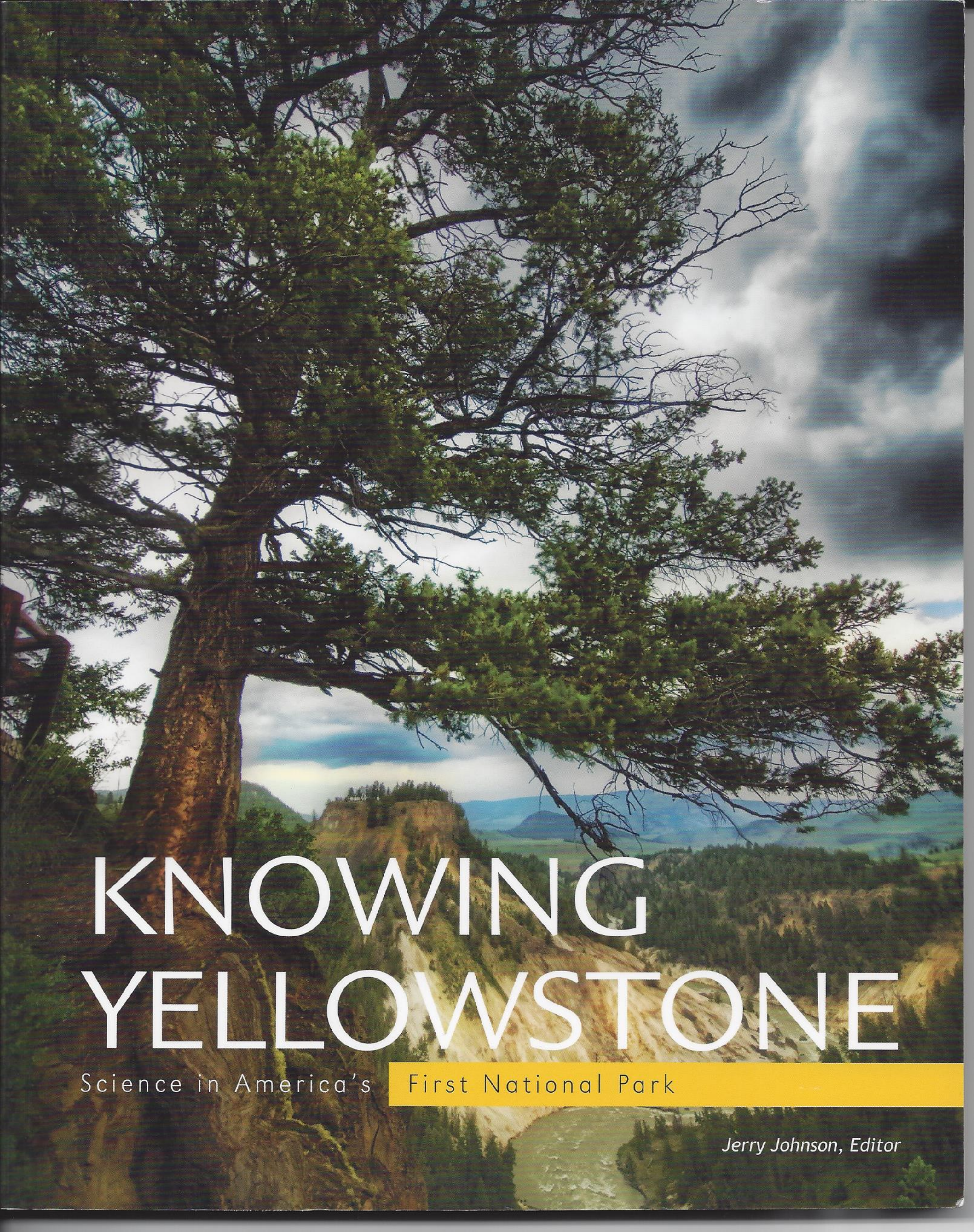

KNOWING YELLOWSTONE

Science in America's First National Park

Jerry Johnson, Editor

Chapter 1

Thinking Big About the Greater Yellowstone

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"How does it look, Jerry?" Jerry Johnson had just side slipped out of sight down the summit snowfield checking out the route for our descent. Bruce Maxwell and I were finishing lunch on the top of Hummingbird Peak in the Lee Metcalf Wilderness on the northwest side of the Greater Yellowstone Ecosystem.

The July morning air was crystal clear. The view was dominated by the steep, snow-covered Spanish Peaks and the long runs of conifer forests spilling off their sides. We had seen elk, moose, mule deer, black bear, and possibly a grizzly bear on the drive through a large private ranch into the trailhead. Like most places in Greater Yellowstone, this place is big and wild.

To the north, we could see farms, rural homes, and subdivisions dispersed among the cottonwood trees on the Gallatin River floodplain. The fertile soils of the Gallatin Valley attracted a few hearty farmers in the late 1800s and the valley's population remained small until a wave of immigration started about forty years ago. Many of those newcomers wanted to live "out of town". We could see their rural homes and ranchettes sharply delineating the boundary of the Gallatin National Forest.

