Well-behaved Scientists Seldom Make History

Karen Wade

Former Intermountain Region Director, National Park Service

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Karen Wade retired in 2003 as director of the Intermountain Region, National Park Service, and currently resides near Glacier National Park, Montana. Her NPS career began in 1960, as a radio dispatcher at Mesa Verde National Park, and eventually led to assignments as superintendent of Fort McHenry National Monument and Historic Shrine, Guadalupe Mountains National Park, Wrangell-St. Elias National Park and Preserve, and Great Smoky Mountains National Park. Karen currently serves on the board of the Sonoran Institute, and is one of the founders of Earth Care Connection, USA, a mentoring organization for women in conservation. Throughout her career, Karen has emphasized the importance of developing and nurturing professional relationships across the full conservation community, and involving local communities in park management dialogue. She was a member of the team that developed the Natural Resource Challenge for the National Park Service.

Note: The text that follows is an edited transcription of Ms. Wade's remarks at the conference.

Good morning. I haven't been the center of attention for two years! When the planning team asked me to come to speak with you today, I was very, very pleased to have that opportunity. I was pleased to have the opportunity to speak anywhere, to tell you the truth. It's an interesting transition to go from being the center of the vortex to being spun outside the vortex and to spending a whole lot of time with yourself—time that you haven't had for a long time—I think. When Paul [Schullery] called to ask me to speak, I thought maybe the word just hadn't gotten up to Yellowstone yet that I'd retired. It's been a really special treat, too, to sit here and listen to some of my modern-day heroes speak and inspire, do a little bit of coaching and sharing, because basically I think that's what a conference ought to be about: the interchange that occurs between the participants. And I hope you've had as great a time as I've had. I've certainly enjoyed it. It's been something that all of the organizers here can be very proud of. Congratulations.

And I also couldn't help but reflect, as I sat here, about the efforts that you've made during this conference to honor the [U.S.] Forest Service. I started out working on a really tough project, the Appalachian Trail project in the East. Our responsibility was to protect the Appalachian Trail from Maine to Georgia. And if it had not been for my forest service colleagues who worked right alongside me in some of the toughest places in Virginia and Pennsylvania, I would never have been successful in providing the right of way for the trail across some of the really tough valley crossings in Virginia. So I have great experience with forest service colleagues and I think it's wonderful that you've chosen this time to honor some of the leaders of the forest service and have them here. And I know they're engaged every day in work that you do.

I also was struck by the words of [National Elk Refuge Manager] Barry Reiswig, and I love these words: he said there is something special about this place. It's truly magnificent, truly awesome. And that's why I chose, after being a vagabond for 40 years, moving around the country and the world, to make my home in Montana. . . . I'm very, very happy to have found the last best place to settle down. In doing that, I also feel like I have a responsibility, and that responsibility is to continue to assure that it remains the last best place. So it's been my pleasure to engage in Montana and to be a part of trying to find the solutions to many of the opportunities and issues that we have here.

I also wanted to provide you with a little bit of perspective that I gained along the way, particularly in the Great Smoky Mountains National Park. I know this ecosystem is a bit different, but just picture a summer day in 1995, in Great Smoky Mountains National Park. I'm the superintendent, but on this particular day I happen to be with a group of park employees and a number of volunteers from Trout Unlimited. We're in a remote part of the park, doing a very important project of fish restoration. On this particular day we're taking tanks on our backs, hiking

up to the very high waters in one of the valleys there, and catching fingerlings—putting them in the tanks and hauling them to another section of the park. As some of you may know, the brook trout in Great Smoky Mountains National Park are sandwiched at high elevations between the encroaching brown trout and rainbow trout at the lower elevations, and the pollution that's descending from the higher elevations. Their range is beginning to dwindle and decline. So the challenge is to take these fish and begin to put them at locations where they have a chance of populating new streams. Where are those streams? Well, they are streams that in the early 1900s, before the creation of the park, were destroyed—where all life was destroyed by the logging activities that took place there. So the logging had removed all life from these streams, and our job now was to take these little fingerlings, these little brook trout, and put them in those streams and begin to restore brook trout into the Great Smoky Mountains National Park on a level that had never been tried before.

Much of the fisheries work that gets done in the Great Smokies is done by volunteers—by Trout Unlimited. On that particular day we spent a very long, hard day doing this task. And at the very end of it, as we were hiking up the last grade, beside me was this wonderful man who spent the whole day carrying this tank of little fish. I said to him, "You know, you really look exhausted. Why don't you let me carry that tank for just a little bit? Just let me give you a little break, or we can sit down here and rest a little bit." And he looked at me with tears in his eyes, and he said to me, "You know, Karen, I can't rest until this job is done." He said, "My grandfather was a logger here in Great Smoky Mountains, and he was a contributing factor to what happened to the decline of the native brook trout in this area and the decline of this place." And he said, "It's my responsibility today to be a part of this effort and to make sure that these fish get to their new home. It's my responsibility to make sure that these fish are a part of the future of Great Smoky Mountains National Park, and not only that I remember that, but that my children remember that."

So I kind of flashed back on a story that I had used just a few days earlier in a speech. In that speech, I had spent some time talking about Aldo Leopold's clock repair story. Do you all know that story? Leopold wrote that if you're going to take a clock apart, the first rule of intelligent tinkering is to save all the parts. Makes sense, doesn't it? Leopold used his clock repair story, as you probably know, as a way to get others to envision the ecological complexities of the landscapes within which we live. Without understanding, and with[out] all the pieces, we cannot ever expect to fix that which is broken.

As I left our fish restoration project that day, I couldn't help but think what a privilege it was to share time with a citizen who not only understood the task we were involved with, but also the bigger idea. He clearly knew that if we lost the native brook trout in this system, we would have very little chance to fix and to maintain the systems that sustain all life—and quality of life and experience—for humans in that ecosystem. Importantly, he not only appreciated it, but also was willing to devote his time and energy to that project.

