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COURSE 1: RESEARCH DESIGN IN ECOLOGY

An Introduction to Ecological Monitoring with Case Studies

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An Introduction to Ecological Monitoring with Three Case Studies

Introduction

The term "ecology" was defined in 1870 by German zoologist Ernst Haeckel as being inclusive of that body of knowledge relating "to the economy of nature- the investigation of the total relations of the animal both to its inorganic and its organic environment" (Brewer 1994, p. 1). Haeckel also notes that ecology represents the study of all of the complex interrelations of nature as identified and published by Darwin (Brewer 1994). Along this same vein of thought, John Muir (1911, p. 157) observes, "When we try to pick out anything by itself, we find it hitched to everything else in the universe."

Yet the idea of ecology as a distinct science didn't gain a strong foothold in American consciousness until the 1960's and 1970's (Brewer 1994). It was during this era that national and international issues relating to pollution, resource consumption, and population growth were recognized as being ecological rather than merely economic in nature (Odum 1953, Carson 1962, Brewer 1994). Hardin (1998) notes in his Extension of "The Tragedy of the Commons" that we are seriously exceeding the capacity of our natural ecosystems; with a corresponding loss of human freedom and dignity. As increasing demands are being placed upon natural and managed ecosystems around the globe, the need for identification, management, and long-term maintenance of ecological processes becomes ever more imperative.

General Analysis

A wide variety of monitoring and assessment methods have been developed for identifying and quantifying ecological impacts at different spatial scales. Ecological or environmental monitoring efforts may range from annual collection and cataloguing of baseline data for land-use planning (Willard 1974, Cooperrider 1986, Jones 1986) to detailed university or governmental research utilizing complex models and analytical procedures (Snedecor and Cochran 1980, Krebs 1985, Gauch 1999, Krebs 1999, Manly and others 2002, Wiersma 2004).

The evolving complexity of ecological monitoring methodologies corresponds to the increasing need for scientific data that is both collectible and adaptable at broad geographic scales (Picket and White 1985, Master 1991, McCullough 1996, Krebs 1999, Manly and others 2002, Wiersma 2004, Stem and others 2005). However, the complexity of large system or population modeling, monitoring, and associated management paradigms may also lead to a tendency by ecologists or other scientists to discard or ignore smaller pieces of the ecological puzzle (Cross 1986, Kochert 1986, Ohmart and Anderson 1986, Pierson 1998, Opler and Wright 1999).

As Aldo Leopold (1949) reminds us, when we manipulate our environment it is imperative that we retain all of its natural mechanisms. The value of ecological monitoring is that it can be carried out at a variety of spatial scales in order to ascertain the effects of human activities on systems or populations. While ecological monitoring has becoming increasingly necessary at a grand scale, we must also recognize that many ecologically important systems and populations function at very fine or otherwise limited scale (Cooperrider 1986, Jones 1986, Wiersma 2004).

To categorically eliminate small systems from monitoring and management programs can undermine succeeding hierarchies of ecological function. This may in turn lead to the development of inappropriate ecosystem models or to a failure to detect important changes in populations or environmental quality at differing scales (Vaughan and Ormerod 2003). While recognizing the utility of computer modeling and other types of environmental tools for large scale ecological monitoring, Wiersma (2004) strongly reiterates the longstanding value of empirical and site-specific data.

The following case studies illustrate three different methodologies commonly used to carrying out ecological monitoring on public lands in the western United States. These case studies present a summary of results for three original research projects carried out by myself as a graduate student. Projects described below include: 1) a baseline study at a local scale, 2) a vegetation trend study at a local scale, and 3) a wildlife resource selection study at a landscape scale.

Case Study One:

A Baseline Comparison of Wildlife Mortality to Posted Speed Limits

The construction of roads through wildlife habitat may result in significant fragmentation as well as lead to increased disturbance or the direct mortality of wildlife. The effects of road construction and motorized traffic can be examined in order to determine what adverse impacts, if any, can be identified or otherwise quantified in relation to wildlife populations at a variety of spatial scales.

I surveyed two segments of local surface roads across a several month time period in order to determine if speed limits can be shown through a simple baseline study to have a direct impact on the mortality of local wildlife. Both of my surveyed road segments are located in the Snake River Canyon south of Hagerman, Idaho. Wildlife and unrestrained domestic animals are able to utilize both road segments freely if they choose, as the two road segments are closely adjacent to each other.