Among the tall mountains to the south stood Lone Peak. In the 1970s, Chet Huntley, the famous retired newscaster, built a ski area in this high rocky country. In recent years, the real estate market has flourished around the Big Sky Ski Resort. We could see the Rocky Mountain version of mansions perched on the steep forested slopes of the mountain.

"Bruce, most of the houses we see were not here when you were a kid in Bozeman. How do you think they influence the wildlife and ecosystems in Yellowstone National Park and the surrounding wilderness?" This was the question that many scientists were asking as more and more people are moving in around the fringes of the Yellowstone wilderness.

"Steep, damn steep!" Jerry's voice punched into our conversation. This got my attention because Jerry is so solid on skis that I never heard him say this before. Bruce jumped to ski the headwall with Jerry. I skirted left to a slope that was just steep. We then did turns down a 457 m vertical drop and then hiked some 16 km to the car.

In a place as large and wild as greater Yellowstone, it might seem silly to ask about the effects of the growing, but still small, human population. Greater Yellowstone is often referred to as the largest "intact" ecosystem in the coterminous United States. Yellowstone National Park, at 8,987 km^2 is the largest national park in the lower 48 states. As large as YNP is, however, it represents less than 10 % of the Greater Yellowstone Ecosystem, the larger surrounding ecosystem that YNP and Grand Teton National Parks are dependent upon.

Here is what "big" means. Within the GYE is Yellowstone Lake, the largest lake above 2438 m in the lower 48, the Beartooth Plateau, the largest area above 3048 m in the lower 48, and Two Oceans Pass, close to the place that is the most distant from a road (ca 53 km) in the lower 48. Greater Yellowstone is about 482 km north to south and 450 km east to west. According to MapQuest, the time to drive around the 1320 km perimeter of the GYE is more than 17 hours.

Currently, around 425,000 people live in the GYE. Because of the large size of the system, the population density is only 2.93 people/km^2, very low compared to most places in the lower 48 states. The U.S density is almost 30 people/km^2. Sixty eight percent of the ecosystem is publically owned; residents live mostly in the perimeter ring of the system, leaving the vast interior as a wilderness with more grizzly bear, wolves, and elk than humans.

The current low density of people, however, is twice the density as it was in 1970. Lewis and Clark were the first EuroAmericans in the area in 1806. Blackfeet, Crow, and other Native American tribes continued to control portions of the area until the mid 1870s, soon after YNP was established. Euro-America population growth over the next century was relatively slow due to the area's harsh climate, limited agricultural opportunities, and distance from major cities. The same factors that dissuaded population growth prior to 1970, however, now act as attractants to the region. As part of the environmental movement, many people left the cities looking for places with wilderness, scenery, outdoor recreation, and other "natural amenities". The Internet and increased wealth allowed many people and businesses to relocate to what they considered to be very desirable places. Thus, there has been a wave of rural home construction around the perimeter of the public lands of the GYE. These trends have led many scientists and conservationists to ask if and how rural homes at the edge of the wildlands might influence wildlife and ecosystem processes in Yellowstone and Grand Teton National Parks.

How would you answer this question? In a place so big and wild, how would one assess the effects of homes sprinkled along the vast perimeter of the Yellowstone wildlands? This is a question I have been working on over the past 15 years. In this chapter, I will share the variety of methods that my colleagues my students helped me develop to investigate large-scale ecological impacts in and near protected areas. Some of them are based on high technology but as we shall see, getting to know the backcountry with other scientists from an array of disciplines and mobilizing large field crews is one of the key methods.

Overview of Methods

In a large wild system like Greater Yellowstone, a first task is to quantify where wildlife and rural homes are located across the landscape. With this information, specific places can be used to study how various types and densities of rural home development influences wildlife. Finally, these effects can be summarized across Greater Yellowstone to draw conclusions for conservation. Some of the data needed for this mapping are easier to obtain than others. Satellite data can be used to map land cover and use (e.g., agriculture, cities, vegetation type) over large areas and such land cover products are now available for free download from the internet; these data are readily incorporated into GIS software (see sidebar). Rural homes are too small to be detected with the satellite sensors regularly used but homes can be seen on aerial photographs and mapped accordingly. However, hundreds of photos would be needed to cover the GYE and this method is prohibitively expensive. County governments record permits for the water wells that are typically drilled at rural home sites and attach geocodes (latitude/longitude) to the well location. They also record individual land tracts for tax assessment. By going to the 20 counties of Greater Yellowstone, one can obtain these data and map the density of rural homes. Data on wildlife typically must be collected in the field. The methods can be very time consuming and thus relatively few species are well studied. Moreover, wildlife abundance, birth, and death vary across landscapes, so studies must be done in many landscape settings. The effects of rural homes on wildlife vary with home type, home density, and location. Putting all these data layers and interactions together to answer what might seem a simple question is challenging.