We'll fast forward maybe just a year, to another experience in the Smokies that kept my thinking going. I was hiking up Greenbrier in the park not very far from my home, one of the prettiest spots on Earth, I must say, in the spring. Wildflowers all over the place. Just kind of poking along trying to restore my soul and say, "oh yeah, you know, being a superintendent isn't too bad, especially on days when I can get out of that office." And I'm poking along and there's an older gentleman along the trail, kind of sitting there on a log. And I say hi and just pass some pleasantries with him, and then I continue on up the trail a ways and spend probably another hour or so just poking around. And then I come back down and he's still there. And being the service person I am, I thought, well, you know, he doesn't know I have anything to do with the park service, but I really have a responsibility to just check on him and see if he's okay, because he was quite an elderly gentleman.

So I said, "How are you doing; are you enjoying the day? Beautiful, isn't it? You want to walk on back down the trail with me?"

"Oh, no, I got a job to do."

I thought well, gee, that's interesting.

"What kind of a job do you have to do here?" I asked.

"Well, I'll tell you about it because it looks to me like you're mighty interested in these flowers along here."

"Yeah, I am mighty interested in these flowers along here; they sure are beautiful, aren't they?"

"Yeah, they're beautiful, and they're also precious." Well, that's right—I can identify with that. They are precious.

"What do you do?" he said.

"Well, I work for the park, and I think they're precious, too. I really enjoy sharing this day with you

and being up here; isn't this the prettiest spot on the earth?"

He allowed as how it was, and then said, "Well, I want to tell you something. If you work for the park, I want to just share something with you. Now, this is a secret."

"I like secrets, so go ahead—what did you want to tell me about?"

"Well, I've been keeping an eye on a plant here for about 20 years. It's a really special plant. The park doesn't even know it's here; those park people, they don't know very much, you know. But I know it's here. Do you want to see it?"

"I sure would like to see it."

So he moved over a few feet from where he was sitting and kind of brushed the leaves out of the way, and here's this beautiful little wildflower, an anemone of some kind. And he pulled out of his pocket this little packet of papers, and I could see there was writing, little teeny-tiny writing, on these sheets of paper.

And he said, "It bloomed 10 years ago on (this day); first time it bloomed was 10 years ago. The first time, the earliest it bloomed was 10 years ago and on (this day). And last year it bloomed on (this day)." And he went on and showed the annotations that he had made over the course of many, many years about this one plant. "I've done a lot of research on it. It doesn't exist anywhere else in the Great Smokies."

"Well that's very interesting, very fascinating."

That conversation stuck with me. I went back to the office, back to the botanist, and I said, "Tell me about this flower."

"Oh, it doesn't exist in the Smokies."

"Well, let me tell you, I don't know if I can find it again, and it's covered up with leaves, but I know it's here. I know it's here."

So when I was asked to speak at this conference, I reflected on the conference theme, "Greater Yellowstone Public Lands: A Century of Discovery, Hard Lessons, and Bright Prospects," and what that means for science and scientists. I thought of my own involvement, since 1978, as a land manager, and I again thought about the Smokies, and I thought about brook trout restoration, elk reintroduction, all the things we had going on there, and all the things that I've been exposed to in this region that are associated with saving all the parts, and keeping all the pieces. And I thought about citizen stewardship and this man who devoted his life to protecting this flower in Greenbrier. I hope he's still alive—and if he's not, I hope he's passed along his responsibility to somebody else. And I thought about the lasting consequences of some of the things we learn as we go along.

We had an opportunity in the Great Smokies, at one point in time, to take advantage of the fact that we had citizen involvement and commitment and dedication, and we had an ecosystem where the parts and pieces were going to remain parts and pieces until they were lost if we didn't do some major efforts. And so in 1999, we began the first-ever all-taxa biodiversity inventory [ATBI], conducted under a nonprofit we formed called Discover Life in America. Some of you have probably heard of this. The idea—a pretty broad idea—was to inventory all of the more than 100,000 species of life in Great Smoky Mountains National Park. The framework of Discover Life wasn't just the collection of data, which would be done by scientists, our staff, volunteers—whoever we could mobilize to do that under protocols established for the purpose of doing it comprehensively—but also the education associated with what we were learning. That education would be done by instructors that we would bring in, [with] their students. However we could get a curriculum set up and going, we would be doing that. The goal was to excite, engage, and involve everyone possible—anyone who wanted to—in a voyage of discovery. A scientific inquiry with a depth of understanding not previously known about any place on the planet. Think about that. That is a grand adventure, wouldn't you say? A new frontier. Learning things in depth. We've already known the broad picture of things. But how much do we know in depth? And as we inventoried and looked at every single thing we found, we would then begin to study the inner relationships of those things that live in one place on the planet.

To date, because of the all-taxa biodiversity inventory in Great Smoky Mountains (if you go to the website <www.dlinamerica.org>, you'll learn what's happened since 1999), 565 species new to science have been discovered in the Smokies. [To repeat,] 565 species **new to science** have been discovered in the Smokies, largely through volunteer efforts. Three thousand five hundred sixty-seven—it's probably more today than it was yesterday, when I found these figures—3,567 species previously not known to inhabit the park were located. And I'll never forget the day that one of my staff people walked in with this worm that was about (this long, and big around,) and said, "Guess what, we have a new species not known to science." But it was known to the maintenance people who'd worked in the park for years. They

didn't know the name of it, but it was "that worm." Sixty-seven species of algae not previously known to science have been discovered.

The Smokies project also spun off the education components that we were able to get funded later under a National Park [Service] initiative called the Natural Resource Challenge. So the education component (and I wish I could quote such precise statistics about the success of that) has really prospered and grown, and is an amazing thing in the Smokies. But it's also been spun off into other areas of the system. The Smokies project of inventorying has now spun off into the Adirondacks. The Tennessee state parks are doing comprehensive inventory surveys utilizing volunteers; Point Reyes, in the [National] Park System; Rock Creek Parkway; Boston Harbor Islands. And I have to say—I know very well [that] here [in Yellowstone], you're not going to say you spun anything off the Smokies—but I know [that] here, [former Yellowstone Center for Resources chief] John Varley and [current chief] Tom Olliff and perhaps many of you have done the greatest microbe inventories ever done—something to be extremely proud of—and probably a lot of other things I don't know anything about.

