. However, several carefully researched case histories provide insightful syntheses of the interactive effects of human and natural disturbances on the ecology of river systems (reviewed in Davies and Walker 1986).

Rather than attempt to summarize the important inferences of these and many other studies chronicling human disturbance in catchments, we present below a single case history of a large catchment that retains numerous pristine attributes but is threatened by a variety of interactive effects. In this case an ecosystem-level understanding might be very productive in fostering a new management ethic. The goal is to sustain the natural ecological connectivity of the system. We use this example to set the stage for articulation of some new approaches to that goal that may be useful elsewhere.

A Case History of Interactive Effects on Ecosystem Connectivity

Background

The Flathead River-Lake ecosystem in northwestern Montana provides a good example of a tightly coupled system where natural and human disturbances are clearly interactive. Understanding of this catchment is based on ecological studies by scientists at the Flathead Lake Biological Station (a field station of the University of Montana), where biophysical data have been routinely collected since 1896, and a wide variety of management-oriented research has been conducted by tribal, state, and federal agencies (reviewed by Stanford and Hauer 1992). Salient points are summarized here.

This 22,000 km^2 catchment is dominated by runoff from the myriad tributaries that feed the sixth-order Flathead River (mean annual discharge = 340 m^3/s), which flows through 496 km^2 Flathead Lake (Figure 5.3). Water quality in this river-lake system is extremely good; solute concentrations and bioproduction are uniformly low (oligotrophic); waters are usually highly transparent (Secchi disc readings in Flathead Lake routinely exceed 15 m autumn and winter); and native fisheries are healthy. Fewer than 80,000 people reside in the entire catchment, and no major industrial or agricultural sources of pollution currently exist. The Flathead River dominates the inflow of solutes and particulate materials that influence water quality, structure food webs, and drive bioproduction in the lake. For example, the river provides 65% of the annual load of bioavailable phosphorus reaching the lake. Six of the ten native fishes in the lake are adfluvial; that is, they reside in the lake but migrate upstream into tributaries to spawn (cf. bull charr in Figure 5.3). Hence the fishes constitute an upstream feedback loop and enhance the ecological connectivity of the ecosystem (Figure 5.5).

Ecological connectivity of the Flathead system is of course maintained in a quasi-equilibrium status by natural disturbance events (Figure 5.5). For example, the catchment is naturally disturbed by floods. Catchment hydrology is annually dominated by spring snowmelt, and in that sense the hydrograph is very predictable. But the magnitude of the spring spate is highly unpredictable, based on a 90 year period of record. Climatic events alternately juxtapose either continental (cold, dry) or Pacific maritime (warm, wet) air masses over the catchment, determining precipitation patterns. Infrequently and under the extreme moisture conditions in the Pacific front, the two air masses collide directly over the catchment, resulting in intense precipitation. Intermediate levels (10–20 x mean annual flow) of flooding occur on about a 10 year return pattern and almost always during spring; but high magnitude (20–50 x mean annual flow) floods have occurred 17 times during the historical record. The timing and duration of high magnitude floods and other extreme climatic events (Figure 5.5) are stochastic. Another example concerns the occurrence of wildfires caused by lightning strikes during dry periods. Mosaics of successional stages in forest stands characterize the uplands of the catchment as a result of these randomly distributed burns over many decades. Thus natural disturbance is a fundamental feature of this ecosystem and, coupled with the zoogeographic history of the area, is responsible for the generally high biodiversity of plants and animals by preventing dominance by a few species.

However, four generalized classes of human perturbations clearly have affected the natural attributes of this catchment: (1) stream regulation, (2) eutrophication, (3) food web manipulation, and (4) erosion (Figure 5.5). While localized effects may vary and the magnitude of the impacts has not been so severe as to completely compromise ecosystem connectivity, anthropogenic disturbances have degraded natural structure and function.

Stream Regulation

Two large hydroelectric and flood control dams partly regulate flows in the mainstem river and volume in Flathead Lake (Figure 5.3). The spring flood pulse of the Flathead River is predominantly stored behind these dams and discharged during the baseflow period. Owing to the presence of a natural bedrock sill at the outlet, the backshore of Flathead Lake historically was inundated up to about 882.5 m above sea level (masl) during the spring spate; however, the lake returned to base level (878.8 masl) by mid-July. Kerr Dam was built downstream from the sill in 1937 and extends the full pool (881.8 masl) period into late October to facilitate hydropower production. Hungry Horse Reservoir was first filled in 1953 and stores runoff from the entire South Fork subcatchment. Hydropower operations currently cause both flow and temperature problems in the river segments downstream from the dams. The varial zone of the river channel (Figure 5.1) is alternately inundated and dewatered by fluctuating flows related to power production below the dams. As a consequence, the varial zone is quite large and is essentially devoid of aquatic biota. Sluicing of the substratum by clear water flows has removed the smaller particles, leaving larger rocks and cobblestones firmly implanted on the river bottom (a phenomenon of regulated rivers known as armoring; Simons 1979). Capture of flood flows has partly or totally eliminated the natural fluvial disturbances on the floodplains of regulated river segments, thereby allowing senescence or other alteration of riparian plant communities. Since Hungry Horse Dam discharges from the bottom of the reservoir, nutrient concentrations are elevated relative to the free-flowing river segments, and algal mats coat the armored substratum in the minimum flow channel below the varial zone. Stream regulation has reduced the biodiversity in the dam tailwaters by about 80%. Spawning, juvenile recruitment, and growth of resident and adfluvial fishes have also been seriously compromised by extension of the varial zone in both regulated river segments; and cold (5–8°C) summer temperatures in the effluent water from Hungry Horse Reservoir compound the problem in the mainstem river upstream from Flathead Lake (Stanford and Hauer 1992).

Eutrophication

Plant growth in most of the lakes and streams of the Flathead catchment is limited by a general lack of labile nutrients. Most of the waters appear to be phosphorus limited or co-limited by paucity of both nitrogen and phosphorus (Dodds and Priscu 1989). Many alpine and subalpine lakes contain no measurable soluble reactive phosphorus and <20 mg/L nitrate, owing to the lack of these minerals in the Precambrian argillites that dominate the bedrock of much of the catchment. Therefore, bioproduction in these waters is very low (Stanford and Ellis 1988, Stanford and Prescott 1988).

Consequently, abnormally accelerated algal production associated with anthropogenic nutrient enrichment (i.e., eutrophication) is a primary concern, particularly as it relates to degradation of the high quality water in Flathead Lake. Of the total bioavailable phosphorus load entering Flathead Lake annually, 17% is derived from sewage treatment plants in the catchment and 30% is atmospheric deposition. Smoke from homes heated with wood burning stoves and from slash burning may be the primary source of labile phosphorus measured in bulk precipitation samples. In 1983 a lakewide bloom of the noxious blue-green alga *Anabaena flos-aqua* occurred for the first time in Flathead Lake since records began in 1902. The bloom was not severe and it has not recurred, but it did suggest that conditions were near a threshold beyond which major changes in the autotrophic community of the lake might be expected. Recent nutrient bioassays and analyses of long-term mass balance data have supported this inference (Stanford et al. 1983, 1990).

Food Web Manipulation

Since the turn of the century, 17 fish and 2 crustacean species have been purposely introduced into the Flathead catchment, primarily by fishery managers. Most fishes and both crustaceans established viable populations and gradually immigrated widely within the catchment. Today only a very few lakes in Glacier National Park have entirely native food webs, because of their remote localities and the presence of cascades, falls, or other migration barriers that prevented invasion by nonnative species from waters downstream.

These introductions had major impacts on native populations and dramatically restructured food webs in the lakes and streams throughout the catchment. Often effects cascaded through the food webs in ways that were unanticipated and sometimes involved both terrestrial and aquatic species.

For example, the kokanee salmon (*Oncorhynchus nerka*) fishery has undergone extreme fluctuations since the species was introduced into Flathead Lake in 1916. The population expanded rapidly and gradually replaced the native cutthroat trout as the dominant planktivore. Adfluvial kokanee from Flathead Lake spawned primarily in the outlet of McDonald Lake in Glacier National Park (Figure 5.3), where they attracted large numbers of migratory bald eagles (*Haliaeetus leucocephalus*). When the kokanee spawners were abundant (>150,000), so were eagles (>700).

In 1981 the nonnative crustacean *Mysis relicta* immigrated to Flathead Lake from intentional plants made in lakes upstream. Within six years, numbers exceeded $125/m^2$. *Mysis* feed on zooplankton near the lake surface at night and rest on the lake bottom during the day. They have reduced zooplankton biomass in the lake by almost an order of magnitude. Kokanee are also dependent on zooplankton, but they prefer to stay near the lake surface, perhaps to avoid predation by piscivorous lake trout (*Salvelinus namaycush*, a nonnative species) and native bull charr. Thus *Mysis* created a trophic restriction for kokanee, and the fishery collapsed in 1987–88. Since 1989, only incidental kokanee spawners have been observed in McDonald Creek and the bald eagles have dispersed elsewhere (Spencer et al. 1991).