Studying Spatial Patterns of Biodiversity

A place like Greater Yellowstone supports many, many species of plants and animals. Which species should be included in studies of rural home effects? We use the term 'biodiversity' to refer to the full range of life in an area. This term is typically defined as, the variety of all forms of life, from genes to species, through to the broad scale of ecosystems. Most people think of grizzly bear, elk, or bison as emblematic of Yellowstone. As interesting as these animals are, every species tends to use the environment is different ways and at different scales. Thus, the response of one species to a given type of land use may be very different than that of other species. Consequently, MSU colleague Jay Rotella and I selected for our initial studies taxonomic groups for which several species could be quantified with one set of relatively cost effective methods. These groups were birds, trees, and shrubs.

Trees and shrubs are stationary and thus are easy to

Geographic Information Systems

Of all the sophisticated analytical techniques employed by the researchers in this book, none compare to the impact of Geographic Information Science (GIS). Every natural and social science benefits from the ability to accurately identify data with a location on earth.

Contemporary digital mapping and analysis is made possible by the deployment of the Global Positioning System (GPS), a worldwide system of 24 satellites and their ground stations. These "man-made stars" use a radio signal and triangulation to calculate positions accurate to a meter in most cases and, in others within centimeters. Once we use GPS to know where we are, we can use GIS software to reference data to the known point; those data can be used for analysis between and among points.

GIS technicians generally utilize three methods to analyze data: mapping, relational data analysis, and modeling. All three methods can be combined in order to understand immensely complex systems like Yellowstone. Here are some examples.

Maps can be constructed from data if it is anchored with a spatial reference. Ecologists frequently use radio collars on animals and use GPS to track them across the landscape. GIS mapping allows them to view animal habits in the context of land cover and elevation as well as the proximity to food or human infrastructure (i.e. roads). By viewing animal habits geographically ecologists gain new insights into behavior.

Many ecological processes (land cover, fires, habitat) are related to geography. Discovering patterns in relationships is known as relational data analysis. Soils, precipitation, and land cover are clearly related and produce known ecological landscapes; the resulting landscape mosaic will help determine the suite of animals attracted to the area and thus, we can build a multilayered representation of an ecosystem. Changes to the mosaic due to, for example, wildfire, may give researchers insights into how ecosystem processes will change. Other layers can be added that represents human caused changes to the landscape such as roads, development, or human activities. In this example, GIS technology could be used to discover how roads or development might impact wildfire behavior and how that might change habitat for particular species.

Models can be constructed from the data to, in effect, create new data. If the data stored in the computer is robust enough, researchers can use the software to imagine a different reality - one where the rate of change is slowed or accelerated, for example. Modelers can then make forecasts about plant or animal populations or how various management scenarios might change the future of the resource.

tally with forest surveys. Many species of birds set up small territories during the breeding season and sing to defend the territories from individuals. Thus, their abundances can be easily surveyed by visiting a location and recording all species seen or heard for a fixed period of time. Through such methods, the abundances of many species can be quantified. Because each species makes a living in a slightly different way, such studies can reveal the variety of ways that land use may influence species and communities.

While abundance of bird, tree, and shrub species are rather easily sampled, estimating population growth or decline requires knowledge of birth rates, death rates, and movement. These are difficult to near impossible to measure for multiple species. We focused on birth rates for several bird species and made assumptions about death rates and movements based on studies in other locations. Measuring reproductive rates on birds requires finding their nests and recording the number of eggs or hatchlings. One returns to each nest every few days until the young die or fledge from the nest. Finding these nests in dense forests takes a special knack and lots of patience. Returning to all nests every few days must be done carefully so as not to attract predators.

Because monitoring wildlife populations is so challenging, the traditional approach is to collect data in several locations and assume that these samples were representative of all places across the landscape. However, ecologists have increasingly learned that populations sometimes vary across landscapes based on habitat quality, food availability, climate, predators, and other factors. This is especially true for places like Greater Yellowstone that have pronounced gradients in elevation, climate, soils, and other factors. Given that it is not feasible to measure every place in the ecosystem, how can we characterize these "spatially explicit" population dynamics?

We attempt to deal with this complexity by quantifying "patterns of association" between wildlife populations and environmental features that influence population dynamics such as proximity to water, road density, rainfall, and slope aspect and angle. Some of these environmental features have been mapped so we use statistical approaches to predict species abundance or reproduction for each location across the landscape based on the value of known environmental feature. In this way, what is learned at field sample sites can be "painted" over the full area of GYE based on controlling factors such as climate or plant productivity.

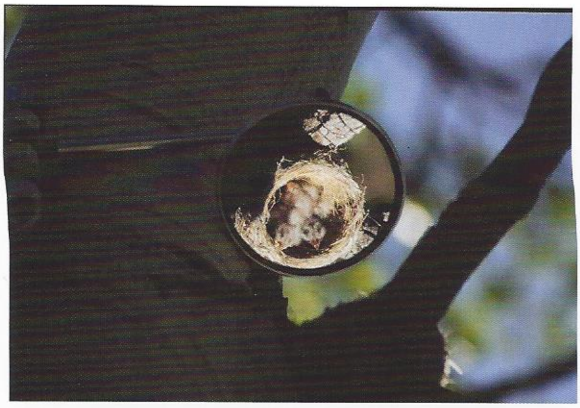
Birds Across Greater Yellowstone

Our first studies in GYE focused on the northwest portion of the ecosystem including the Gallatin, Madison, and Henry's Fork watersheds. This area was chosen because it included the major ecological zones and land use patterns typical of GYE and was of a manageable size for field sampling. Stretching some 200 km north to south, the area was still offered substantial challenges. We hired a crew of 15 technicians and they were housed in three locations across the study area: Bozeman, West Yellowstone, and Island Park.