Now one might ask here today, why put all this time and energy into such an ambitious project at a time when resources are hard to get and there's already more work [to do] than you can ever possibly imagine? Your staff's overloaded. Do they need another thing to do? I don't think so. [So] why do something so ambitious? And I think—to get back to the reason you asked me to come here—the reason relates to the "hard lessons and bright prospects" part of our discussions here this week, and our responsibility as individual scientists, conservationists, public land managers, educators—whatever we are here today. As others have noted during this conference, we know the Yellowstone region has experienced at least a 62% increase in population between 1970 and 2000. And that the amount of developed land in rural areas has grown by 365%. I don't know who did that calculation [but s]omewhere around 365% is a lot of conversion, I would say. If we forecast the rate of development at its fastest-growing scenario, nearly all unprotected lands on private lands would experience some development in the next four years. Whew! Think on that. I live up near Kalispell. Have any of you been up there recently? Some of you live up near there, probably. I don't know. I bought land up there in 1999 to vacation on, and of course it hooked me. I'm up near the Canadian border, a ways away from that, but I have to drive through Kalispell on a regular basis. I have never seen anything like the conversion of land there. It is incredible. And it's not slowing down one iota. The question is not whether we'll have growth in Montana or in the Yellowstone region, but how. [Again, i]t's not whether, it's how. And how it experiences that growth will very much determine the fate of the life sustained on our public lands.

So back to the question: why would we do an ATBI in the Smokies at a time when we're flat broke, the region's growth was clearly overwhelming and choking the life out of the park, and we couldn't even begin to get all the existing workload done? Well, I went back to my friend who's the coach and the connecter, the staff person in the Smokies responsible for the direction of the ATBI. His name is Keith Langdon; some of you know him. I said, "You answer that question—why would we do that?" He said, "At the time I thought you were nuts. I thought you were out of your mind." And I'm not sure I yet have the words, although [Keith], like John Varley, is becoming very articulate and eloquent about why we're doing what we're doing. [But essentially] he said, using citizens, park staff, scientists, and educators in activities together, [we've discovered] . . . undescribed, rare, beautiful, newly arrived exotic organisms. All of that's true, all those wonderful things. But together we've [also] created new ideas. The synergy of studying these things together, finding them, discovering them, being together in this project of discovery, has created pride of ownership and newly won respect for this park by its citizens. The reason, then, [is] the new frontier—the great adventure of it, respect for resources, citizen engagement and commitment in things that matter, things that have to do with the home place, the place that we cherish, the place we have a passion for.

And what's the end result in the Smokies? What do you know the Smokies for? The most heavily visited national park in the system? I'll tell you what it is today. There are lots of words for it, but "one of the most precious life reservoirs on the planet—" how does that sound? And it's not just that to me; it's that to a lot of people. Quite a contrast between those two definitions.

In a nifty little book that I pick up from time to time called *The Pleasure of Finding Things Out*, physicist Richard Feynman talks about both the value and the meaning of science. According to Feynman, scientific knowledge enables us to do and make all kinds of things. It's an enabling power. [At] the

other extreme, it can be a destructive power. But we know it is an enabling power. It gives us access to the fun of intellectual enjoyment. Why do you think people with the great minds do this stuff? Why do you think John Varley's dedicated his whole life to this? Why do you think Karen Wade dedicated her whole life to this? It's the fun! It's the great adventure! As Feynman says, with more knowledge comes deeper, more wonderful mystery, luring us to penetrate deeper and deeper, never concerned that the answer may prove disappointing. With pleasure and confidence we turn over each new stone (or leaf, as it may be) to find unimagined strangeness leading on to more wonderful questions and mysteries. Certainly a grand adventure, as Feynman says. I've read few books, seen few photographs or paintings, and heard no poems that explicitly talk about that grand adventure. And within a government agency, and in scientific forums such as this, even those of us who've had such grand adventures don't talk about them in such language.

So what about the value of science from the standpoint of the grand adventure—the journey to the understanding of big ideas, such as those of my friends in Trout Unlimited? Those of you who have children, and those of you who have a child inside of you, know of what I speak. It's the catching onto the ideas that makes a scientist, a poet, an artist, a conservationist, a photographer, a public servant. Do we presume here that someone else will create the next generation of scientists and conservationists? I hope not. It gets us to the question of what our responsibilities are. And what you study is critically important to share. Maybe that is the most important responsibility you have. You accumulate knowledge and understanding of how the physical world behaves. It's a complex place, right? And man, if you listen to the talks this week, the degree to which we can analyze and look at things, dissect them, penetrate them, get to the depths of them, is tremendous these days. We have tremendous capacity. The other night we were talking about what a pleasure it is to go to one of these [conferences] and watch the computers transform our presentations—in our early days, before overheads, we had filmstrips! Some of you in this room, I know, have seen filmstrips, and then we went to overheads, and man, those were painful things to sit through, let me tell you! And now we're getting to the point where the degree of sophistication we have [is] amazing. You can build a tree out of this data and make it look pretty exciting, I must say. The context in which you are making this contribution is hugely important for people to understand as we march inexorably forward into the future. How do we communicate that knowledge and understanding? How do we do it in ways that people can understand? They do deserve to understand it, don't they? Don't you want them to take this grand adventure, too? Don't you want them to get hooked on the highs of what you do?

Well, what are the key messages, the grand messages that come out of this conference this week? Have you written some of them down? Did they just kind of hit you, like, "wow, that is really neat"? And do you have amongst you someone sitting here that can go to that newspaper tomorrow and talk about something besides fire? Right? So is there sitting amongst us here someone who can take that grand mystery, that grand journey that we're on, and put that into language that can reach everyone who reads the newspaper, or everybody who sees the television? Distill the message. Simplify it. Make it relevant. Relate it to the big picture. Study the fine art of public speaking. (And public swimming!)