Erosion

Soil and other mineral substrata are naturally eroded by fluvial processes within the Flathead catchment, as in all river basins. Owing to the porous nature of the bedrock substrata and extensive tills of glacial origin, very little overland or sheet flow occurs except during extreme precipitation events or during periods of intensely accelerated snowmelt. Streams originate primarily as springbrooks fed by waters that percolate into substrata from precipitation at higher altitudes. Springbrooks coalesce to form the drainage network of the catchment. Therefore, most of the sediment loads carried by the streams and rivers are derived from erosion of stream channels and banks.

The rate of erosion is determined by channel morphology, slope, relative erosiveness of streambank substrata, and the intensity and duration of spates. Most of the sediment load in the system is derived from Tertiary shales deposited as valley fill and Quaternary tills and alluvium. These soils contain nitrogen and phosphorus either within the organic debris or associated with the clay lattice of the mineral particles. Therefore, as much as 60% of the annual riverine nutrient load of the Flathead River may be associated with sediment particles that are transported for short periods, most years during spring runoff, when the rivers and streams of the catchment are flooding. Only about 10% of the nutrients associated with particles can be assimilated by the biota (i.e., only about 10% of the particulate phosphorus is labile or bioavailable; Ellis and Stanford 1986, 1988), and much of the load is deposited either on the river floodplain or into the lakes as a short-term pulse event. In spite of the low nutrient bioavailability, the fertilization effect of the particulates eroded and transported by fluvial processes is significant owing to (1) the oligotrophic nature of the water bodies and (2) the dominance of the hydrograph and nutrient mass balance of both rivers and lakes in the catchment by spring runoff.

Clearly, erosion is a natural process that both shapes the catchment landscape and to some extent fertilizes patches within the landscape. Natural (e.g., lightning-caused fire, insect epidemics, beaver [*Castor canadensis*] and other large herbivore influences) and human (e.g., road building, clearcutting) deforestation increases the seasonal and annual variation in water yield, particularly during spring snowmelt (Hauer and Blum 1991), thereby accelerating erosion of streambanks and increasing sediment loads. Erosion of road surfaces and berms or stream crossings is of particular concern, because unstable roads are known to be major sources of fine particles in some streams in the Flathead catchment, as elsewhere (see Megahan et al., this volume). Accelerated erosion, locally associated with logging and road building, has increased the volume of fine particles within the channel of disturbed streams, clogging interstices and reducing interflow and aeration of the substratum. Speciosity and biomass of zoobenthos may be reduced by 80% in highly sedimented areas compared with adjacent cobble substratum (Spies 1986), and survival of bull charr eggs and juveniles decreases markedly when fines (particles <6.35 mm) exceed 40% of the substratum volume (Weaver and Fraley 1991). Moreover, recent work has shown a clear correlation between sedimentation rates in on-channel lakes and road building activities in the McDonald and Whitefish subcatchments (Spencer 1991). Inflowing riverine sediments apparently fertilize the water column of Flathead Lake in the spring, based on the observation that phytoplankton productivity is highest in years of high runoff and high sediment loading from the catchment (J. Stanford and B. Ellis, unpublished); however, the sediment load has not been apportioned in terms of natural versus human disturbances.

Interactions Between Natural and Human Disturbances: Management Considerations

Many different management jurisdictions exist within the Flathead River Basin. Seventy-two percent of the basin is federally administered, involving the Flathead National Forest (U.S. Department of Agriculture), Glacier National Park (National Park Service), national wildlife refuges (U.S. Fish and Wildlife Service), and the Flathead Indian Reservation trust lands (U.S. Bureau of Indian Affairs). Large areas of state and tribal (Confederated Salish and Kootenai Tribes of the Flathead Indian Reservation) lands exist, with the remainder of the basin primarily in privately held tracts. Hungry Horse Dam is a federal project operated by the U.S. Bureau of Reclamation. Kerr Dam is located within the Flathead Indian Reservation and operated by a private corporation, Montana Power Company, Inc., on the basis of a rental agreement with the Tribes as mandated by the Federal Energy Regulatory Commission. Many other federal, state, and local agencies have statutory authority to manage specific resources in the catchment. Since the headwaters of the North Fork are in British Columbia (Figure 5.3), many provincial and Canadian federal agencies are involved. For example, the authority of the International Joint Commission (organized under the U.S.-Canada Boundary Waters Treaty of 1909) was invoked during 1986–88 to quantify and reference the potential impacts of a large open-pit coal mine (International Joint Commission 1988) proposed by a Canadian subsidiary of an American corporation in Canada (Figure 5.3). This maze of management jurisdictions and associated interactions between natural and human disturbances complicates resource management within the ecosystem.

The threat of deteriorating water quality in Flathead Lake from urban sewage, the proposed Canadian coal mine, and burgeoning road building and clearcutting on federal and private forest lands stimulated management actions designed to implement conservation of natural conditions in the tributaries and to reduce nutrient loading in the lake by about 20% (i.e., to near natural conditions). Actions included a ban on the sale of phosphorus-containing detergents (mandated by the Montana state legislature), construction of new sewage treatment plants to allow phosphorus and nitrogen removal from all urban effluents in the catchment, and voluntary imposition of best management practices (BMPs) to reduce nonpoint sources of nutrients, especially those associated with accelerated erosion in the catchment (mandated by the State Water Quality Bureau, which has statutory authority to enforce water quality laws).

During 1983–90, annual nutrient loads into the lake decreased (least squares regression, $P<0.1$, J. Stanford and B. Ellis, unpublished); and, as noted above, *Anabaena* blooms did not recur. This, of course, suggested that initial management actions were successful. However, construction of a new sewage treatment plant for Kalispell, Montana, which has been the largest point source of bioavailable nutrients in the past, is not yet complete. Moreover, very little, if any, of the reduced nutrient load can currently be related to voluntary BMPs, because their utility in improving water quality has not been quantified empirically in the Flathead Basin. The apparent reduction in nutrient loading and lack of recurring *Anabaena* blooms may be due to at least three other interactive linkages.

First, catchment precipitation has been below average since 1983. Natural loading rates of water and nutrients have been generally lower on an annual basis than occurred earlier in the period of record. However, average concentrations in the river did not change significantly.

Second, operations at Hungry Horse Dam changed from primarily midwinter to summer and fall discharges, in response to economic considerations for hydropower production as related to demands for higher summer flows in the lower Columbia River to more effectively flush smolts of anadromous salmon out to sea (discussed below). Owing to thermal stratification in the reservoir and the hypolimnial (bottom) release mode of the dam, the high volume water masses from Hungry Horse Reservoir are cold (4–7°C) and dense relative to ambient temperatures (unregulated, natural) in the river below the dam and within the epilimnion (surface) of Flathead Lake, which is also thermally stratified in the summer (22°C surface, 4° bottom). Thus summer discharges from Hungry Horse Dam essentially dilute the pollutants entering from the urban and argricultural areas in the Kalispell Valley. Moreover, these cold waters and the nutrient load immediately sink to the lake bottom (underflow) upon entry into Flathead Lake. Since the lake is maintained at full pool during the summer for ease of access by boaters, Kerr Dam must discharge water volumes equal to the inflowing volumes. But Kerr Dam releases water from the surface layers of the lake, owing to its location below the natural outlet sill. The net effect on the limnology of the lake appears to be (1) a significant reduction in the heat budget, (2) cooler surface temperatures during the plant growing season, (3) stripping of plankton and nutrients from the surface by the Kerr withdrawal current, and (4) deposition of a large portion of the summer and fall nutrient load far below the upper portion of the water column that is penetrated by sunlight. Therefore, conditions favorable for sustained algal biomass, especially forms like *Anabaena*, in the epilimnion of the lake may have been compromised by hydropower operations.

Third, food web shifts caused by the collapse of the kokanee fishery may have influenced grazing rates on the algae. Owing to intense predation by *Mysis*, zooplankton biomass decreased almost an order of magnitude in the peak *Mysis* years, 1987–88, compared with pre-*Mysis* measures. During 1988–90, *Mysis* numbers decreased from $125/m^2$ in 1987 to $30/m^2$ in 1989 (Spencer et al. 1991) and $35/m^2$ in 1990 (Spencer 1991), owing to predation by bottom-oriented fishes (whitefishes [*Coregonus* spp.], lake trout, and bull charr). Phytoplankton primary production was the highest on record in 1988 and decreased during 1989–91 in concert with declining *Mysis* numbers. At the same time, cladoceran zooplankton have recovered during periods of thermal stratification. Apparently, large numbers of *Mysis* do not penetrate the thermocline and enter the epilimnion during summer. This thermal refugia from *Mysis* and the lack of kokanee or other surface-dwelling planktivores apparently allowed *Daphnia thorata* to increase, and the inference is that grazing on phytoplankton has also increased (Stanford et al. 1990). These interpretations are based on preliminary analyses of long-term trends in the various data bases for Flathead Lake. Our main point here is simply to reinforce by example the idea that food web dynamics in lakes can be strongly interactive in response to both bottom-up (nutrient supply) and top-down (*Mysis* introduction) effects (see also Carpenter 1988).