Many bird species select habitat for breeding based on local vegetation conditions and on availability of foods such as insects, seeds, and fruits. In the Northern Rockies, habitat types, soils and ecosystem productivity are broadly related to elevation. Thus, we choose to stratify sampling for birds among the major habitat types in the area and among three elevation zones.

This resulted in field plots being distributed among riparian forests on fertile soils in valley bottoms, aspen and Douglas-fir forests on moderately productive midslopes, and lodgepole pine forests on infertile soils at higher elevation. Douglas-fir and lodgepole pine forests are subjected to disturbances including logging and

▲ PHOTO 1.1 Once bird nests are located, they are revisited every two to four days to monitor the fates of the eggs and chicks. We try to vary the path to the nest as well as the time so we do not lead predators to the nest location. (Landscape Biodiversity Lab, MSU)



▲ PHOTO 1.2 If a nest is far up in a tree we will employ a mirror or small video camera on the end of an extendable pole. This is the nest of a Yellow Warbler in the Gallatin National Forest. (Landscape Biodiversity Lab, MSU)

fire. Thus we placed samples in forest stands recently disturbed by fire and logging, mid-successional pole stands, and mature and old-growth stands. This complex sampling strategy eventually yielded 99 sample sites.

The field crews were equipped with four wheel drive pick-up trucks, mountain bikes, kayaks, and good hiking boots. Even so, we restricted sample sites to those that were within 3 km of a road to maximize the number of sites the crews could sample.

For the first three years of the study, the crews focused on sampling bird abundances and vegetation. Each morning during the bird breeding season (June-August), the crews would rise at 3 am, drive, bike, and hike to the sample areas by sunrise (ca 5 am) and begin sampling birds. Censusing the birds was the fun part of the study. As morning light begins to brighten the darkness, an explosion of bird song begins. Crew members frantically record all birds species they see or hear for a 10 minute period. It takes special skill to immediately identify the individual songs of the 60 or more species that might be encountered and the crew had spent the month of May training their ears to the birds using digital recordings. After a point count was completed, the recorder would charge 200 m through the forest to the next point and begin another count. This would continue for three or four hours until the "dawn chorus" of bird songs concluded for the day.

After a bit of "lunch" at 9 am or so, the crews shift over to sampling the vegetation at each bird count point. Now the more tedious work would begin. Crews tallied by species and size class all trees, shrubs, and herbaceous plants in one to eight meter radius plots distributed around the bird point count locations. This could involve hundreds to thousands of stems. By days end at 2 pm or so, the crews made the long trek and drive back to the field headquarters. By rights, the crews should have fallen exhausted into their bunks. Being college undergraduates with lots of energy, however, they typically went fishing, climbing, or white-water kayaking until dark.

The last two years of the study focused on estimating bird reproduction. Each crew member had two large tracts of forest where their task was to locate bird nests and monitor the fate of young in the nests. Most of these bird species attempt to avoid nest predation by hiding their nests from the ever-present crows, ravens, magpies, and squirrels that make meals of eggs or nestlings. Finding these heavily camouflaged nests takes great skill and patience. Some days, a crew member would find one nest in a 6-8 hour search. Other days they might find 8 or 10 nests. Once the nests were located, the crews enjoyed returning to them every 2-4 days to record the number of eggs or young remaining. Often, crews had to use mirrors on extendable poles to view inside the nest from below. It was especially fun later in the season to see nestlings make their first flights as they fledged from the nest.