One of the great units in the Intermountain Region of the National Park Service is in Santa Fe. The unit is called the submerged resources unit. They're divers and scientists, and these people go around the world diving into the waters, finding the treasures, the mystery, the stories, and speaking of them into cameras that are broadcast with the stories across the country into classrooms, [and] wherever [else] the stories can be captured and told. Now I don't think those people, when I first went to Intermountain Region, had any idea that their job was to look into that camera, [or to] point at this thing [or that] later on, in a voice over, describing what it is and what its value is and why we need to know more about it. They never saw themselves as TV personalities, I can tell you, but they're getting mighty good at it, and if you catch one of them one day on public television, you're going to be very impressed.

In the Smokies we believed that it is the duty of every individual there to begin to tell the stories of the kinds of things that are going on. Every program there is open to volunteer effort and citizen involvement, and the ATBI is only one part of the many things like that in the Smokies. I just choose the Smokies as an example; when you become a regional director, you're not supposed to speak eloquently about other people's programs or take any credit for them. And I'm not going to take any credit for what goes on here in this ecosystem. But I can take credit for the fact that I learned some mighty lessons from

my experience.

A friend of mine, a very dear friend of mine, my primary mentor who died just a few years ago, always used to answer the question, "what's the value of parks?" (and he could have been saying "public lands") by saying [that they] are the university system of the planet. I've only just begun to fully appreciate what he meant when he said that. I can say with confidence, before you here today, that if you were asked, "what is the value of Yellowstone's public lands?" you would agree—we would all agree—that [they're] part of that great university system of the planet. And you here in Yellowstone have a platform for that that is greater than [that of] any [other] park in the system, greater than any unit amongst the agencies that are part of this ecosystem. Even more important, these lands are the incubators of great ideas and great adventures. People become more fervent and impassioned when they engage in the exploration of new frontiers and new ideas. It's not just the experience of seeing an elk, or seeing a bison; it's the experience of understanding the being of an elk or a bison and the relationship of life in this ecosystem.

I don't really think I need to remind you that our interests in these public lands for their relevance to science and education are not the interests shared by others, or by everyone. Never in my lifetime have public lands been so up for grabs for purposes that are the antithesis to their preservation for the purposes of knowledge and understanding. This is a political fight that most of you cannot engage in. What you can do, however, is consider a message on one of my favorite t-shirts. And I brought my favorite t-shirt. There is a quotation on here. And if you remember, [earlier in the conference, former Yellowstone superintendent] Bob Barbee said something about "adventuresomeness in bureaucracies may not be appreciated—" something like that. Well, I sort of disagree, and he's not here so he can't defend himself, and I can say anything I please! So I'm not so sure that we want to stay too tied to that historical perspective. I think adventuresomeness, as long as we treat it as a contagious disease, is a good thing. My favorite t-shirt quotation is (some of you would already guess, I think. I wear this up at the ranch all the time. It just really shakes up my neighbors): "Well-behaved women seldom make history." Some of you are wondering, "what the heck has that to do with me?" But I would adapt it to this audience, and if I could have found a place that had these letters en route here, I would have had another one made up, and it would say, "Well-behaved scientists seldom make history."

So with that in mind, get to work. Find a way to take people on a grand adventure, engage them in ideas, at times kind of inoculate them with adventure and ideas. Share the mystery and the wonder of what you do, and do it in ways that can engage them, involve them in your projects, in your fieldwork, whatever you're doing. Let them become involved. If you're successful, I can guarantee that how the Yellowstone region grows will be dramatically different in the future than how it has grown in the past.

The other day I got a news clip in an envelope from Great Smoky Mountains National Park. Gatlinburg [Tennessee] (if you've never been there, you should go—once, anyway) and the park have jointly funded a wildlife biologist to work full-time on bear issues associated with the community of Gatlinburg. Never would I have believed that. In fact, I almost fainted when [Gatlinburg] passed a proclamation requiring that people take care of their garbage—a garbage ordinance of some kind. But that's the kind of thing that can happen: citizen commitment. Concern that extends well beyond the kind of concerns that we have as stewards.

In conclusion, people do care about the quality of their lives. People do care what happens to their home places. People from the Smokies to Yellowstone to Point Reyes are looking for a better future, one with healthy landscapes full of mystery, vibrant economies, and livable communities. As scientists, resource managers, educators, citizens, we must work together to find the necessary hooks that provide the opportunities for people to fully engage in our passion for this place. I don't believe there's anything you can do that's more important or more necessary at this time in our nation's history. And what's the worst that can happen? You might be known as the scientist who is not well-behaved.

Thank you.

Spatial Distribution of Snow Properties to Enhance Our Understanding of Snow–Elk Relationships, Northern Elk Winter Range, Yellowstone National Park

Mark Williams

University of Colorado, Institute of Arctic and Alpine Research (INSTAAR), Campus Box 450, 1560 30th Street, University of Colorado, Boulder, CO 80309 (303-492-8830, markw@snobear.colorado.edu)

Craig Anderson

INSTAAR, University of Colorado, CB 450, Boulder, CO 80309 (cranders@colorado.edu)

Robert Crabtree

Yellowstone Ecological Research Center, 2048 Analysis Drive, Suite B, Bozeman, MT 59718 (406-556-1414, crabtree@yellowstoneresearch.org)

Abstract

Winter severity is the primary control on elk mortality in the northern elk winter range of Yellowstone National Park (YNP). Our ability to measure and model snow parameters that control elk mortality has not kept pace with recent improvements in measuring elk movements at high spatial and temporal resolution, such as collared tags with GPS units. Here, we evaluate the development of a spatially-distributed snow model based on parsimonious data requirements to improve our understanding of snow–elk interactions on the northern range. We spatially distributed the 1-d SNTHERM point model in the Crystal Creek drainage of YNP by classifying the study area into 30 discrete regions using a combination of elevation, aspect, and landcover type (based on 1,200 snow depth measurements), with elevation having the largest effect on snow water equivalent (R^2 = 0.45). A regression analysis shows that modeled estimates of snow depth, density, and water equivalent were highly correlated with results from monthly snow pits in each region (R^2 ranged from 0.91–0.94, all slopes near 1). A comparison of our daily snow water equivalent measurements from SNTHERM to SNOTEL sites at Canyon and the Northeast Entrance showed an R^2 of about 0.95 for both SNOTEL sites, suggesting that we may be able to estimate the spatial distribution of snow properties over the northern elk winter range domain from historical records of point measurements at SNOTEL sites. These results show that we can obtain detailed information on snow properties at hourly to daily resolutions on the spatial scale of tens of meters.