Interactions between dam operations, natural circulation patterns, and shoreline erosion in Flathead Lake are also noteworthy. It is exceedingly difficult to move large water masses through Flathead Lake while also maintaining it at full pool elevation. Often the lake exceeds the full pool owing to lack of coordination between the dams coupled with the complexities of wind and temperature-driven internal circulation events and patterns. Flathead Lake is an extremely large, deep lake and therefore its hydrodynamics are profoundly influenced by Coriolis and density currents and circulation patterns in addition to volume regulation by the dams. The lake has a 30 km wind fetch on the long axis, and storms and shoreline erosion rates exceed 2 m per year (lineal cross section) at the north end of the lake where the shoreline is dominated by deltaic sand substratum. Surface and internal seiches are common after storms and may influence the pattern of sediment transport from eroding shorelines. As a consequence of these natural (wind) and human (lake level regulation) disturbances, the 970 ha depositional delta of the Flathead River has entirely eroded into the lake within the last 50 years; littoral and riparian communities of the lakeshore have also been vastly altered, if not partly uncoupled from processes in the main (pelagic) part of the lake (Bauman 1988, Hauer et al. 1988, Lorang et al. 1992).

The negative effects of both Kerr and Hungry Horse operations have been carefully documented (see review by Stanford and Hauer 1992), and a mitigation plan for hydropower impacts (e.g., fluctuating flows and lake levels, temperature changes, migration barriers, habitat and production losses, accelerated lakeshore erosion) on fish and wildlife resources has been proposed to regulatory authorities. In this case, two different regulatory authorities exist. The Federal Energy Regulatory Commission is currently considering a plan related to Kerr Dam, since it is operated by private concerns. Owing to Hungry Horse Dam's operation by a federal agency, mitigation of impacts falls under the mandate of the Northwest Power Planning Act of 1984 for the entire Columbia River Basin, which involves the Northwest Power Planning Council (planning) and the Bonneville Power Administration (research and implementation). The mitigation plans were jointly developed by the state (Montana Department of Fish, Wildlife and Parks), the tribes, and the entities that operate the dams, with input from university scientists and other agency biologists. Proposed actions include: retrofitting Hungry Horse Dam to allow selective withdrawal to facilitate more natural temperature regime downstream; construction of re-regulation dams or operational changes to moderate flow fluctuations from Hungry Horse and Kerr dams; reducing the full-pool level of Flathead Lake to reduce shoreline erosion; revetment of some shorelines to curtail erosion and enhance wetland development for waterfowl; habitat restoration in damaged fish and wildlife production areas; and hatchery supplementation of fishes as replacement for losses associated with hydropower operations at both dams (Fraley et al. 1989, Fraley et al. 1991, Jourdonnais et al. 1990, Stanford and Hauer 1992).

Differences of opinion remain as to whether the various mitigation actions are appropriate or whether they will work as proposed, primarily because the statutory authorities of the two processes are independent and mandate solution of impacts on fish and wildlife without in-depth consideration of other ecosystem interactions, such as influences on timing and magnitude of nutrient loads and connectivity between riverine processes and food web dynamics (Stanford and Hauer 1992). However, the pervasive effects of stream and lake regulation were thoroughly documented and an interagency consultation and public information transfer was effective. This was fostered by forums coordinated by a public information and oversight group called the Flathead Basin Commission. This commission was legislated by the state to bring together agency heads and informed citizens in a manner that stimulated interagency cooperation to fund research, effectively monitor ecosystem indicators (e.g., catchmentwide water quality and population dynamics of important indicator organisms, like the bull charr), and facilitate interactive discussion of results and proposed management actions in a nonstatutory fashion.

The natural ecological connectivity of the Flathead catchment remains largely intact. It is a high priority area for conservation and effective resource management, since large areas are designated as national parks, wildlife refuges, wilderness areas, and tribal lands. Environmental problems exist but they have been quantified, articulated, and periodically reassessed in the process of understanding how this large catchment is influenced by natural and human disturbances. More information is needed, but the presence of a legislated commission to coordinate monitoring of ecosystem conditions by the many different management agencies has proved to be an effective and empirically based forum for considering and implementing alternative actions to protect and enhance ecological connectivity in this large catchment.

Interference Management and the Illusion of Technique

The Flathead experience illustrates the travail of contemporary resource management. Interactive and cumulative effects become seemingly intractable in large and ecologically complex catchments. Managers often want simplistic methodology that will explicitly satisfy an increasingly circumspect public. Unfortunately, in the absence of practical and conceptual understanding of ecosystem structure and function, management actions often produce results significantly different from what was expected. Usually this happens because management questions are not posed in an ecosystem (whole-catchment) context and actions evolve as interferences with the natural ecosystem connectivity. The introduction of *Mysis* as a forage stimulus for sport fishes in a very tightly coupled system interfered with the quasi-equilibrium of the Flathead Lake food web and produced a trophic cascade that ultimately displaced a critically important population of bald eagles.

On a larger scale, influences far downstream may have unanticipated effects on the operations of the two large dams in the catchment. In particular, we are concerned that efforts to increase the runs of Pacific salmon and steelhead downstream in the middle and lower reaches of the Columbia River may interfere with mitigation efforts in the Flathead Basin and other headwater reaches that, because of natural barriers, never contained anadromous fishes. The plight of the anadromous salmonid fishery involves overharvest, continually increasing dominance of runs by cultured stocks (apparently at the expense of naturally reproducing runs, owing to genetic introgression and increased harvest), predation of wild and cultured smolts by resident fishes, highly variable oceanic survival, and passage problems created by the nine mainstem dams (Ebel et al. 1989). Prominent in this discussion is the fact that early summer flood crest of the Columbia River has been eliminated by storage of the spring spate in four large reservoirs (Hungry Horse, Dworshak, Libby, and Mica) in the headwaters. Historically, the flood pulse of the river not only flushed smolts along on their outmigration, it also stimulated bioproduction in the estuarine food web which sustained the fisheries (Simenstad et al., this volume). Recovery plans for the fisheries call for a water budget for the river that mandates "fish flows" that will very likely interact with the economics of hydropower production and the need for flood control in a manner that will introduce a large measure of uncertainty in operations of the headwater dams. Unless the needs of resident fishes directly influenced by these dams have equal priority with downstream objectives, mitigation of resident fish and wildlife in the headwater segments may be compromised by actions for anadromous fishes.

A related problem is the tendency of today's managers to use a standardized methodology that often relies on little or no empirical data, or data that have little or no predictive power at the ecosystem level. Because of the natural complexities of river ecosystems, the intractability of cumulative effects in large catchments, and the cost of long-term data acquisition, managers too often tend to seek simple answers to complex problems. Often this involves nothing more than a formalization and synthesis of "best professional judgment" with no ecological rationale that is empirically based.

For example, one approach in current vogue is to assemble groups of professional hydrologists, biologists, engineers, silviculturists, and foresters to assess or "audit" forest practices (BMPs) as they relate to observed, but not empirically quantified, impacts on water quality. Specific sites are visited, and each person simply provides his or her qualitative judgment as to whether the logging activity has had any impact on the streams draining the area. Again, audit values are apportioned among BMPs on an areal basis and summed up to allow inferences about levels of disturbance to be drawn (Ehinger and Potts 1990).

In the Rocky Mountains and Pacific Northwest, including the Flathead, another popular approach for assessing the impacts of forestry on water and sediment yield is to assemble a series of impact or "risk" values and recovery rates for various land disturbance activities (e.g., roads, skid trails, site preparation, logging method). These values are then apportioned on an areal basis for the catchment and summed to provide a measure of cumulative effects (Klock 1984, United States Forest Service 1988, Cobourn 1989). This approach can be greatly improved when formalized as a true risk analysis (Cairns and Orvos 1990) or Markovian simulation, in which the impact values are based on catchment-specific experiments and the results are expressed in terms of specific forest dynamics such as the mass transfer of water, sediment, or nutrients (Pastor and Johnston, this volume).

Unfortunately, subjective methods or model results are often never verified in terms of actual impact measured *in situ* (e.g., increase in fine sediments, decrease in fish production), and inferences and recommendations can be misleading to those seriously interested in minimizing negative instream effects associated with anthropogenic land disturbances. Clearly, these methods will identify pervasive effects, such as severe sedimentation resulting from roads collapsed into streams or skid crossings that are not bridged. But it is virtually impossible to detect chronic effects (e.g., accelerated water yield and bank erosion, slow reduction in woody debris accumulation, changes in water chemistry and bioproduction, fish habitat alteration) via nonempirical audits. The value of the judgment is lost in formalization of the approach unless the audit result can be verified by temporal and spatial ecological measures obtained within appropriate experimental designs.