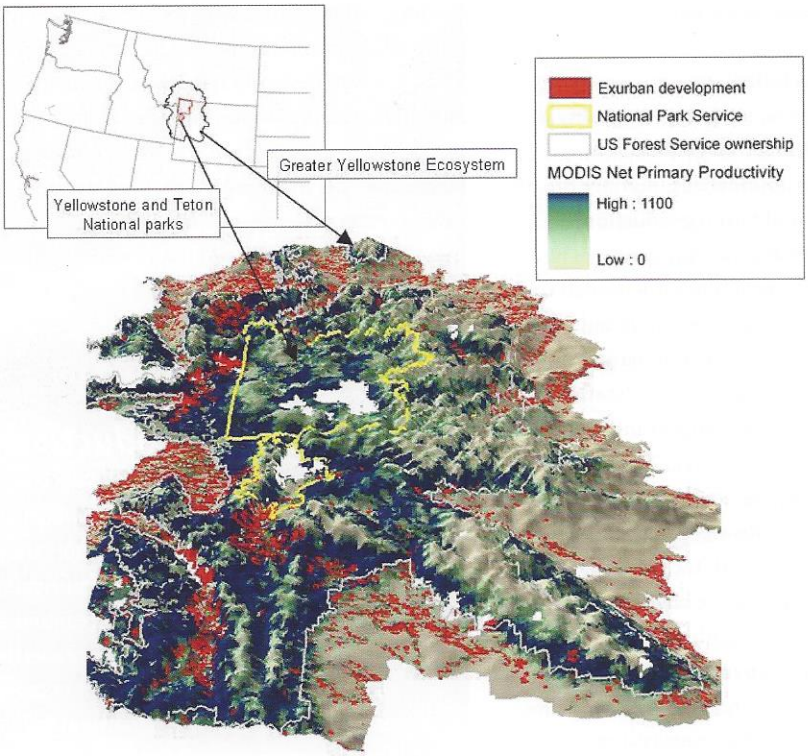
Working in the backcountry of Greater Yellowstone brings a wealth of potential dangers and hazards. One team awoke in their tent in the night to find that three feet of snow had fallen and that avalanches were crashing down the nearby slopes above the tent. Another crew watched a bull bison jump a five strand barbed wire fence when it charged them. Most harrowing was a grizzly bear encounter. The large bear appeared a few meters from a crew at a point count station. One new member of the team panicked and began to run away, a sure way to cause a grizzly to charge. Fortunately, the more seasoned companion grabbed and held him as they both slowly backed away from the bear. The bear followed them keeping within several meters for the terrifying one kilometer march to the truck. Fortunately, none of the crew was injured over the course of the study and a large quantity of data was collected.

After the field season was concluded, the data were entered into computer databases, subjected to quality controls and statistically analyzed. The goal was to summarize patterns of species abundances, number of bird, tree, and shrub species, and bird reproduction among the biophysical settings and habitat types sampled. A variety of statistical techniques are needed to determine how these measures of biodiversity varied with elevation, soils, habitat type, seral stage of habitat, and local "microhabitat" conditions. The resulting "statistical patterns of association" are especially important for studies of large landscapes like ours in GYE. They can be used in reverse to predict biodiversity patterns for places where birds, trees, and shrubs were not sampled. Because we had maps of elevation, habitat type, soils, and seral stages, we were able to predict based on these factors the abundances of species, numbers of species, and bird reproductive rates for all parts of the study area with a known level of confidence.
This set of methods for "painting" biodiversity across the landscape involve high technology tools including remote sensing, computer-based geographic information systems, stratified-random sampling designs, and statistical techniques. However, a key ingredient to producing good results is old-fashioned "knowing the land". Our backcountry forays on skis, mountain bikes, and kayaks are aimed at coming to know how the ecological system and the wildlife species are interrelated and patterned. Being intimate with the ecosystem allows us to select the right study areas and sampling methods to produce results with high levels of confidence.

We learned from this study that wildlife species were by no means evenly distributed over the landscape. Quite to the contrary, most species were concentrated is small areas that we call biodiversity "hotspots". They tended to be in valley bottoms with fertile soils, adequate ground water, warmer summer temperatures, high net primary productivity, and deciduous woodland habitats. These cover only about 3% of the study area. They are mostly outside of Yellowstone National Park and outside the national forest. They are primarily on private land. The explanation is that most of GYE is higher in elevation, has long harsh winters with very short growing seasons, poor volcanic soils, and lower net primary productivity. Thus, the well-developed habitats, warmer temperatures, and more abundant foods favored by many bird, shrub and tree species are scarce over most of the landscape. It is the more mesic - "moderately moist" valley bottoms, largely outside of the public lands, where these conditions occur and many wildlife species are concentrated.

Ecosystem Productivity

Ecosystems are composed of individual plants and animals and the physical factors they require such as soil, water, and nutrients. The collective interactions of organisms and environment result in emergent properties of the ecosystem. One of these is ecosystem productivity. This is a general term for the amount of energy that flows through the ecosystem. Sunlight is converted by primary producers (green plants) to organic molecules in the form of leaves, wood, fruits, seeds, etc. Primary consumers (herbivores) eat these plants and convert the energy to animal protein, which may then be consumed by secondary consumers (predators). Ultimately, dead organic matter is consumed by decomposers. The amount of new biomass fixed by plants per unit time and area is called net primary productivity (NPP). NPP is critical to the birds and mammals that live in the ecosystem because it sets the total amount of food available. Consequently, the number of species in an ecosystem and the abundance of each are often related to NPP. NPP varies across the landscape with climate, soils, and other factors. These spatial patterns of NPP influence the distribution of biodiversity across the landscape.