Note: The text that follows is an edited transcription of Dr. Williams's remarks at the conference.

We're going to chat some more about snow. This is work done by my co-authors, Craig Anderson, who did this for a Master's thesis, and Bob Crabtree from YERC [the Yellowstone Ecological Research Center]. . . . [W]e know . . . that snow is a major control on elk, so the amount of snow, the duration of snow, the extent of snow, [all have] a big effect on elk populations. In fact, if you look at the elk literature, the main control on elk mortality is winter severity. Right? And everybody knows what winter severity is, correct? So let me give you the definition of winter severity right now, because I chat with a lot of people, and everybody I talk to [has] sort of a different impression. So how many of you know what pornography is? You can't really define it, but you know it when you see it, right? Winter severity is sort of that way. And we're trying to get a little bit more detail of what it means when we say that there's a "severe winter" and there's high elk mortality because of it.

The snowpack is composed of a lot of different properties. The depth . . . [and] . . . density [of the snowpack] . . . have different effects on elk locomotion and energetics. The stratigraphy is particularly important to snow–elk interactions. How many of you have gone skiing or snowboarding or snowshoeing? [Depth, density, and stratigraphy] all affect

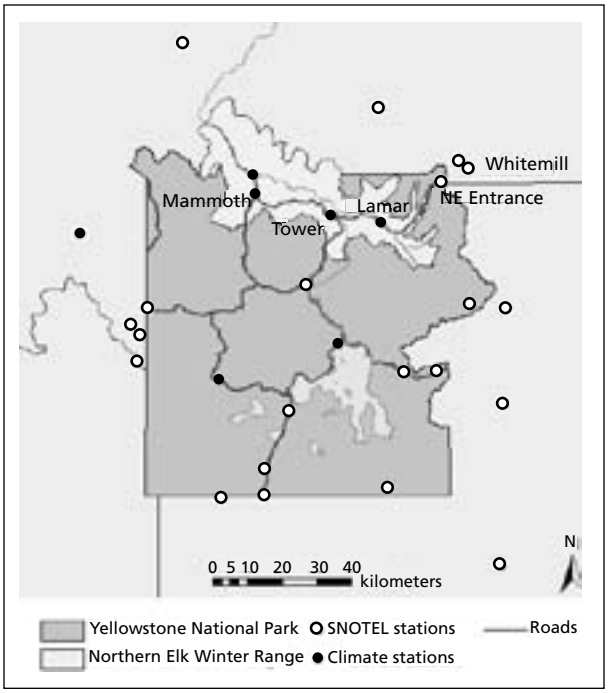

Figure 1. Study area: northern elk winter range, Yellowstone National Park.

your ability to move around in the snow, don't they? And they affect elk. If you have a crust layer on the snowpack that can support the weight of a wolf but not that of an elk, an elk's going to sink and flounder, but a wolf's going to be able to move really easily and the kill ratio goes up quite highly. It's really hard to get that information, and so we're trying to come up with some techniques to allow us to model things like snow depth, density, stratigraphy, and snow water equivalent (SWE), which is the amount of water you get if you melt the snow—the depth of water—to figure out what the elk would be doing [under certain conditions], what would happen to them.

Why do we need the model? [Because physical sampling of snowpack characteristics is logistically impossible, models are needed to effectively characterize snowpack properties over large spatial domains.] It sounds like we take a lot of snow measurements, right? We've got the SNOTEL site, [which is] really comprehensive. In Colorado, we measure snow with one measurement site every 893 square kilometers; that's essentially an 8 × 4 sheet of plywood about every 1,000 square kilometers. That's not very high density. But the elk see a lot finer resolution than that. So what we're going to try [to do] is take this very low resolution data and provide a high spatial resolution model.

This is our domain right here (Figure 1). The northern elk range is [represented by the light color]

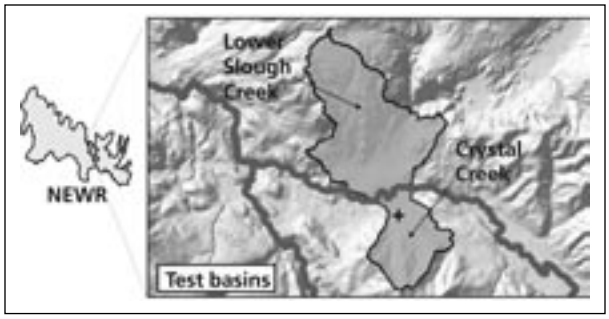

Figure 2. Test basins.

on the top. . . . [T]he dots are SNOTEL sites [and climate stations]; there are no SNOTEL sites in the winter elk range. So even though we know snow and winter mortality is a main control on elk, there are no SNOTEL sites [in their winter range]. So that makes life a little difficult. So . . . we [came] up with research in two test basins (Figure 2). The main one is Crystal Creek, up on the road . . . to Lamar River. The Crystal Creek basin is where the [park] did the initial wolf release, and it's pretty representative of the type of habitat [on] the northern elk range. We [also] include a part of Slough Creek, so we have some southern exposures, as well.

[When we collected our] field data, one thing we did was [to take] very high-resolution measurements of snow depth. On one survey we took 1,200 measurements of snow depth in five square kilometers, and we registered each point with a GPS unit—pretty high spatial resolution. So we have very good measurements of what the snow depth was at that time, and that's part of this modeling technique that I'll explain. We took monthly snow-pit [measurements] at 30 different sites. . . . At each of those snow pits, we measured depth, density, stratigraphy, snow water equivalent, temperature, grain size, etc., and that's a lot of work. That's what graduate students are for. So Craig did all that!

Then we still needed higher-resolution meteorological data, because that's what drives the model that I'm going to talk about. And so we had to put up our own climate station, because Yellowstone National Park doesn't collect that type of information. So that went up at Crystal Creek, and I want to thank the park service for facilitating the permitting process to allow us to put up that climate station.