Thirteen separate mortality surveys were carried out between the months of February and July of 2005. Each surveyed road segment is approximately 1.5 miles long. Each survey visit represents a different calendar week. The two surveyed road segments are separated by a physical distance of approximately.3 miles at the south end of the survey routes. The northernmost ends of the two road segments actually meet at an intersection, forming a rough triangle. Habitats are similar for both road segments and consist of remnant shrub-grass slopes above rural residential properties.

A natural waterway (Salmon Falls Creek) and a number of marshy areas are closely associated with both road segments. The riparian habitat associated with the creek and marshy areas consists largely of Russian olive, willow, and a variety of introduced and native forbs and graminoids. The riparian habitat, accessible to wildlife utilizing either road segment, may necessitate or otherwise encourage frequent crossing of both road segments by avian and other wildlife species.

The posted speed limit for one road segment (Idaho State Highway 30) is 60 mph, while the posted speed limit for the other road segment (River Road is a paved Twin Falls County, Idaho road) is 35 mph. The segment of River Road utilized for my study is quite narrow, with enough sharp turns to prevent motorists from traveling much above the posted 35 mph. Due to several turns associated with the State Highway 30 segment, vehicular traffic on this segment tends to adhere to the 60 mph posted limit. The types of vehicles using these routes are similar for both road segments, ranging from motorcycles and other recreational vehicles to passenger vehicles and large tractor-trailer rigs.

Surveys consisted of slowly driving each of the designated road segments one time between 0600 and 1200 hours (both segments were surveyed on the same day) on a weekly to bi-weekly basis. Utilizing each road segment as the center point of a one-hectare strip, all wildlife and unrestrained domestic animals observed within approximately 75 meters of either side of each roadway were recorded. Any observed incidences of mortality on the two road segments were also recorded during each survey visit, along with the species if recognizable.

Between February 28 and July 17 of 2005, eight incidents of mortality that appeared to be directly related to motor vehicles were observed for the two selected road segments. Wildlife mortalities observed for the State Highway 30 segment during survey periods included red squirrel (two), Ring-necked Pheasant (two, male and female), porcupine (two), and bushy-tailed woodrat (one). Wildlife mortalities observed for the River Road segment during the same survey periods included American Robin (one).

A total of 131 birds and one unrestrained domestic pet were observed during surveys of the State Highway 30 segment. A total of 622 birds, one mammal, and 12 unrestrained domestic pets were observed during surveys of the River Road segment. Based solely upon the results of this limited study, it would appear that the higher speed limits set for the surveyed segment of Highway 30 may have a slightly greater impact on local wildlife populations when compared with the speed limit set for the surveyed segment of River Road.

The higher numbers of wildlife associating with the River Road segment also indicates that disturbance, noise, or other factors may be affecting wildlife distribution in relation to the Highway 30 road segments. Further field investigations could be carried out in order to examine other issues relating to habitat fragmentation or wildlife behavior associated with rural roads. Observer detection and carcass removal bias trials could also be carried out to determine of mortalities were under-reported or if annual or other mortality estimates could be made from the my study data.

Case Study Two:

A Vegetation Study to Establish Trend for Noxious and Exotic Weeds

Grazing by domestic livestock has an inherent capacity to permanently impair natural landscapes. Soil compaction, accelerated erosion, exotic or noxious weed invasion, degradation of wildlife habitat, and a host of other adverse impacts can occur if livestock grazing is not managed properly (Bell 1973, Ohmart and Anderson 1986, Chaney and others 1991, Leonard and others 1997, Donahue 1999, Winward 2000).

Some of the most readily quantifiable results of livestock grazing are shifts in plant community composition. The pressure of herbivory, as represented by domestic livestock grazing, can result in the reduction or loss of some desirable forage plants and the increase of undesirable or unpalatable plants such as exotic or noxious weeds.

Vegetation monitoring studies can be carried out in rangeland settings to help determine if undesirable plant community shifts are occurring (BLM 1999a, BLM 1999b).

A common monitoring practice used to determine shifts or trends in vegetation composition over time are nested frequency studies. Nested frequency is a measure used to collect data reflecting the frequency of occurrence of selected plant species within a particular community (BLM 1999a). Nested frequency surveys may consist of reading values for nested quadrats arranged along a transect line. This type of monitoring can be repeated in subsequent seasons in order to establish plant community trends over time. Following a minimum of 2 years of data collection, nested frequency plot results can be analyzed through the use of Chi-square contingency tables in order to detect plant community trends.