▲ FIGURE 1.1 The highest biological productivity in the Greater Yellowstone Ecosystem is found along the edges of the forest boundary and the fertile river valleys – places that also attract people. Often, in the case of national parks like Yellowstone, the least fertile ground enjoys the highest levels of protection but they are not the landscapes with the highest species richness. Expansion of land conservation strategies captures larger areas of relatively high productivity in a protected areas system and leads to greater protection of biodiversity. (Landscape Biodiversity Lab, MSU)

Spatial Patterns of Land Use

Land use describes the ways that people live in, travel across, work and play on the landscape. Data on some classes of land use can be drawn from readily available maps of cities, roads, and land allocation boundaries. Other classes of land use, such as location of agricultural fields, must be mapped from satellite imagery, aerial photographs, or other data sources such as US census data. No one had previously mapped the distribution of rural homes across the vast GYE. We had to use innovative methods to generate the first such maps of rural homes.

Andrea Parameter led the first step, which involved mapping as many land use classes as possible from Landsat satellite imagery. These classes included urban areas, irrigated crop lands, dry-land crops, and timber harvest units. We additionally mapped natural vegetation types including grasslands, shrublands, deciduous riparian forests, Douglas-fir forests, and lodgepole pine forests. The Landsat satellite sensor records the reflectivity of light from the land surface in seven wavelengths called spectral bands. A sensor on the satellite records these data at a 30 m spatial resolution; each of the land use and land cover classes reflects these seven bands in different intensities that can be represented as colors in the lab. Only one to four cloud-free images can be obtained per year. Before we can load the satellite data for analysis we frequently need to calibrate the "spectral signature" of each land cover and use class with observed data from aerial photographs. The photographs have a spatial resolution of about 1 m and the land cover and use classes can be identified by eye on the photos. We randomly select on the photos

▲ PHOTO 1.3 Many landscape features such as habitat types and land use patterns can be detected by eye on high resolution aerial photographs. The resulting data can be used to both calibrate use of satellite data for quantifying landscape features over large areas and for determining the accuracy of the satellite-derived maps. (Landscape Biodiversity Lab, MSU)

for the study area some 30-50 locations of each land cover and use class. These samples are collocated on the satellite imagery and the spectral properties of each class are determined with statistical classification techniques. The resulting spectral signatures are then used to classify each pixel of the satellite imagery for the study area into one of our land cover and use classes. This method typically misclassifies some pixels so we assess the accuracy of each mapped class by comparing the known land cover or use class type with an independent set of aerial photo samples and then with cover classes predicted through the satellite data classification.

As mentioned above, rural homes are too small to show up on Landsat imagery. Masters Student, Patty Hernandez Gude contacted each of the 20 counties of GYE and asked them for access to well permit or tax assessor data. Some counties sent digital copies; others invited us to come to their offices and photocopy their paper summaries of these data. A few counties had not compiled their data into data summaries. In these cases, Patty spent many days in the basements of county assessor offices going through individual home records one at a time. After months of work, we had a complete record at a resolution of one square mile of all rural

Confidence Intervals

In ecological studies, it is often not feasible to measure all individuals in a population or all places across an ecosystem. Instead, we strive to collect samples from a population or system and use these samples to estimate an attribute of the populations, such as density of a particular species or number of species in the ecosystem. These estimates usually differ from the true population attribute because the samples are an incomplete representation of the full population. We use statistical approaches to estimate how much our estimate from samples is likely to differ from the true population attribute.

One statistical measure is the confidence interval. A confidence interval is a range of values within which the true population mean occurs with a particular probability. For example, each time we do a bird point count in a particular habitat type, we tally a slightly different number of bird species, generally between about 10 and 20 species in aspen habitat, for example. We do many point counts in each habitat type, generally more than 100, and estimate the average or mean number of species encountered in each sample. This mean for aspen is about 17 species. We then use the variation among samples in the data to estimate a confidence interval for this estimate. We found that the 95% confidence interval for bird species richness in aspen was 15.5 - 19.5 species. This means that there is a 95% probability that the true population mean lies within this interval of species richness. The narrower the confidence interval, the higher our level of certainty that our sample estimates are good descriptors of the overall population.

homes across the ecosystem and the year they were built since 1860. The accuracy of these records was quantified by comparison with aerial photographs.

We found that the dominant change in land use across GYE was from natural and agricultural land uses to urban and exurban development. Developed land increased faster than the rate of population growth - while the GYE experienced an increase in population of 58% from 1970 to 1999, there was a 350% increase in the area of rural lands supporting exurban development. While GYE is thought to be a large wilderness landscape, we found that some 11% of the total land area of the GYE and 43% of the unprotected land area have been converted to urban, exurban, and cropland uses.

The locations of the rural homes were surprising. Yes, fertile valleys like the Gallatin Valley in Montana and the Snake River Plains in Idaho were covered with rural homes, just as Bruce and I had seen from the top of Hummingbird Peak. Unexpectedly, however, homes ringed virtually the entire public land boundary around the entire GYE. Some of these places, such as the Wind River drainage in Wyoming are very remote from cities or airports. Virtually every river or stream draining the Yellowstone Plateau is lined with rural homes. Despite the low density of people in GYE and the immensity of the wildlands, a surprising amount of the lower elevation habitats contain rural homes. Among the aspen and willow on private lands in the GYE, only 51% are free from intense human land use when defined as more than 1.6 km from agriculture, rural homes, or urban areas. Only 11% of streamsides are not near homes, farms, or cities.