The winters [when we took our measurements], 2003 and 2004, [were] warmer than usual, and particularly in the later parts of the winter, there was less snow than usual. So we're talking about two winters that were a little warmer than usual and had earlier snow melt. We used a one-dimensional model called

SNTHERM, which was developed by the U.S. Army to figure out where kinks have been in cold regions. It's a very good model, and it gives us all the snow properties that we want: density, stratigraphy, grain size, etc. To drive it, you need a lot of climate information, and because the snow changes diurnally—it's cold at night, the sun comes out during the day—snow properties change radically; you have to collect the information at hourly intervals. So we're collecting all this climate data at hourly intervals, and running our model at hourly intervals.

So what do the models show us? Measured in orange, modeled in blue, Figure 3 shows the information from our index site where the climate station is. We ran [the model] for 80 days. With all that input, we're usually much better than 10% in snow depth, and that was the case here. Snow depth estimates were accurate within 1–16%; density, within 7–11%; SWE, 3–8%. So the model does well.

Figure 4 shows stratigraphy. [W]e had some sun crusts, [visible in the photo on the left], and the model actually captured those crusts. So we can, with this model, actually get information on ice lenses and sun crusts and things of that nature within the snowpack; this is information you don't get from a SNOTEL site.

And then we wanted to spatially distribute it over our domain. To do that, we developed a landscape classification scheme. We took those 1,200 snow depth measurements, and then the DEM [digital elevation model] information that we got from the park to see what explained those snow depth deformations. [E]levation [proved to be] the major component, so we used two elevations (high and low); . . . aspect; and . . . vegetation cover, which was coniferous forest, deciduous forest, and non-forested, as our parameters.

We ended up with 30 combinations, so we divided our domain of five square kilometers or so into these 30 discrete regions. . . . The snowpack properties differed among the regions, but within each of these landscape types they were the same; they were treated as homogeneous units.

[Because] we ran our snow model in each one of these 30 units separately, we had to spatially extrapolate all our climate drivers at an hourly time-step over 30 regions and run the model. The thing that's most important is getting the solar radiation right. [W]e ran [the model] every hour over the entire domain for 80-something days. Figure 5 is a snapshot of one day. At the bottom is a north-facing aspect, at the top a south-facing [aspect]. You can see that solar

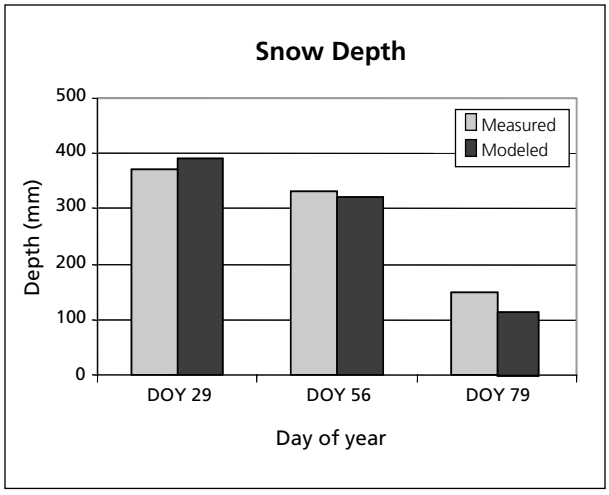

Figure 3. 1-D SNTHERM vs. field data, Crystal Creek index snowpit, winter 2004.

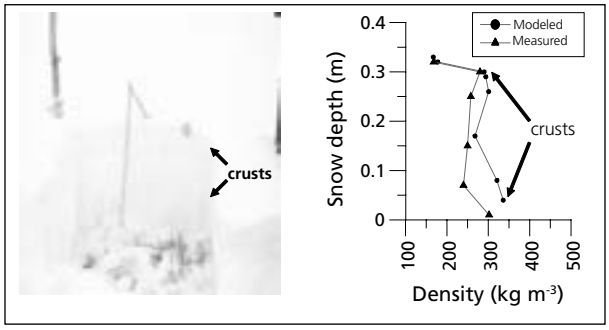

Figure 4. Snowpack stratigraphy, Crystal Creek index snowpit, February 25, 2004.

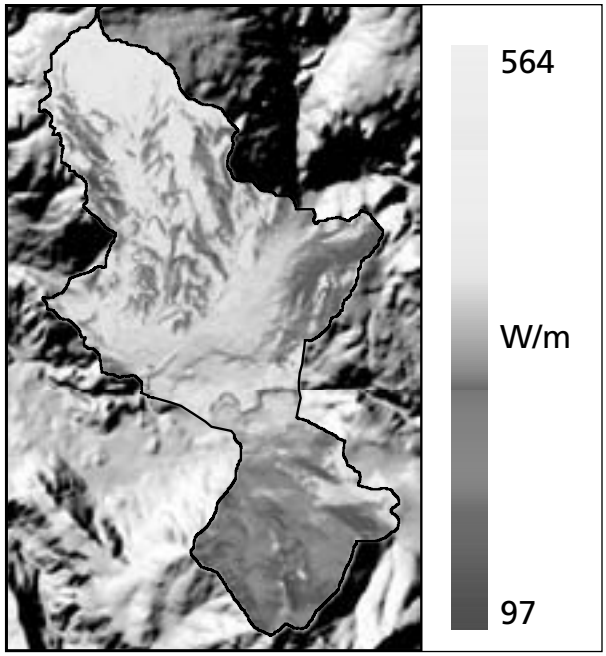

Figure 5. Solar radiation distribution. Modeled incident solar radiation, March 10, 2004. Hourly time-step for sunny and cloudy conditions.