I have carried out a series of nested frequency transect measures at selected locations within the Pleasantview Hills (a small mountain range located west of Malad, Idaho) during the summer months of 2004 and 2005. Certain introduced and noxious plant species were selected for frequency monitoring in order to detect increases or decreases in noxious weeds, unpalatable species, and/or species that increase under heavy grazing pressure or that are known to readily colonize heavily disturbed sites.

One of my survey locations is identified as Sheep Creek nested frequency transect NF-2. Sheep Creek drainage is part of the Pleasantview Hills BLM Grazing Allotment and is within an area referred to by the Bureau of Land Management as the Sheep Creek Riparian Pasture. The NF-2 transect represents a mesic grassland adjacent to an intermittent creek. The nested frequency transect parallels the west side of the creek, and is located approximately 15 meters away from the creek bank.

Sheep Creek nested frequency transect NF-2 consists of square meter plots separated by >10 cm. For this survey effort, my transect line consists of 20 plots. I have utilized .01, .1, and 1 meter quadrats as is commonly used by The Nature Conservancy, comprising a total of 60 quadrats per transect. Plants of monitoring interest have been identified by genus below. Specific species are noted only if more than one species within the same genus has been observed in the Sheep Creek watershed.

2004 frequency detections for Transect NF-2 include results as follows: *Cardaria (0), Chorispora (80%), Centaurea (0), Cirsium (0), Cynoglossum (5%), Descurania (5%), Hyoscyamus (0%), Isatis (0), Lactuca (35%), Malva neglecta (10%), Sisymbrium (10%), Taraxacum (70%),* and *Thlaspi (10%). Chorispora* was detected at the following quadrat frequencies: .01m^2 (20%), .1m^2 (20%), and 1m^2 (40%). *Cynoglossum* was detected at the following quadrat frequencies: .01m^2 (0%), .1m^2 (0%), and 1m^2 (5%). *Descurania* was detected at the following quadrat frequencies: .01m^2 (0%), .1m^2 (0%), and 1m^2 (5%). *Lactuca* was detected at the following quadrat frequencies: .01m^2 (0%), .1m^2 (5%), and 1m^2 (30%). *Malva neglecta* was detected at the following quadrat frequencies: .01m^2 (0%), .1m^2 (0%), and 1m^2 (10%). *Sisymbrium* was detected at the following quadrat frequencies: .01m^2 (0%), .1m^2 (5%), and 1m^2 (5%). *Taraxacum* was detected at the following quadrat frequencies: .01m^2 (10%), .1m^2 (20%), and 1m^2 (40%).

2005 frequency detections for Transect NF-2 include results as follows: *Cardaria (0), Chorispora (0%), Centaurea (0), Cirsium (0), Cynoglossum (50%), Descurania (0%), Hyoscyamus (0%), Isatis (0), Lactuca (100%), Malva neglecta (35%), Sisymbrium (5%), Taraxacum (85%),* and *Thlaspi (20%). Cynoglossum* was detected at the following quadrat frequencies: .01m^2 (0%), .1m^2 (10%), and 1m^2 (40%). *Lactuca* was detected at the following quadrat frequencies: .01m^2 (35%), .1m^2 (50%), and 1m^2 (15%). *Malva neglecta* was detected at the following quadrat frequencies: .01m^2 (15%), .1m^2 (0%), and 1m^2 (20%). *Sisymbrium* was detected at the following quadrat frequencies: .01m^2 (0%), .1m^2 (5%), and 1m^2 (5%). *Taraxacum* was detected at the following quadrat frequencies: .01m^2 (5%), .1m^2 (10%), and 1m^2 (70%).

Application of these two years of plant community data to Chi square analysis of frequency reveals that some plant species populations have statistically increased, some have statistically decreased, and some have remained essentially the same. *Chorispora* decreased (2005 observed frequency = 0, expected frequency = 40, and $p<0.001$). *Cynoglossum* increased (2005 observed frequency = 50, expected frequency = 27.5, $p<0.001$). *Descurania* decreased (2005 observed frequency = 0, expected frequency = 2.5, $p<0.05$), *Lactuca* increased (2005 observed frequency = 100, expected frequency = 67.5, $p<0.001$), *Malva neglecta* increased (2005 observed frequency = 35, expected frequency = 22.5, $p<0.001$), *Sisymbrium* decreased slightly but remains statistically similar(2005 observed frequency = 5, expected frequency = 7.5, $p>0.05$), *Taraxacum* increased slightly but remains statistically similar (2005 observed frequency = 85, expected frequency = 77.5, $p>0.05$), *Thlaspi* increased slightly but remains statistically similar (2005 observed frequency = 20, expected frequency = 15, $p>0.05$).