Too often standardized techniques or mathematical models are used to evaluate impacts when they have little or no predictive power in terms of ecosystem connectivity. This amounts to an "illusion of technique" (R. Behnke, Colorado State University, unpublished).

A prime example of the illusion of technique is the very popular incremental method (IFIM) that is recommended by the U.S. Fish and Wildlife Service to determine minimum flows to protect fisheries from the effects of stream regulation. The method is based on field surveys that determine the area of the varial zone that is inundated at different instream volumes (i.e., wetted usable area, WUA), along with other physical habitat components (e.g., velocities). These data are then used to drive a sophisticated simulation model involving target species and different flow scenarios to determine minimum flows required to sustain fisheries (Nestler et al. 1989). The model does nothing more than predict physical habitat availability for various life stages of specific fishes, and in some cases it does not appear to do that very well, among other problems (Mathur et al. 1985, Orth and Maughan 1982, Scott and Shirvell 1987, Shirvell 1989, Gan and McMahon 1990). However, the IFIM clearly is a refined and standardized technique and its use has in some instances prevented chronic dewatering of rivers. Our point is that this and other models are not responsive to processes that ultimately determine variability of bioproduction and other important aspects of ecosystem connectivity (Figures 5.4 and 5.5). In spite of warnings to the contrary by the authors of IFIM (and other standardized approaches), the illusion for naive users in this case is that WUA is deterministic, when in fact complex interactions of abiotic and biotic components of a river are naturally stochastic. This is precisely why the ecosystem exists in a quasi-equilibrium state. Naive managers and administrators easily confuse quantification, objectivity, and sophistication with biological reality, and such illusions should not be fostered (R. Behnke, Colorado State University, unpublished; Lee, this volume).

A more rationale approach is to recognize and appreciate the complexities of river catchments and utilize standardized tools and models in the limited sense for which they were designed. It is not likely that any model or other deterministic construct will ever accurately predict ecosystem structure and function at the catchment scale. But model building is one very effective way to plan and articulate the need for collection of long-term ecological data that will ultimately explain observed variability caused by natural and human disturbances. In almost all assessments of cumulative impacts at the catchment level, long-term empirical data describing ecosystem structure and function are required as baselines to firmly quantify environmental change.

Integrated Management

In this age of desktop computer power and electronic communication, it is paradoxical that interference management should occur. However, as communication power has burgeoned, so have agency bureaucracies. For example, the Bureau of Reclamation has run out of dam sites and is now attempting to add supervision of fish and wildlife resources of western rivers to its official mandate (our observation). Indeed, we think that many state and federal agencies are purposely fostering an insular approach to resource management. Each wants to do ecological research, develop and follow standardized management criteria and procedures for ecological resources, and, most important, minimize influence of other agencies. Local and regional fragmentation of management authority is guaranteed to result in interference management, which in turn fragments catchment ecosystems.

The structure and function of catchment ecosystems and the cumulative effects of human disturbances are in fact intractable without an integrated analysis based on long-term data (Magnuson 1990). No single agency can effectively deal with the plethora of management/research problems on a large catchment scale. Yet the bureaucracies and their individual mandates are firmly entrenched, as are the public groups that are increasingly sensitized by the negative effects of interference management and the illusion of technique.

What should be done? If human disturbances are to be managed for the purpose of maintaining natural ecological connectivity at the catchment scale, management agencies must cooperate to minimize interferences. Cooperation is needed for collection of long-term data that will allow BMPs and other management actions to be quantified and adjusted before they interfere with each other. That level of cooperation requires effective information transfer, continual education, and independent coordination.

State-of-the-art ecology almost always originates from research at the university level or in agency research centers closely allied with universities. Although university-based research is also often very insular, we note a recent trend toward interdisciplinary work at the ecosystem level. The long-term research initiatives of the National Science Foundation described above have greatly fostered this trend. It may therefore be expected that university research will provide guidance for a new integrated management ethic.

However, we note three fundamental problems. First, creative research is currently compromised by dwindling funding at the national level and particularly at the state level. Part of the problem is rooted in the growing tendency of agencies to attempt their own basic and applied research in opposition to cooperatives with universities. Second, we perceive a growing gulf between agencies and universities because it is often university scientists who point out flaws and interferences in agency management actions (see also Marston, this volume). Third, universities are not currently producing management specialists in the natural resource arena who are astutely attuned to ecosystem connectivity. Graduates are trained primarily to do basic research, and in most cases that training is highly specialized. We should not be surprised that agencies are becoming insular in their approach to management. Moreover, we should not be surprised that agencies tend to attempt ecological manipulations (e.g., introductions of exotic species, hatchery supplementation of wild populations) rather than focusing management on public education and regulation of human disturbances.

Conducting research and managing resources should be distinguished as separate but complimentary activities. The successful manager must understand ecosystem connectivity and must be able to translate research findings into holistic resource management. It is also the manager's job to involve the public in the decision-making process by communicating how proposed actions relate to the whole and will thereby serve to reconnect severed interactive pathways.

Because those making high-level management decisions must (1) comprehend ecosystem connectivity at the catchment level, (2) be familiar with the relevant primary literature, (3) determine when additional problem-oriented research is needed, and (4) translate all of the above into appropriate managerial decisions while effectively communicating with the public, their proper training is indeed a formidable task. University curricula in natural resource management need to be revamped to foster an understanding of such matters as economic and environmental sustainability, cultural needs and influences, demography and political change, and conservation ethics (Marston, this volume) in addition to traditional biology and ecology. Moreover, high level management jobs (e.g., forest supervisors, park superintendents) require more rigorous training. Doctoral programs typically train either researchers or managers. We argue that to properly protect and manage our valued natural resources requires a solid grounding in research plus managerial expertise. We believe that contemporary management problems at the catchment scale are so complex that nothing less than a Ph.D. degree accompanied by a postdoctoral internship program will suffice to train conservators of ecological connectivity in river ecosystems.

This cannot be done by the universities alone. Agencies must return to the university environment for basic research and cut down wasteful duplication of space, equipment, and effort. University scientists must accommodate managers by doing innovative applied research and by providing educational forums that articulate management problems and potential solutions to students and agency personnel. Some of the cooperatives between a few universities and regional research units in the National Park Service, U.S. Forest Service, and U.S. Geological Survey have been somewhat successful in this regard. However, we envision formal cooperatives at the level of local Forest Service districts and state fish and game regional offices and involving many, if not all, research universities.

We emphasize that education and effective management of natural resource issues also must formally involve the public. Many management interferences and failures could have been avoided simply by the quality control afforded by an *a priori* public forum. A template for success in this regard is a state legislated catchment commission composed of all pertinent agency heads (e.g., forest supervisor, park superintendent, local land use planner, fish and game agency, tribal resource administrator, county commissioners) and at least an equal number of informed citizens who equitably represent the various publics (e.g., industry, agriculture, urban development, conservation). University scientists should be used as advisers or sources of basic information in analyzing and guiding the process. One fairly successful example is the Flathead Basin Commission described above.

In summary, we propose several important principles of integrated management at the catchment level.

1. *The major objective should be to conserve and enhance ecological connectivity.* Processes and disturbances within the catchment are interconnected biophysically in time and space.

2. *The key management questions should define the catchment scale.* However, for very large catchments (e.g., the Columbia River Basin) no

good formulas for success currently exist. Coordination and representation can become quickly fragmented or politicized because there are too many participants at the same table. We suggest that, if possible, the focus should be areas more the size of the Flathead catchment, as described above. The inference is that if ecosystem connectivity can be conserved in all subcatchments of very large drainage basins, the ecological integrity of the entire system should remain stable. Or, at least, an approach to problem solving in very large catchments should be forthcoming from an integration of subcatchment data and knowledge.

3. *A research and monitoring agenda should be established that will provide long-term data bases that may be used to separate variability due to natural and human disturbances (e.g., precipitation, discharge, nutrient loading, primary productivity, population trends of indicator organisms such as the bull charr in the Flathead case history).* University scientists should be utilized independently and in cooperatives with agency research and management personnel to plan monitoring programs and collect and interpret data. If planned properly, monitoring programs can be both an ongoing evaluation of BMPs and an assessment of environmental change at the catchment level. The latter may be expected to provide insights into the effects of regional or global influences on the catchment.

4. *Management actions should be examined from an ecosystem point of view.* A formal evaluation is needed of the risks that management actions portend and alternatives should be developed that can be activated if monitoring or research data suggest that interferences are manifested.

5. *A mechanism (we recommend a commission) should be provided that brings managers, researchers, and public groups into a forum for open debate.* The objective is education and information transfer before management actions are implemented.