These maps revealed that rural homeowners often selected the same habitats as bird species. Bird hotspots and rural homes both are both concentrated in the small percentage of the landscape that is on fertile soils at lower elevations with warmer temperatures and near riparian deciduous forests. Thus, while rural homes cover a relatively small percentage of the lands of Greater Yellowstone, we learned that they are concentrated in the key areas of the landscape that are important for native species.

Effects of Rural Homes on Biodiversity

Ecologists in the western US have long studied the ecological effects of human land uses such as livestock grazing, crop farming, mining, and timber production. The effects of rural homes on ecosystems, however, were virtually unstudied in the Yellowstone area when we began this work in the early 1990's. Perhaps ecologists presumed that the influence of scattered homes across the landscape was small compared to logging, mining, and livestock grazing that can be more conspicuous.

With little local research to draw on, we decided to read all available studies from other places and synthesize their results into a general model of rural home effects on ecosystems. This model included four general ways by which rural homes can influence biodiversity: altering or destroying natural habitats; altering ecological processes such as fire and flooding; favoring some weedy or predatory species that negatively impact other native species; and disturbance or even death of wildlife by pets and homeowners.

The net effect of these four mechanisms is that wildlife communities tend to change in close proximity to rural homes or in areas with increasing housing density. Areas associated with homes have weedy plants like spotted knapweed and dandelions and more midsized predators like crows, jays, skunks, and raccoons. Consequently, native prey species like cup-nesting birds are reduced near rural homes due to the abundance of meso predators. Large predators are also reduced with increasing home density due to displacement by dogs, road kill, and direct human persecution.

This synthesis of previous studies led us to hypothesize that birds nesting in hotspot habitats may have reduced reproduction because of the effects of nearby rural homes. Because the mesopredators like foxes, skunks, and coyotes favor rural homesites, they are also abundant near livestock and crop agriculture. We quantified from our land use data sets the density of rural homes and area of croplands within 6 km of each of our bird study stands. To get data on livestock densities, we identified pastures on aerial photos and then contacted landowners to get estimates of stocking densities in proximity to the bird sampling stands.

Jay Rotella, who led the work on bird reproduction and survival, used statistical techniques called model selection to quantify the relative importance of natural factors such as habitat type and elevation class and, human factors including density of rural homes, livestock density, and area in croplands to bird reproductive success. Such statistical analyses require large sample sizes. Although we had substantial nest success data for 6 or more bird species, we focused the analyses on two species for which we had very large samples - yellow warblers and robins.

Yellow warblers are typical of many bird species in the study area in being highly susceptible to predators and brood parasites. The yellow warbler is a small colorful bird that nests in open, cup-like nests that are generally placed in shrubs 1-2 m above the ground. While yellow warblers are skilled at hiding these nests, predators such as red squirrels, magpies, jays, and ravens often find them. Brown-headed cowbirds also find yellow warbler nests. These cowbirds are "brood parasites", that is, they lay their eggs in the nests of other species and the host parents often raise the large noisy cowbird young at the expense of their own smaller, less aggressive chicks. The American Robin also uses open, cup-like nests. However, unlike the yellow warbler, the robin is tenacious at defending nests from predators and cowbirds. Comparing the yellow warbler and the robin allows us to determine reproductive success for a species vulnerable to the types of changes associated with more intense land use and for a species less susceptible to these human caused effects.

We found that the abundance of cowbirds and nest predators increased significantly with home density. The choice riparian woodlands on the Gallatin Floodplain are loaded with avian predators and cowbirds, partially due to the large number of rural homes and associated activity in the vicinity. Nest success for both yellow warblers and robins is related to elevation class. Lower elevations have warmer climates that allowed for early nesting, longer nesting seasons, higher nest success. For

▲ PHOTO 1.4 Reproduction of many native bird species is reduced by predation. Red squirrels are highly effective at locating nests and eating eggs or young birds. Some predators, like squirrels, are native to the region. Others, such as raccoons, are not and prey on upland game bird, waterfowl and other ground nesting bird eggs and young. (Landscape Biodiversity Lab, MSU)

the Robin (less susceptible to cowbirds and predators), nest success is high enough (60-70%) to offset estimated mortality and thus the population is predicted to be stable or increasing; human habitation measured as home density seems to have no detrimental effect. Nest success for Yellow warblers, in contrast, is only 20-40%, largely due to the effects of cowbirds, who parasitized some 44% of the yellow warbler nests. For these birds, home density is negatively related to yellow warbler nest success. The estimated nest success was too low to offset mortality, thus the population in the sampled habitats was predicted to be declining. Contrasting undisturbed land we identified as hotspots, we can view highly disturbed lands as population sinks.