A comparison of the above data for introduced noxious or introduced species shows that populations of annual weed species decreased, while populations of biennial and/or perennial weed species increased. The presence of fewer annual weed species that require disturbance or bare ground in order to perpetuate populations (Larcher 1995; Whitson and others 2004; Belsky and Gelbard 2000) and an increase in perennial weed species indicates that lower levels of disturbance related to livestock grazing or other human activities within the transect area may be responsible for a desirable shift in plant community composition. Over time, continued lower levels of human disturbance may facilitate the re-establishment of desired native forbs and grasses.

Case Study Three:

Resource Selection Study to Determine if Distance to Water is Significant

A number of western U.S. bat studies have found that roost site selection by bats appears to be significant for distance to water, while other studies have found that distance to water does not appear to be significant for roost site selection. While it is known that some bats (e.g. *Corynorhinus townsendii*) may forage up to 40 miles from a known water source, many western North American species are found in relatively close association with open surface water or riparian vegetation (Barbour and Davis 1969; Navo and others 1992; Ormsbee and McComb 1998; Bradley 1999, personal communications, unreferenced; Harvey and others 1999; Taylor 1999; Bohn 1999; Waldien and others 2000; Johnston 2004; RWR 2004).

As Hayes (2003, in press) notes, attempts to determine whether or not bats select roosts closer to water than for expected frequencies may be “equivocal.” It would not be unlikely to expect that western North American bat species reliant on aquatic or riparian foraging strategies would be found roosting closer to water sources, while other species of western bats reliant on arid upland vegetation types for foraging (e.g. pinyon-juniper, sagebrush steppe, salt desert scrub) might be found roosting at greater distances from water simply because water is less available across the landscape (Barbour and Davis 1969; Nowak 1994; Harvey and others 1999).

Between the years of 1998 and 2004 I carried out a bat resource selection study in southeastern Idaho for Idaho Department of Fish and Game. The proximity of bat roosting sites to known water resources was one of the parameters I considered when evaluating bat roost site use within my research study area. I recorded distance to a known water source (based upon observation of a natural water sources or bat-accessible waters such as livestock tanks) for each of 200 potential roosts identified during random sampling efforts. Signs of bat use were detected at 50 of these potential roost sites.

Comparison of frequency of distance to a known water source from identified bat roosts was accomplished using chi-square analysis (Krebs 1999; Bluman 2001; Manley and others 2002). The null hypothesis can be expressed as follows:

> Distance to water is random and bats select roosts without regard to distance to water.

In order to meet assumptions of expected frequency values for chi-square analysis (Bluman 2001), all samples two miles or greater from water needed to be combined Expected frequencies for analysis were developed assuming all searches had equal opportunity of detecting bat use ($F_{category}$ = # of searches in category · # positive searches/ # total searches). Chi-square analysis of the observed and expected frequencies for distance to water is expressed by the following formula: $X^2 = \sum (f-F)^2 / F = 3.044$. The value of X^2 is less than the $P<0.005$ critical value of 4.605 (df = 2). Therefore, the null hypothesis that bats are selecting roosts randomly in relation to distance to water must be accepted for this particular sampling effort. Bats within the study area appeared to be selecting roosts without regard to distance to water.

As has been noted by Hayes (2003, in press), my findings may not necessarily apply to all bat roosting localities. As all potential roosting sites within my particular survey area were physically located within 5 miles of a known water source, I was unable to determine whether or not any particular species might prefer to roost more closely to a water source than another species. Similar sampling efforts carried out in habitats where water resources are more widely dispersed might result in different findings as has been reported by other western bat studies.

Discussion

Jones (1986 p.9) defines a successful monitoring study as one that involves "careful planning, precise problem and objective identification, and complete compilation of results." Jones (1986) also describes a successful inventory or monitoring process as consisting of six distinct categories: 1) problem definition or scoping; 2) data collection; 3) data analysis, interpretation, evaluation, presentation, and storage; 4) management decisions; 5) monitoring studies to determine the effectiveness of the management decision; and 6) management review.