Conclusion: Reconnecting Catchment Ecosystems

Ecology as a science has evolved into an understanding of landscapes as interconnected patches that vary in scale from a single rock in a stream to whole catchments (Gillis 1990; Naiman et al., this volume). Research is focused on processes, time frames, and disturbances that control the transfer of materials and energy through catchment landscapes. Management in this context refers to actions that limit interference of human disturbances to the extent that catchment ecosystems are sustained in a natural quasi-equilibrium.

In many catchments, human disturbance has eliminated or severely compromised natural connectivity. Catchment management in the future may logically involve reconnecting patches into landscapes. One example might be reestablishing floodplain springbrooks as functional patches (e.g., as important rearing areas for salmonids). This may involve removing revetments and allowing flood-pulse events to reconnect the channel and the floodplain

(Figure 5.2). Integrated forests, agricultural lands, and urban management can provide many other avenues to allow damaged catchment ecosystems to recover.

Threats to catchments usually manifest measurably in aquatic habitats as problems related to stream regulation, eutrophication and other forms of water pollution, food web changes, and accelerated sedimentation. These phenomena can be used as benchmarks that integrate the environmental health of the catchment if the data are gathered systematically over long periods. Analysis of trends in such data can reveal how leaky or unconnected the system may be and provide clear insights where management actions can be effective in reconnecting the system. This effort can best be accommodated by insightful, integrated management.

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[July 94]

Grumbine C.B.

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Bob —
Your comments would be most welcome.
Bob

draft --- please send comments to author

The Seven Pillars of Ecosystem Management[1]

by

Robert T. Lackey[2]

[1]Modified from a presentation given at the Symposium: *Ecosystem Health and Medicine: Integrating Science, Policy, and Management,* Ottawa, Ontario, Canada, June 19 - 23, 1994. This paper has been subjected to scientific peer review but does not necessarily reflect policy positions of the Environmental Protection Agency.

[2]The author is deputy director of EPA's Environmental Research Laboratory, 200 SW 35th Street, Corvallis, Oregon 97333 and holds a courtesy professorship at Oregon State University in fisheries and wildlife.

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Abstract

Ecosystem management is widely proposed in the popular and professional literature as the modern and preferred way of managing natural resources and ecosystems. Advocates glowingly describe ecosystem management as an approach that will protect the environment, maintain healthy ecosystems, preserve biological diversity, and assure sustainable development. However, definitions of ecosystem management are vague and clarify little. Seven core principles, or pillars, of ecosystem management define and bound the concept and provide operational meaning. The pillars are: (1) ecosystem management is a stage in the continuing evolution of social values and priorities; it is neither a beginning nor an end; (2) ecosystem management is place-based and the boundaries of the place must be clearly and formally defined; (3) ecosystem management should maintain ecosystems in the appropriate condition to achieve desired social benefits; (4) ecosystem management should take advantage of the ability of ecosystems to respond to a variety of stressors, both natural and man-made, but all ecosystems have limited ability to accommodate stressors and maintain a desired state; (5) ecosystem management may or may not result in emphasis on biological diversity; (6) the term sustainability, if even used in ecosystem management, should be clearly defined -- specifically the time frame of concern, the benefits and costs of concern, and the relative priority of the benefits and costs; and (7) scientific information is important for effective ecosystem management, but is only one element in a process that is fundamentally one of public and private choice. A definition of ecosystem management based on the seven pillars is: "The application of biophysical and social information, options, and constraints to achieve desired social benefits within a defined geographic area and over a specified time period." As with all management paradigms, there is no "right" decision but rather those decisions that appear to best

respond to society's current and potential future needs as expressed through a decision making process.

Introduction

Ecosystem management is a bold paradigm:

> *Ecosystem management defines a paradigm that weaves biophysical and social threads into a tapestry of beauty, health, and sustainability. It embraces both social and ecological dynamics in a flexible and adaptive process. Ecosystem management celebrates the wisdom of both our minds and hearts, and lights our path to the future.* (Cornett, 1993)

It is proposed as the modern and preferred way of managing natural resources and ecosystems. When implemented, ecosystem management will, at least according to its advocates, protect the environment, maintain healthy ecosystems, permit sustainable development, preserve biodiversity, and save scarce tax dollars. One might be tempted to add to the list: alleviate trade imbalances; reduce urban crime; and pay off national debts. Is ecosystem management a revolutionary concept, or are the critics right who assert that it and the associated jargon are closer to cold fusion than cold fact?

Ecosystem management may be "hot tub science applied to new age management" -- or it might be "a paradigm and policy shift that is long overdue;" either way scientists and managers are increasingly becoming involved in the debate. Why should scientists and other technical people care about ecosystem management as a concept or follow the spirited debates over its exact meaning? Three reasons: first, the concept has been embraced widely by politicians and appointed officials. At least in the political arena, the debate is concluded over whether ecosystem management is a good idea; it will be implemented, or at least attempted in word if not in deed.

A second reason is that it might just be a bold new concept and be a very different, and better, way of managing ecosystems. Beyond the rhetoric, there may in fact be some technical substance. Ideas do have consequences -- especially those that are put into practice on a wide scale.

Third, society needs to move beyond the debates over rhetoric and focus directly on policy issues and the role science could and should play. There is a considerable amount of interesting and challenging research on ecosystems, but what are the critical needs that will make a *difference* in ecosystem management?

Ecosystem management is offered as a management approach to help solve complex ecological and social problems. Examples of current problems are the Pacific Northwest forest/salmon/spotted owl impasse; purported decline of biological diversity; and "degradation" of ecosystems from "poor" urban, industrial, transportation, agricultural, ranching, and mining policies and practices. Some critics may charge that ecosystem management is the triumph of the politics of "process" over the politics of "substance," but the public choice problems are definitely real and substantive.

Ecosystem management problems have several general characteristics: (1) fundamental public and private values and priorities are in dispute, resulting in the existence of partially or wholly mutually exclusive decision alternatives; (2)

substantial and intense political pressure to make rapid and significant changes in public policy; (3) public and private stakes are high, with substantial costs and substantial risk of adverse effects if the wrong policy choice is selected; (4) the technical facts, both biophysical and sociological, are highly uncertain; (5) the "ecosystem" and "policy problem" are intertwined in a large framework such that policy decisions will have effects outside the scope of the problem. Solving these kinds of problems in a democracy has been likened to asking a hungry pack of four wolves and a sheep to apply democratic principles to deciding what to do for lunch. Given public choice problems with these characteristics, it is little wonder that there may be a tendency for advocates to focus on *process* and not *substance.*

The purpose of this article is to summarize my view of ecosystem management. The views are my own; they do not necessarily reflect the views of my employer or any other organization. Reviews of earlier drafts of this talk have convinced me that they may not even represent the views of many of my colleagues. It is clear that the range of opinions on ecosystem management is wide.

I have organized the fundamental concepts of ecosystem management around seven *pillars* which I consider to be the supports underlying ecosystem management. Just as physical pillars don't completely define a building; neither do intellectual pillars completely define ecosystem management. Nevertheless, it is my hope that these pillars will effectively describe the essential underpinnings of "ecosystem management," the circumstances under which it might be successfully applied, and its relationship to public and private choice. The seven pillars are not procedures or blueprints for ecosystem management, but are principles upon which ecosystem management should be based.

Definition

Articulation a clear *definition* for ecosystem management seems a reasonable place to start. The diversity of definitions provides some indication of the current amorphous nature of the concept (Bengston, 1994).

Commonly used definitions of ecosystem management are:

1. "A strategy or plan to manage ecosystems to provide for all associated organisms, as opposed to a strategy or plan for managing individual species," (FEMAT, 1993).

2. "The careful and skillful use of ecological, economic, social, and managerial principles in managing ecosystems to produce, restore, or sustain ecosystem integrity and desired conditions, uses, products, values, and services over the long term," (Overbay, 1992).

3. "To restore and maintain the health, sustainability, and biological diversity of ecosystems while supporting sustainable economies and communities," (EPA, 1994).

These definitions have an unmistakable similarity to traditional definitions of fisheries management, wildlife management, and forest management. In fact, there is even a striking similarity to the much maligned definition of multiple use management. For example, a typical definition of fisheries management is the "practice of analyzing, making, and implementing decisions to maintain or alter the structure, dynamics, and interaction of habitat, aquatic biota, and man to achieve human goals and objectives through the aquatic resource," (Lackey, 1979). But in the definitions of ecosystem management, there are some new words -- *ecosystem and community sustainability, ecosystem health, ecosystem integrity, biological diversity, social values, social principles.* The new words are where differences arise, and from these words I will develop the pillars.