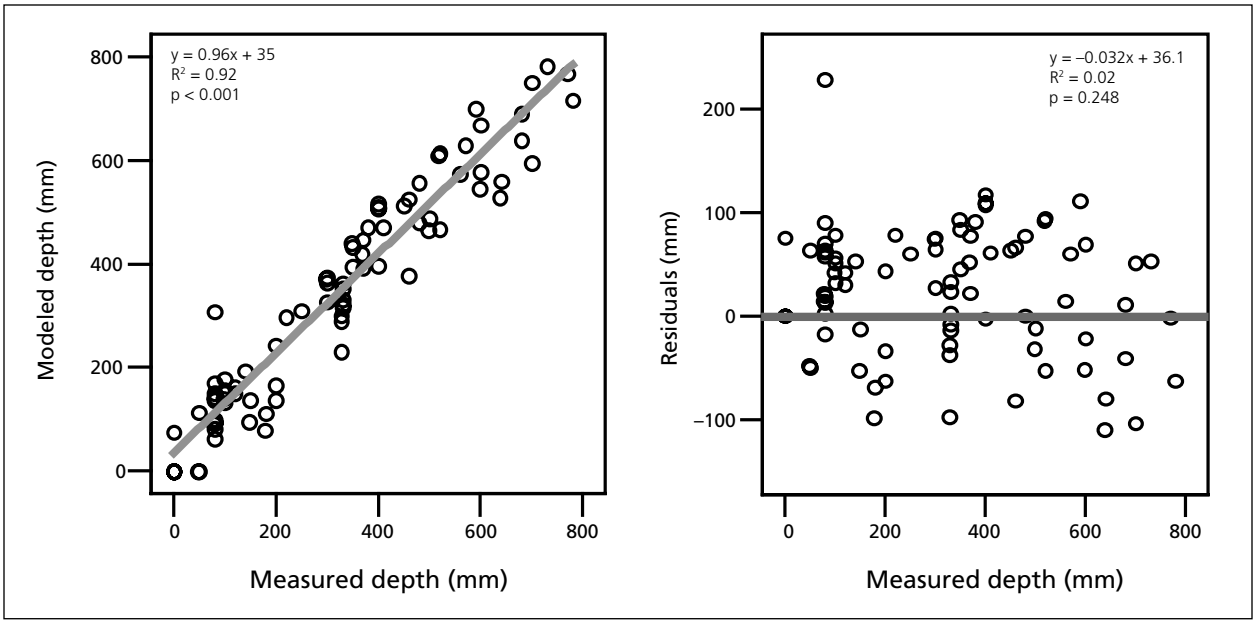

Figure 6. Distributed SNTHERM vs. field data, NEWR test basins, winter 2004.

radiation ranges by a factor of five from north-facing slopes to south-facing slopes. The snowpack conditions respond to that, and the elk and wolves are sensitive to those changes in snowpack properties.

So here's what the results look like (Figure 6). We compared our SNTHERM distributed results with the field measurements from 30 pits and got an R^2 of 0.96. That's just incredibly good. R-squareds range from zero to one, with one being perfect, and so . . . it was much better than I expected. I think it has a lot to do with the special sort of terrain that's in Yellowstone. We [also] can test how well we did by a different way, which is to look at the residuals, the error. It's not correlated, so we're doing a pretty good job there.

We also got the stratigraphy right, in general. [In Figure 7,] the red is where we got the stratigraphy wrong. On the rest of it we got the stratigraphy right, so we can actually spatially distribute ice lenses and things that either help or hinder elk and wolf movement reasonably well.

There's another model out there, developed by CSU [Colorado State University], called the NREL model, and we compared [this model to] that model just to see if we're doing as well as they did. Their R^2 is quite a bit less; that's because they're using those SNOTEL sites to drive the model, and it's static (Figure 8). There's no daily meteorological data. So I think our model is a big improvement over that.

[W]e can spatially distribute the data reasonably well with the current year's data. Now the question is, can we spatially distribute past years? [To] do that, we take our 2004 data and correlate it against SNOTEL sites, and then take that SNOTEL data and run it through the model and compare it against field measurements in 2003. If that works, then we can spatially distribute those point measurements from SNOTEL back 25 years, or with Dave [McGinnis]'s data, back to 1948.

So this is how we do it. Figure 9 shows our data from Canyon. The R^2 is 0.97, so we're doing really well, our data at this index site is well correlated with the SNOTEL data. And that was for 2004, so in 2003 what we did is just take that SNOTEL data, spatially extrapolate it based on the model, with no other

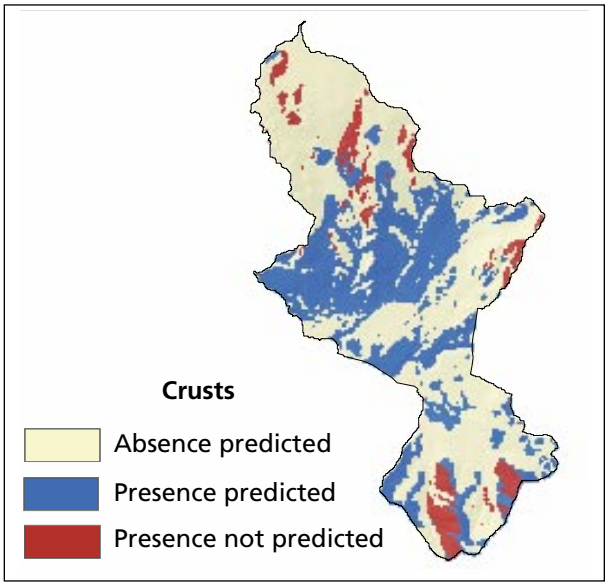

Figure 7. Distributed SNTHERM stratigraphy.