Problem definition or scoping remains will always constitute the most critical component of any ecological monitoring effort (Jones 1986, Wiersma 2004). Jones (1986 p.1) also notes that the crucial elements of problem definition involve identification of concerns, reduction of problem(s) from the general to the specific, identification or prediction of potential impacts, definition and prioritization of objectives, and deciding what type and level of data collection is needed. In keeping with Jones, Willard (1974 p.9) notes that the objectives upon which any ecological study are centered "should be clearly and precisely stated." Willard (1974) also reiterates the practical importance of matching monitoring studies to available labor and funding resources in order to ensure timely completion of monitoring studies.

The three types of ecological monitoring introduced in the case studies above (baseline, trend, and resource selection) can all be employed at a variety of spatial scales depending on resource management needs. Information that is site-specific, such as the baseline road mortality or vegetation trend study, may be most helpful for delineating the needs of endemic populations or for monitoring the impacts of local management. Ecological information gathered at larger geographic scales, such as the resource selection study that involved multiple mountain ranges, can be used for more general conservation efforts, for natural resource planning, and for wide-scale management decisions. Each of the three types of ecological monitoring introduced in my case studies above is discussed in further detail below.

Baseline Studies

Jones (1986 p. 2) notes:

> Baseline data for land-use planning are the driving force of wildlife inventories because they show conditions as they currently exist. Baseline

data are useful in determining potential impacts and in comparing actual impacts after development.

Several published studies have examined potential impacts from road construction on wildlife populations (St. Clair 2003, Hawbaker and Radeloff 2004, Jager and Fahrig 2004, Laurance and others 2004, Steen and Gibbs 2004). While the results of my baseline study indicate that posted speed limits may reduce wildlife mortality, the sheer volume of wildlife observed for the road segment with the lower posted speed limit indicates that there may be other factors involved with the mortality levels beyond speed limit alone.

Factors associated with the road segments such as carcass removal rates (e.g. by road crews or natural scavengers), overall habitat fragmentation, adjacent land use practices (e.g. agricultural fields or landscaped yards), proximity to water sources, proximity to and types of available cover may all be influencing the density and composition of wildlife associated with the two road segments. As Jones (1986) notes, baseline data shows what is currently occurring.

Baseline data can serve as an excellent starting point for making initial determinations upon which to base resource management actions. Resource decisions can then be followed up with monitoring studies to gauge management success or failure. . For example, surveys carried out following a temporary lowering of the speed limit for the case study road segment posted at 60mph might determine that the speed and/or noise of the vehicles may be significant factors.

Additional surveys of the two road segments described in the case study above might also be carried out on a daily or hourly basis in order to help determine carcass removal rates and other pertinent factors relating to observed mortality. The mapping of vegetation or water courses may also reveal useful information. In other words, a baseline study serves as a springboard for additional or more detailed efforts that can be designed to answer specific questions as they are brought to light.

Trend Studies

Trend has received a lot of management attention in relation to rangeland ecology and the determination of rangeland health or condition. The monitoring of vegetation or other ecological parameters over time can assist in determining whether or not a selected site exhibits an upward, static, or downward trend in relation to management practices (BLM 1998; BLM 1999a, 1999b; Winward 2000; BLM 2003; Stem and others 2005). Procedures for determining trend for land management purposes may range from the comparison of photo plots to statistical analysis of transect data (BLM 1998; BLM 1999a, 1999b; BLM 2003).

As was mentioned above, nested frequency is a common method for determining changes in plant community composition. Frequency sampling is highly objective, repeatable, and represents a relatively reliable and rapid survey method (BLM 1999a). The nested frequency method is suitable for use in a variety of habitat types (e.g. upland, riparian). This monitoring method is most effective when the frequency of species of interest occurs between 10 and 90 percent.

Upon determining that a change in plant community trend (up or down) is significant, changes in livestock management can be made in order to reverse a negative trend or to maintain a positive trend. For example, a change from season-long grazing to a rest-rotation system may result in an observed downward trend for certain noxious weed species and an increase in desirable forage species based on repeated nested frequency measures. Continued nested frequency measures will show whether or not this is directly and positively correlated with the change in livestock management. In this hypothetical case, the frequency measures may show that a change in management was successful in reducing noxious weed populations and increasing desirable forage species.