The last step in this analysis was to use the findings from the sampled stands to project yellow warbler population growth over the entire study area using a spatially explicit simulation model. In the model, yellow warbler abundance varied across the landscape based on habitat type, elevation, soil type, and net primary productivity. Nest success varied based on length of breeding season, habitat type, and density of rural homes. We found that under current conditions population growth was negative at higher elevations such as in YNP due to short breeding seasons and that population growth was negative in low elevation hotspots due to the effects of rural homes. Thus, the models predicted that the entire study area was a population "sink" for yellow warbler and the

▲ PHOTO 1.5 Homes in the rural countryside are spectacular for their scenic location and intimacy to nature. Unfortunately, development of the rural wildland interface can have regrettable consequences. Homes and roads may displace wildlife, be vectors for nonnative species, and add considerable political and economic pressure to natural forest functions such as wildfire. This fire threatened several dozen homes near Bozeman, Montana. (Andy Hansen, MSU)

population cannot support itself without emigrants from other locations.

Finally, we simulated "natural" conditions across the study area by statistically removing the rural home effect. The results predicted that the low elevation hotspots had strong positive population growth and that they offset the negative growth at higher elevations. In total, the results were consistent with the possibility that low elevation habitats, largely on private lands, have traditionally been population source areas that maintained populations at higher elevations, such as in Yellowstone National Park, that are limited by harsher climate and poorer soils. Rural home development on low elevation private lands can favor avian predators and brood parasites, and convert population source areas for species like yellow warblers to population sinks. The lesson is that warbler subpopulations in Yellowstone National Park risk extinction if we lose the low elevation populations that "subsidize" park populations. This is one example of how the seemingly harmless rural homes scattered around the edge of the public lands of GYE may have negative effects on wildlife inside the protected lands.

Strategies for Conservation

Knowing how human land use like rural homes influences biodiversity allow people to develop strategies to minimize negative impacts. Such knowledge can be used to help rural homeowners to live more lightly on the land. We have worked with the Sonoran Institute and other conservation organizations to develop a brochure for homeowners providing guidance on how to manage pets, livestock, weeds, and many other factors to reduce negative ecological impacts. The brochure has been very well received and many homeowners can pride themselves on the ways they have reduced conflicts with wildlife on their lands.

Policy makers and land managers can also benefit from knowing about the complexity of interrelationships between biodiversity and land use. For example, many decision makers would like to know which parcels of private lands have high value for biodiversity and are likely to be developed in the near future. Such lands become high priorities for conservation easements and other incentive-based approaches for protecting private lands of high conservation value.

Patty Hernandez-Gude projected future rural home distribution across the GYE and assessed impacts of various measures of biodiversity. We analyzed the ecological and socioeconomic correlates with past growth in rural home density to parameterize a computer model to predict future growth out to 2020. We also compiled data on some 11 measures of biodiversity relating to habitats of individual species, communities of species (e.g., bird hotspots), and integrated indices of biodiversity that included combinations of individual measures. We overlaid projected home density on the biodiversity maps. This allowed us to determine the parcels of land that are most likely to have rural home construction and that that have the highest value for biodiversity. We provided the resulting maps to land trusts and other groups that are active in working with land owners to develop conservation easements. As a result, some of the most important and vulnerable private lands around GYE are now in a protected status.

Conclusion

After some 15 years of research on rural homes in the GYE, we are beginning to understand where they occur in the landscape, rates of increase, impacts on biodiversity, and ways for home owners and policy makers to minimize negative influences. Although the GYE is very large and mostly wild, we have developed a set of methods that help to understand the complex interactions of people and wildlife in the area. The results of this set of studies of biodiversity and rural homes have provided important information on how to manage GYE to sustain both native species and the human communities in the area.

These methods have also evolved into a more general approach for monitoring and analyzing national parks and their surrounding greater ecosystems that we are now applying across the United States. The approach integrates field data, remote sensing, and simulation modeling to "take the pulse" of the system, analyze trends, and recommend management actions.

Key steps of the approach are as follows:

- Identify the key biotic resources of interest (e.g., native species) and the natural and human factors that influence them;
- Delineate the boundaries of the surrounding greater ecosystem on which the national park is dependent;
- Use remote sensing and other methods to monitor change in the key resources and in the drivers;
- Analyze these data to identify trends past to present, and likely trends into the future that may push the key resources over negative thresholds of change;
- Deliver the resulting data, maps, and knowledge to park managers so that they can include this information when they make decision about park management.

▲ PHOTO 1.6 The most powerful threats to biodiversity in places like the Greater Yellowstone Ecosystem are habitat loss, degradation, and fragmentation. Roads and rural residential development convert natural landscapes to alternative, sometimes damaging, land uses. Careful planning and conservation can mitigate some changes but communities must also cultivate a political will to preserve environmental amenities. (Andy Hansen, MSU)

These methods are among several being used by the new National Park Service Inventory and Monitoring Program. This program is tracking the health of all the national parks and national monuments across the US and providing key information to park managers to keep them ecologically healthy. While Greater Yellowstone is a large, complex system, it is but one piece of a national park structure. The same methods that have helped us understand and manage Greater Yellowstone have promise for working across the entire parks network. Jerry, Bruce, and I have many slopes to ski before we fully understand this complex ecosystem.