Values and Priorities

What does society want from ecosystems? The basic idea behind a management paradigm is to maximize benefits by applying a mix of decisions within defined constraints. Benefits may be tangible or intangible and achieved through maintaining a desired ecological condition. Potential benefits from ecosystems may be commodity yields (lumber, fish, wildlife), ecological services (pollution abatement, biological diversity), intangible benefits (preservation of endangered species, wilderness, vistas), precautionary investments (deferring use to preserve future options), maintaining a desired ecological status (old growth forests, unaltered rangelands, etc), and many others. The management challenge is to figure out what the *goal* is and then design a strategy for implementing a *mix* of decisions to reach the goal (Bormann, 1994). A key challenge to successful management is accurately determining the system's capacity to provide that goal.

The first and foremost management challenge, figuring out exactly what *is* the goal, is complicated by the evolving nature of society's values and priorities. It is difficult to be concerned with an endangered toad or a threatened snail when your family's immediate problem is surviving the winter. And it is difficult to understand the passion for industrial development when your major concern is whether you will take a vacation this winter, or wait until summer. Our individual and collective goals and values differ with our circumstances and change over time.

The other management challenge involves evaluating and selecting the mix of decisions that seems likely to achieve the identified goal. This is no easy task under the best of circumstances, but it becomes impossible unless the analyst at least *assumes* a matrix of societal goals. Our most efficient way to implement policy may be through a series of "experimental" decisions from which we can "learn" how the ecosystem (both biophysical and human elements) responds to various decisions. A modification of an old maxim may be most appropriate here: "the best way to implement ecosystem management may be to learn from past mistakes and also systematically make some new but different ones."

The important and central role of values and priorities has long been recognized in management. Management paradigms, whether they be multiple use, maximum equilibrium yield, scientific management, multiple resource use, watershed management, natural resources management, maximum sustained yield, or ecosystem management are based on values and priorities (Cubbage and Brooks, 1991). Each paradigm has either formally or informally accepted a set of values and priorities, or used a process to obtain values and priorities. Ecosystem management is no different in this regard.

The first pillar of ecosystem management is:
Ecosystem management reflects a stage in the continuing evolution of social values and priorities; it is neither a beginning nor an end.

Boundaries

A practical technical requirement with any management paradigm is to *bound* the system of concern. Because no useable definition of an ecosystem has been developed that works within the public decision making environment, other approaches are used to define the "system" of concern. Historically this was accomplished by focusing on one or more species of concern over a defined geographic area. We manage flyways for migratory waterfowl, for example. The geographic limits of the flyway become the operational boundaries for the management analysis. Or we managed the game fish populations in a certain lake. The lake and its watershed then become the unit of concern.

Another option is to bound the system by what is relevant to elements of society such as a community or interest group. For example, management goals might focus on providing diverse hunting options to society. However, no matter how boundaries are defined in ecosystem management, they end up largely being geographically based -- a *place* of concern.

Within the place of concern the goal then becomes managing for maximum social benefits within a number of constraints, both ecological and societal. And because management optima vary with the scale of consideration, it is essential to clearly define the boundary of concern. For example, a set of decisions to maximize benefits in managing a 1,000 hectare watershed within the Columbia River watershed may well be very different than decisions on the same watershed that were designed to maximize benefits over the entire Columbia River watershed.

There is a natural tendency to gloss over decisions on boundaries because deciding on boundaries explicitly defines the management problem. In a pluralistic society, with varied and strongly held positions, conflict is intensified when perceptive individuals and groups immediately see that their position will lose. However, to not define boundaries will lead to management strategies that are not intellectually rigorous, or result in debates over technical issues when the debates are really clashes over values and priorities.

The second pillar of ecosystem management is:
Ecosystem management is place-based and the boundaries of the place of concern must be clearly and formally defined.

Health

The term ecological *health* is widely used in both the scientific and political lexicon (Rapport, 1989; Costanza, et al., 1992). Politicians and environmental advocates widely argue for managing ecosystems to achieve a "healthy" state. By implication their opponents are relegated to managing for "sick" ecosystems.

Scientists often speak and write about monitoring the health of ecosystems, or perhaps the integrity of the ecosystem. There is the stated, or at least tacit, assumption that there is an intrinsic healthy state and an unhealthy state for any given ecosystem (Norton, 1992).

Much of the general public seems to accept that there must be a technically defined healthy state similar to their personal human health. After all, people know how they feel when they are sick, and so, by extension, sick ecosystems must be in a similarly indisposed condition, which should be avoided. "Health" is a powerful metaphor in the world of competing policy alternatives.

. For example, society may wish to manage a watershed to maximize opportunities for viewing the greatest possible diversity of birds, or for the greatest sustained yield of timber, or for the greatest sustained yield of agricultural products. Achieving each goal would almost assuredly result in ecosystems that are very different, but equally healthy.

The debate is really over defining the "desired" state of the ecosystem and, secondarily, managing the ecosystem to the desired state. Phrased another way: what kind of garden does society want (Regier, 1993)? There is no intrinsic definition of health without a benchmark of desired condition. In ecosystem management, scientists should avoid value-laden terms such as "degradation, restoration, sick, destroy, safe, exploitation, collapse" unless they are accompanied with an explicit definition of what the desired condition of the ecosystem is as defined by society.

In philosophical terms the problem is how does one link "is" and "ought." For example, an ecosystem has certain characteristics -- these are facts that all analysts who study the ecosystem should be able to agree on and to determine. Characteristics such as species diversity, productivity, and carbon cycling are examples. If the same definitions and the same methods are used, all analysts should come to the same answer within the range of system and analytical variability. The "ought" must involve a human judgement -- it cannot be addressed by scientific or technical analysis (Shrader-Frechette and McCoy, 1994). The concept of "health" has a compelling appeal, but it has no operational meaning unless it is defined in terms of the *desired* state of the ecosystem

The third pillar of ecosystem management is:
Ecosystem management should maintain ecosystems in the appropriate condition to achieve desired social benefits; the desired social benefits are defined by society, not scientists.

Stability

Stability, resilience, fragility, and *adaptability* are interesting and challenging concepts in ecology. These are some of the characteristics of ecosystems that provide an opportunity to realize benefits for society; but these same characteristics constrain options for society and the ecosystem manager.

There is a widespread, if sometimes latent, view that ecosystems are best that have not been altered by man. Further, it just seems obvious that such "healthy" ecosystems *must* be more stable than the unaltered, less "healthy" ones, just as the Romantic School viewed nature as a noble world that realized its greatest perfection when not affected by man. This is the old "balance of nature" view. Pristine is good; altered is bad -- perhaps necessary for food, lodging, or transport, but still not as desirable as pristine. However, few seem to be willing to return to the "natural" human mortality rates of at least 50% from birth to age five.

Moreover, this is not how nature works (Kaufman, 1993). There is no "natural" state in nature; the only thing natural is change, sometimes somewhat predictable, oftentimes random, or at least unpredictable. It would be nice if it were otherwise, but it is not. The concept of dynamic equilibrium might be invoked place bounds on ecosystem change in an intellectual attempt to better describe stability, but the intuitive appeal of the concept of stability is not easily fulfilled. Ecologists cling to stability and equilibrium with a near missionary zeal.

Regardless of the reality of stability, ecosystems are impressively resilient, although not without limits. A key role of science in ecosystem management is to identify the limits or constraints that bound the options to achieve various societal benefits. The trick in management is to balance the ability of ecosystems to respond to stress in useful ways, but without altering the ecosystem beyond its ability to provide those benefits. We want shelter, food, personal mobility, energy, etc, but we don't want the systems to collapse that are producing those benefits.

The fourth pillar of ecosystem management is:

Ecosystem management can take advantage of the ability of ecosystems to respond to a variety of stressors, both natural and man-made, but there is a limit in the ability of all ecosystems to accommodate stressors and maintain a desired state.

Diversity

The level of *biological diversity* in an ecosystem is an important piece of scientific information, and this knowledge can be useful in understanding the *potential* of an ecosystem to provide certain types of social benefits. However, it is purely a technical piece of information. What people value about biotic resources, whether biological diversity or something else, is not a technical question.

An argument often made is that biological diversity is necessary to maintain ecosystem stability. This argument contains an element of truth, but there is only the most general linkage between biological diversity and ecosystem stability. Like any other attribute of ecosystems, the value of biological diversity to society must be based on society's preferences. That is not to say that biological diversity (and many other characteristics of ecosystems) is not important; it is. But, as a characteristic of ecosystems, biological diversity operates on the *constraint* side of management, not the *benefit* side *unless there is an explicit society preference.*

It is possible, even likely, that society may value elements of biological diversity as a social benefit in and of itself, but this is a public choice, not a scientific one (Trauger and Hall, 1992). For example, public choice may dictate that no naturally occurring species may go extinct due to human action. This is certainly a legitimate social benefit, but not a scientific one. Biological diversity may or may not have intrinsic worth to society.