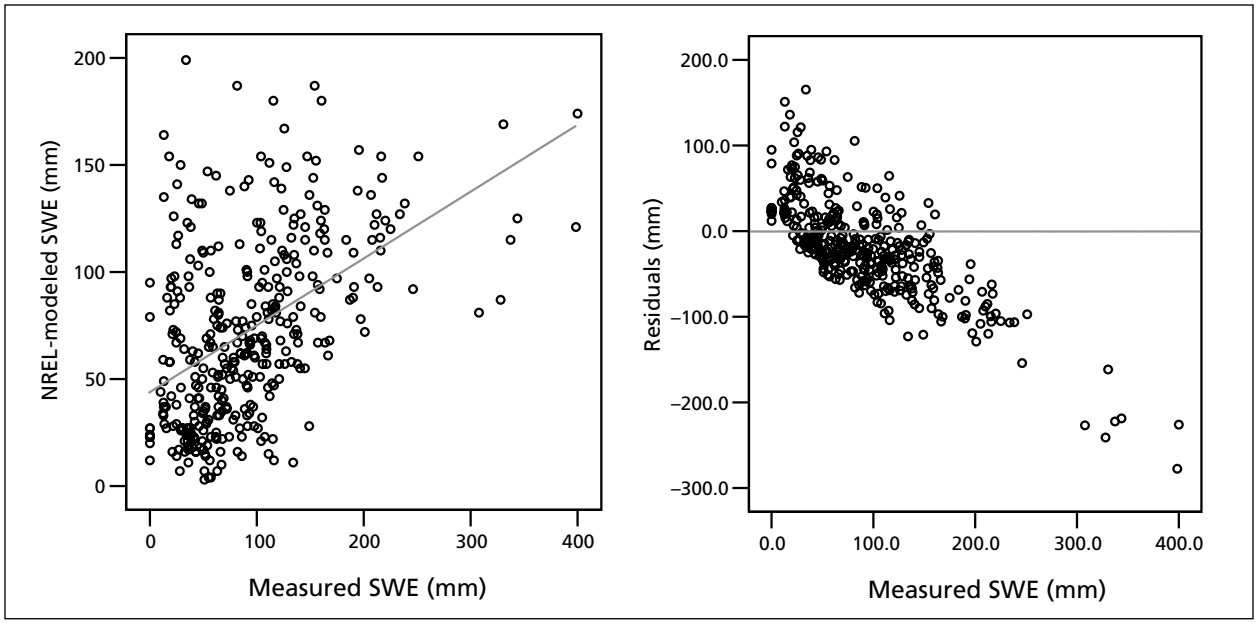

Figure 8. NREL snow model vs. field data, winters 2003 and 2004.

measurements, and then compare it to the field data we had. And the R^2 is pretty good: 0.64. And it's actually a little better than that, because . . . the two black dots . . . are outliers; without those, the R^2 is up around 0.9. [That's] because of wind redistribution. So that's one thing that's not in the model, and that we didn't capture well. [Including] that would improve the model.

So essentially, [our model] worked well, [meaning that] we can actually spatially distribute point measurements of snow properties. We can do it at a scale that the elk actually see. [This work], . . . I think, [is really going to] help the elk researchers and the wolf researchers. We [also] can go back in time. We can take existing data back as far as 1948 and spatially extrapolate those point measurements, and use that to understand elk dynamics and winter severity.

The bad [news is] that Yellowstone National Park, at this point, does not collect sufficient information to drive these models. And that's something that I think we need to think about, and that YNP, in particular, needs to think about. And it's not just our

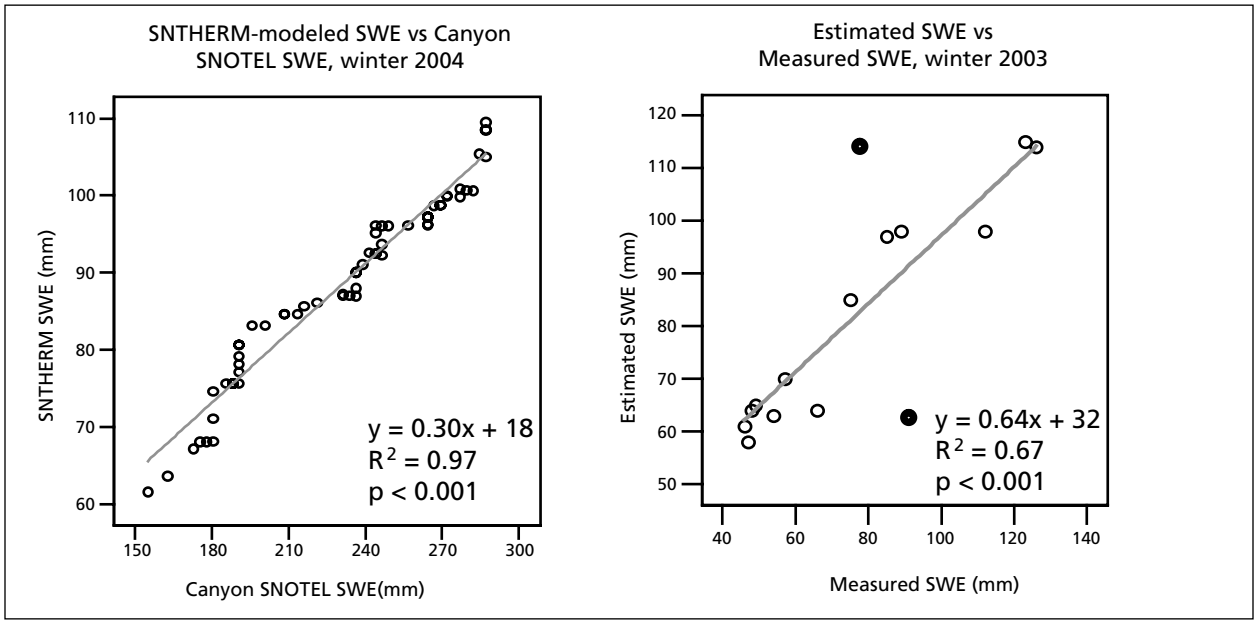

Figure 9. Retrospective SWE estimates. *Left,* SNTHERM-modeled SWE vs. Canyon SNOTEL SWE, winter 2004. *Right,* estimated SWE vs. measured SWE, winter 2003.

model; a lot of the good ecology models now run on this hourly time-step, and they need those meteorological drivers.

Future directions: We've actually expanded the domain all the way up to the Gallatin River. We took those measurements last year; we're working those up now. It would be great to include other physical and biological parameters for which we don't have funding, but which we understand would help—in particular, wind redistribution. And last, we need to work closer with the elk [researchers], because right now we actually have distributed snow measurements at better precision than the elk [researchers] have elk measurements. The elk data is not nearly as precise as you think it is, and at this point we've leapt ahead of the elk [researchers].

Thanks a lot.