Many other important types of trend studies are being carried out in western North America at a variety of spatial scales and complexity. Widespread studies may be as simple in methodology as the Cornell Laboratory of Ornithology's Project Feederwatch, the weekly counting of birds visiting backyard bird feeders by thousands of volunteers. This survey project helps to determine regional and national trends for a wide variety of bird species (PFW 2005).

While obviously not suitable for making local land management decisions, such information becomes extremely valuable for tracking changes in regional and national bird movements. The ability to track irregular irruptions and similar avian phenomena has been greatly enhanced by this type of wide-scale yet relatively simple monitoring (PFW 2005). Other types of studies, such as studies to determine if a particular species of wildlife is declining in population, require multiple years of monitoring efforts in order to determine a statistical trend (Willard 1974, Krebs 1999, Manly and others 2002, Waits 2005). Nur and others (1999) recommend a minimum of five years of point counts or similar survey methods to determine trend for avian populations.

Resource Selection Studies

The distribution of seeps, springs, streams, and livestock watering facilities within the southeast Idaho region utilized for my bat roosting studies made it impossible for any of my surveyed habitats to be more than five miles from a known surface water source. It may well be, as the data from other western bat studies have shown (Hayes 2003, in press), that distance to water is not significant for many species of bats. Distance from water may be dictated for many species of bats simply by the physical availability of water resources rather than by demonstrable species preference.

In addition to the use of frequency (chi square analysis) distribution to determine significance of apparent resource selection by wildlife, a wide variety of other resource selection study methods have also been developed (Krebs 1999; Manly and others 2002). Methods available to wildlife researchers vary from mark-recapture techniques for estimating abundance to spatial patterns, indices of abundance or diversity, and estimates of community parameters (Krebs 1999). Additional survey and monitoring programs have also been developed to measure niche or resource preferences (Krebs 1999; Manly and others 2002).

Many new programs have been developed that allow researchers to run complex statistical procedures on computers. Some programs allow researchers to calculate population values such as dispersal rates or immigration rates and to determine the impacts of such movements on genetic diversity (Waits 2005). Other computer programs allow researchers to calculate risks of extinction or tolerance levels for pollutants (Gauch 1999, Krebs1999, Manly and others 2002, Wiersma 2004). The value of such programs at multiple spatial scales is high. For example, by calculating potential extinction scenarios researchers can assist natural resource managers to select management alternatives that will provide the best safeguards against extinction of an at-risk species at one or more spatial scales.

Recommendations

In designing and implementing ecological monitoring, it is imperative that any study or survey be relevant to the question or problem being addressed. According to Jones (1986) the most common point of failure for inventory and monitoring efforts is failure to adequately define the initial question or project purpose. Without an adequate definition of what needs to be addressed, inappropriate assessment methods may be selected. Problems in methodologies may then be compounded through selection of inappropriate statistical and other analytical processes (Jones 1986; Nur and others 1999; Manly and others 2002, Wiersma 2004).

The interest of science is not furthered if data is gathered incorrectly or otherwise applied to an inappropriate statistical format (Willard 1974, Jones 1986, Manly and others 2002). According to Magnusson and Moura□ o (2004), natural resource studies should not always attempt to utilize statistical programs. Magnusson and Moura□ o (2004) note that many kinds of research, particularly those being carried out for public educational or administration purposes, can benefit from a simple descriptive format rather than utilizing obscure mathematical terminology or attempting to force data into what may be incompatible computer models.

Another problem that may be encountered by researchers is whether or not to eliminate data that does not appear to fit expected norms or that might not approximate the results of other published studies. Rather than taking an original research direction, scientists may feel it is necessary to “pare down” original study results or to throw out important information in an attempt to make collected data fit theoretical models or current (e.g. published) schools of thought. Incorrect application of statistical analysis or a failure to recognize unique information may be watered-down science or incorrect assumptions that cannot adequately serve our local or global natural resource conservation and management needs.

Conclusion

The need for ecosystem monitoring will continue to increase as the human ability to alter landscapes and environmental conditions expands worldwide. Along with our ability to monitor and assess human impacts on the natural world from landscape to global scales, we must also remain willing to employ site-specific monitoring at the local level when and where appropriate. As new analytical procedures are developed and as our understanding of the intricacies of natural ecosystems increases we will be better prepared as a local, national, and international community to address the needs of wildlife and our other natural resources.

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