There are other fundamental public choice issues involved with biological diversity: do you consider all species, exotic or otherwise, as part of the fauna and flora for the purposes of assessing biological diversity? At what scale do you measure diversity? By some measures diversity has increased; by others it has decreased (Berryman, 1991).

If the public expresses a social preference for biodiversity in its *own right,* then do our management options include increasing biological diversity beyond what would naturally occur? Should we introduce species to increase diversity? Should we use the tools of genetic engineering to double or triple biological diversity? Producing agricultural crops with high performance seeds is not natural, so why not use the tools at our disposal to increase biological diversity if it is a social benefit?

The fifth pillar of ecosystem management is:
Ecosystem management may or may not result in emphasis on biological diversity as a desired social benefit.

Sustainability

Sustainability is an important element of nearly all management paradigms. There is always considerable debate over whether various societal benefits and ecosystem outputs are sustainable or not, but the basic goal is invariably to produce sustainable yields of something, tangible or otherwise. Sustainable commodity yields are much easier to determine from an analytical standpoint than are the more intangible benefit yields typical in ecosystem management. However, whether "yields" of benefits are described and measured in trees, fish, deer, visitor days, diversity of recreational opportunity, or maintenance of wilderness areas that no one visits, all are realized *benefits* accruable to man.

Much more tenuous is the analytical basis for sustainable development -- a term often used interchangeably with sustainability. The goal of sustainable development is typically offered as " . . . to meet the needs of the present without compromising the ability of future generations to meet their own needs." The concept of sustainable development masks some fundamental policy conflicts (Norton, 1991). If one assumes existing social values and priorities, increasing human population, and constant technology, then we cannot *develop* in perpetuity. By necessity we must assume that either values and priorities will change and/or technology will change, or sustainable development is an oxymoron (Dovers and Handmer, 1993). There are precise definitions of "develop" that have been offered to counter the logical inconsistencies in the concept of sustainable development; however, at least how sustainable development is typically used in public and political rhetoric, the inconsistencies remain.

Selecting *what* is to be sustained is a societal choice (Kennedy, 1985; Gale and Cordray, 1991). Do we measure sustainability of commodity yields as surrogates for total societal benefit? Do we measure sustainability of the ecosystem in some defined state? Over what time frames do we measure sustainability? A generation? Over 50 years? Over 100 years? A millennium? What is the scale of sustainability? A small watershed? An ecoregion? Or the entire nation? How is sustainability to be measured when societal values and priorities change? In short, sustainability implies more questions than it answers.

Further complicating the concept of sustainability is the chaotic characteristic of ecosystems. Sustainability is often based, at least tacitly, on a homeostatic view of nature -- that is there is a certain natural condition of a ecosystem. There is no natural state of any ecosystem, only conditions from a wide array of possibilities, known and unknown. The term "balance of nature" has passed out of common usage in ecology, and this reflects the acceptance, albeit reluctant, of the dominant chaotic nature of ecosystems.

The sixth pillar of ecosystem management is:
The term sustainability, if used at all in ecosystem management, should be clearly defined -- specifically, the time frame of concern, the benefits and costs of concern, and the relative priority of the benefits and costs.

Information

Some level of ecological understanding and *information* specific to the ecosystem of concern is essential to effective ecosystem management. How much understanding and information is needed is a real question. After all, it is the ecological characteristics of the ecosystems that largely bound the various management options to produce societal benefits.

Other types of information are also important, for example, knowing how individuals and groups might respond to various decision options (Ludwig, et al, 1993). Tax incentives may be an especially important tool in ecosystem management, so a solid understanding of how people will respond to modifications in tax law is essential. Erroneous predictions of individual and group response to regulations, policies, or other regulatory tactics are all too common in policy analysis.

Scientific information is by its nature uncertain -- sometimes highly uncertain. Oftentimes scientific information and predictions based on scientific information can become the lightning rod for debate over various management options. Debate over values and priorities is important and should be encouraged in the public policy arena; this is not, however, the arena in which to debate scientific information. It is important to isolate the two types of debates.

Part of the responsibility for the confusion over "providing information" vs. "advocating" rests with scientists. Many ecologists have a strong tendency to support "environmentalist" worldviews and positions. This is understandable in part by the self selection of all professions (environmentally oriented individuals are undoubtedly more likely to select ecologically oriented fields than are more materially oriented individuals). The same self-selection takes place in economics (business oriented individuals are prone to select economics as a profession). Individuals in any profession naturally tend to be advocates for what is important in that profession. It is not difficult to understand the difficulty that many ecologists have in deleting from their scientific vocabularies such value-laden and emotionally charged words such as "sick," "healthy," and "degraded." Language is not neutral, and scientists should be very careful with language when they are speaking as *scientists.* Equal vigilance by scientists should be given to avoid unspoken assumptions that reflect value-laden or emotionally charged opinions.

The seventh pillar of ecosystem management is:
Scientific information is important for effective ecosystem management, but is only one element in a process that is fundamentally one of public or private choice.

Conclusion

Where does this leave us? The seven pillars of ecosystem management collectively define and bound the concept of ecosystem management. Whether the concept turns out to be useful will depend on how well its application reflects a collective societal vision. Whether it is possible to develop a collective societal vision in a diverse, polarized society such as ours is a major, and yet to be answered, question. The democratization of science, policy, and choice is not a smooth process, nor will it ever be efficient.

At least in North America the ideas behind ecosystem management represent a predictable response to evolving values and priorities. Those values and priorities will continue to evolve, although the direction and degree of their evolution are ambiguous and largely unpredictable. Without major social jolts such as war, economic collapse, the return of plagues, or natural disasters, it is likely that the direction toward values and priorities of the affluent will continue. Such values and priorities tend to be toward non-consumptive and non-commodity benefits.

There are other directions for ecosystem management that are less clear but potentially much more significant. At a recent conference a statement was made that illustrates such a possible direction. The statement was something like this: "It is time to change our [society's] charter with individuals. We have massive and critical problems with our ecosystems that cry out for immediate action because we have subordinated the collective good of society to the will of individuals. Personal freedom must be weighed against the harm it has caused to the whole of society and more importantly to our ecosystems." A response to the statement was equally instructive: "Society and freedom are at greatest risk from those with the noblest of agendas."

By its very nature ecosystem management will continue to be place-based. Ecosystem management problems need to be bounded to make them tractable. A practical implementation problem is that much of the "place" is owned by individuals, not by society. By being place-based, application of ecosystem management will become a lightning rod for debates over individual vs. societal "rights." How does society balance the rights of individuals to not have their property taken without compensation against the right of society to collectively prosper?

At a superficial level the role of scientific information will continue to become more prominent in ecosystem management. However, most of the really important decisions are choices among competing and often mutually exclusive values. The role of scientific information is important, but it does not substitute for choices amongst values.

Ecosystem health, ecosystem integrity, biodiversity, and sustainability have evolved from scientific terms to terms used in debates over values. Unless these terms are precisely defined and clearly separated from values and priorities, their value in science is severely diminished. I recommend that they be dropped from use in science all together and more precise, non value-laden terms be used. Scientists need to be involved throughout the process of ecosystem management, but in a clearly defined, but interactive role.

The definition of ecosystem management is:

The application of biophysical and social information, options, and constraints to achieve desired social benefits within a defined geographic area and over a specified time period.

In conclusion, ecosystem management is not a revolutionary concept but rather an evolutionary change from existing, well established paradigms. What is revolutionary is the fact that the issues have moved from the hallways of obscure bureaucracies and remote academic outposts to the political landscape. For better or worse, ideas do make a difference.

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September 27, 1994

Dr. Behnke,

Thank you for giving me an opportunity to review Robert Lakey's paper "The Seven Pillars of Ecosystem Management". I believe any individual that tackles a review of the literature on the subject and attempts to synthesize it should be congratulated. My comments are very brief and I'm not sure how helpful.

While I believe his pillars have validity, I disagree with his ultimate definition of ecosystem management. He states that definitions of ecosystem management are "vague and clarify little". He defines ecosystem management as "The application of biophysical and social information, options and constraints to achieve desire social benefits within a defined geographic area and over a specified time"

I would argue that the definitions of ecosystem and ecosystem management actually vary little from land management agency to land management agency (Grumbine's paper "What is Ecosystem Management?" is helpful in describing the central themes which characterize land manager's and scholar's definitions of the term). What is vague to clarify or determine about ecosystem management is 1. How to determine the units of management. 2. How to design and implement strategies to manage that unit.

Lackey's focus on managing to achieve desired social benefits within a defined geographic area ~~and~~ over a specified time seems similar to the traditional approaches to resource management such as optimizing timber yields or deer harvests. I found Salwasser's paper "Ecosystem Management: From Theory to Practice" helpful in describing the difference between ecosystem managment and traditional resource management approaches.

Once again, thank you for giving me an opportunity to comment.

I have made copies of both papers. Mr. Lackey may find them of interest.

Linda Dres

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Drees

What Is Ecosystem Management?

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Abstract: *The evolving concept of ecosystem management is the focus of much current debate. To clarify discussion and provide a framework for implementation, I trace the historical development of ecosystem management, provide a working definition, and summarize dominant themes taken from an extensive literature review. The general goal of maintaining ecological integrity is discussed along with five specific goals: maintaining viable populations, ecosystem representation, maintaining ecological process (i.e., natural disturbance regimes), protecting evolutionary potential of species and ecosystems, and accommodating human use in light of the above. Short-term policy implications of ecosystem management for several groups of key actors (scientists, policymakers, managers, citizens) are discussed. Long-term (>100 years) policy implications are also reviewed including reframing environmental values, fostering cooperation, and evaluating success. Ecosystem management is not just about science nor is it simply an extension of traditional resource management; it offers a fundamental reframing of how humans may work with nature.*

Qué es manejo del ecosistema?

Resumen: *El concepto del manejo del ecosistema en desarrollo es el foco de gran parte del debate actual. A los efectos de clarificar esta discusión y proveer un marco para su implementación, reconstruyo el desarrollo histórico del manejo de ecosistemas, proveo una definición de trabajo y resumo los temas dominantes tomados de una extensa revi-sión bibliográfica. El objetivo general de mantener la integridad ecológica es discutido conjuntamente con cinco objetivos específicos: mantenimiento de poblaciones viables, representación de ecosistemas, mantenimiento de procesos ecológicos (i.e., regímenes de perturbaciones naturales), protección del potencial evolutivo de las especies y ecosistemas, y acomodamiento del uso humano en función de lo anterior. Se discuten las implicaciones de las medidas de corto término en el manejo del ecosistema para distintos grupos de actores claves (científicos, diseñadores de políticas, administradores, ciudadanos). También son consideradas las implicaciones a largo plazo de las medidas (>100 años), incluyendo la reconsideración del marco de los valores ambientales, el fomento de la cooperación y la evaluación del éxito. El manejo del ecosistema no es ciencia sólamente ni la simple extensión del tradicional manejo de recursos; el manejo del ecosistema ofrece una reconsideración del marco de cómo los humanos podemos trabajar con la naturaleza.*

Introduction

Deep in a mixed conifer forest on the east side of the Washington Cascades, a U.S. Forest Service silviculturalist, responding to a college student's query, suggests that ecosystem management means snag retention and management of coarse woody debris on clearcut units.

In northern Florida on a U.S. Department of Defense reservation, a team of biologists and managers struggles with the design of a fire management plan in longleaf pine (*Pinus palustris*) forests that mimics natural disturbance regimes while minimizing the risk of burning adjacent private lands (USDOD Air Force 1993).

To avert what he calls "national train wrecks," Interior Secretary Bruce Babbitt announces that the Clinton Administration plans to shift federal policy away from a single species approach to one that looks "at entire ecosystems" (as quoted in Stevens 1993).

Commenting on a draft federal framework for the Greater Yellowstone Ecosystem that proposes increased interagency cooperation, a lawyer claims that "Congress

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United States
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Sustainable Ecological Systems:
Implementing an Ecological Approach to Land Management

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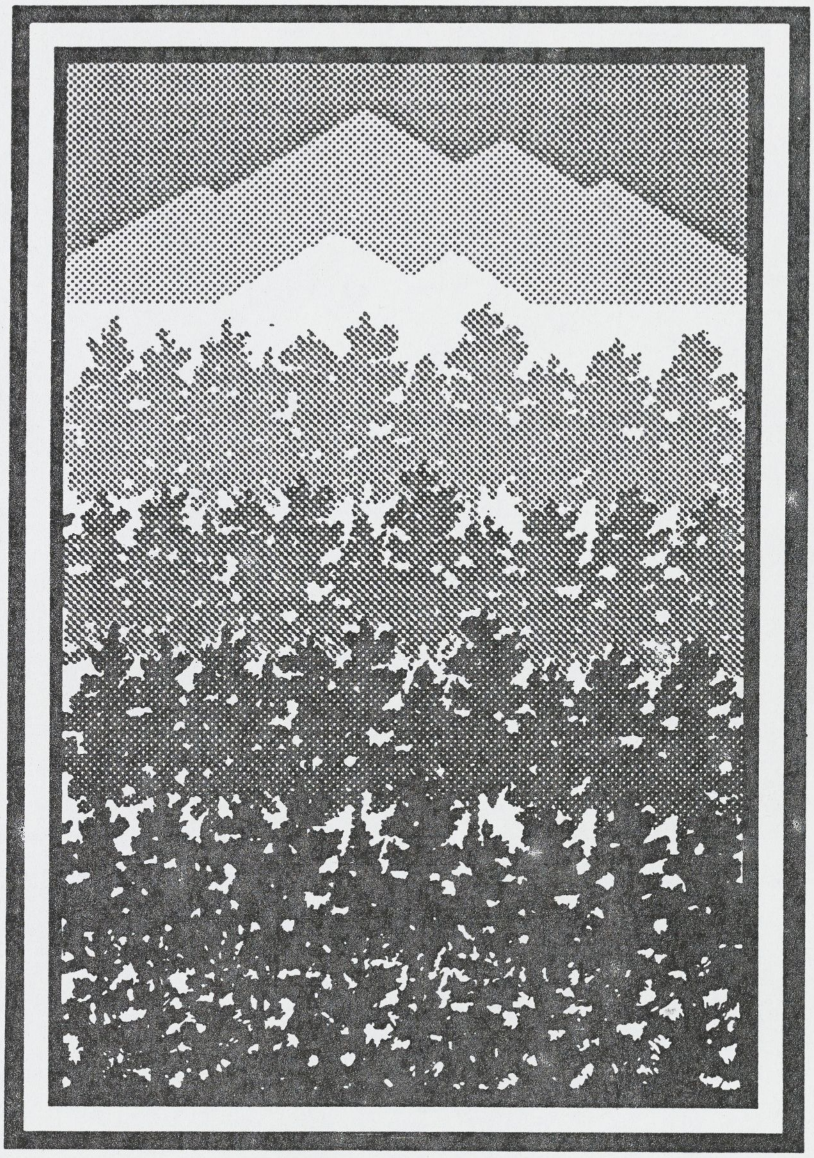

Ecosystem Management: From Theory to Practice

Hal Salwasser and Robert D. Pfister[1]

Abstract — Ecosystem management (Robertson 1992) and sustainable development (UNCED 1992) have emerged in the early 1990s as major concepts and policies for the stewardship of human and biological communities in the United States. Both have a similar goal: the sustenance of desired conditions of lands, waters, biota, human communities, and the economic enterprises that depend on healthy, productive land and natural resources. Both have a similar compelling urgency: the human population is putting increasing pressures on the health and productivity of lands, waters, air, and resources, jeopardizing the ability to reach that goal (Silver and DeFries 1990). Ecosystem management and sustainable development are proposed as a prudent path to pursue. Both are already more than dreams; to some extent they are in practice or are being seriously tested. But they are also rapidly evolving. The purpose of this paper is to describe some principles and practices that we believe are crucial to the success of an ecosystem approach to land and resource stewardship that aims to sustain desired conditions of environmental quality as well as development of human communities and economies.

DEFINING ECOSYSTEMS

The ecosystem concept is central to the new era in land stewardship and resource conservation. Ecosystems are communities of organisms working together with their environments as integrated units (after Tansley 1935). They can occur from microscopic scales to the scale of the whole biosphere. For any plant or animal, including humans, an ecosystem is its home (Sahtouris 1989, Berry 1987, Rowe 1990).

All resources for life come from an ecosystem and all waste products eventually return to an ecosystem for recycling or storage. A rotting log is the ecosystem for a fungus. A pond is the ecosystem for a sunfish. A watershed is the seasonal ecosystem for a migratory ungulate. A whole mountain range is the ecosystem for a population of wolves. And the planet is now the ecosystem for the human population. In all cases, the organisms are integral parts of a complex of other organisms working together with their physical environments as a whole. The parts could not persist without the whole and its myriad of processes.

An ecosystem perspective on land and resource management means thinking about land—its soils, waters, air, plants, animals, and all their relationships—as whole units that occur in a hierarchy of nested places. The places—or ecosystems—are open to a constant flow of materials and energy in and out. They are constantly changing over time and much of the change is not precisely predictable by science (Botkin 1991). People are integral parts of ecosystems; both dependent on their resources and factors in affecting some of their changes.

Defining Ecosystem Management

Ecosystem management is variously defined by those who are shaping its course. Beginning with a standard dictionary definition, management is the process of taking skillful actions to produce desired outcomes. Combining this with the term ecosystem, ecosystem management is the process of seeking to produce (i.e., restore, sustain, or enhance) desired conditions, uses, and values of complex communities of organisms that work together with their environments as integrated units. This

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