ISBN 0-912186-30-5

FOREWORD

The fourth annual William T. Pecora Memorial Symposium focused on the application of remote sensing data to wildlife management. Previous symposia considered the applications of remote sensing data to mineral and mineral fuel exploration, mapping, and petroleum geology. Remote sensing technology has shown great utility in natural resource inventory and management, and new techniques appear likely to provide wildlife managers with new perspectives under their supervision. In sponsoring Pecora IV the National Wildlife Federation sought to provide a forum for the transfer of information on the use of data acquired by satellite and aircraft from the research and development conmunity to the user community.

To insure that a significant amount of information was available for transfer in a short period of time, and to allow a good deal of flexibility for both speakers and participants, the program committee decided to schedule technical sessions and poster sessions. Technical sessions were intended to provide broad overviews of applications to various resource situations. Speakers were invited on the basis of their expertise and experience concerning the subject matter. Poster sessions were intended as detail to the technical sessions, providing the opportunity for face-to-face interaction between researchers and users concerning applications of a specific nature. In order to insure that participants without prior remote sensing knowledge or responsibilities would derive benefit from the symposium, the initial technical session reviewed and summarized remote sensing terminology, systems, data and analysis techniques.

Featured during the symposium were tours of the Earth Resources Observation Systems Data Center. The tours provided an opportunity for participants to observe in operation the high volume photographic laboratories and equipment, the central computer complex, and the Data Analysis Laboratory. Interactive digital and analog image analysis equipment as demonstrated to illustrate techniques for the analysis of wildlife habitats using satellite images.

For those unable to attend the symposium, the papers in this report represent the most complete collection available of state-of-the-art applications of remote sensing technology to solving wildlife resource management problems. The National Wildlife Federation and the Pecora IV Coordinating Committee hope this report will help train future users and managers and encourage them to adapt present and future technologies to the practice to scientific wildlife management.

Michael E. Berger
General Chairman

TABLE OF CONTENTS

Page

The Changing History of Wildlife Management

W. Leslie Pengelly

I have been asked to review for you a brief history of North American wildlife from when good habitat was common and people were scarce. As we reversed those conditions it became imperative that we intensify our management skills and efforts to maintain viable populations. The passage of the Marine Mammal Protection Act and the Endangered Species Act is evidence of our concern and also of the seriousness of the threats to wild animals. I will try to show that just as technological developments can accelerate these threats, so can we take advantage of technology to aid us in proper management of these resources.

> "The process of wildlife management, one of several fields of wildland stewardship, has developed out of the modern complexity and urgency of those relationships (between man and wild creatures)." (Weeden)

Stewardship is not always a noble ideal however. It may even be a smug paternalism, and we should examine our management goals very objectively. Especially those goals based on quantification. "What is worthwhile is very often not measurable. What is measurable if too often not very worthwhile."

Our attitudes toward wild places and wild things have changed over the centuries. This "cultural evolution" is best exemplified by an anonymous Englishman in the 19th century who described wilderness as "a damp dreary dismal place where all manner of wild beasts dash about uncooked." Since then, the main efforts of man have been to correct this 'waste' of land on wild creatures. "The cult of the simple rustic life is giving way before the cult of compulsive manipulation." (Barbour)

One of the requirements of being a great nation, is to start with a great piece of real estate. So lets take a look at this property of ours.

In recent history, say the past 300-400 years covering the exploration and early settlement of this continent, the oral and written accounts of ear;y explorers give us clues as to the diversity and abundance of wildlife, probably unsurpassed anywhere in the world.

The original wealth of American wildlife in the pre-settlement period can only be inferred from these scattered records, diaries, and oral reports. Some of these accounts may have been more fanciful than factual, but undoubtedly wildlife occurred in an abundance and variety unknown to the early European explorers.

The effect of man upon the fauna of North America probably began at the end of the glacial period when Paleolithic pioneers migrated eastward out of Asia across the Bering Bridge where they found a huge, productive, and unexploited ecosystem unoccupied by hominids.

These wild Mongoloid peoples, the ancestors of the modern Indian, and Inuit, were perhaps the last large mammals to invade North America from Asia. The deer, bears, elk, moose, bison, mountain sheep, and caribou had preceded them. These species are still with us, but the mastodons, mammoths, camels, extinct horses, and ground sloths are gone.

Whether the mass extermination of large mammals was brought about by Stone Age hunters is still being debated. Anthropologist Paul Martin makes a strong case for it as a major factor in his essay on the causes of post-Pleistocene extinction of these inexperienced prey.

Modern explorers decimated the island faunas first--usually the flightless bird life, but also many forms of marine mammals which were killed for food and hides. In addition to the actual killing, many species of wildlife were further reduced by habitat destruction and by the introduction of predators or competitors on the islands where they had never been encountered before.

The richness of North American fauna was made possible by the diversity and quality of the habitat. The North American continent stretches from the icy Arctic to the warm subtropics. In between are fertile plains, deserts, well-watered valleys, and vast mountain ranges. The land possesses almost every possible variation in temperture, precipitation, soil fertility, altitude, and vegatative cover.

This diversity resulted in an exceedingly varied flora and fauna that astonished the early travelers. They described the tremendous flights of passenger pegeons "that darkened the sun for hours on end," and the vast herds of bison that flowed past them for days, of flights of waterfowl numbering in the millions. Most of us were taught that our ancestors came here to be able to have freedom to worship as they pleased. I'm inclined to believe the old sailor who denied that and said "I came here to catch fish."

By 1900 the great flocks and herds were gone and the Conservation Movement began--George Perkins Marsh had already warned us of the consequences of our profligacy. Then came Pinchot, T. R. Roosevelt, John Muir, Burroughs, Seton, Hornaday and others "to stem the tide." We first blamed the Indians, but they were too scarce and too poorly armed to have made much of a dent in the animal populations. Natural disasters--"acts of God" if you will--in the form of fire, flood, and storm further reduced some populations temporarily. We have always blamed the predators and waged war on them for several centuries. We tried artifical propagation, introduced exotics, set aside refuges, and hired game wardens to enforce season closures and put a halt to market hunting. Finally, it became apparent that where the original habitat was in good condition, the animals usually did well. We have also discovered that some of the early writers like Seton so exaggerated the numbers of certain species that we despaired of ever restoring them.

The writings and teachings of Aldo Leopold, following publication of his classic book "Game Management" in 1933, profoundly influenced the training, thinking, and subsequent flood of habitat management-oriented research in the U.S. and in foreign countries to a lesser extent. While the new profession of wildlife management was getting underway and providing suggestions for improving wildlife habitat, another phenomenon was taking place--runaway human population growth. The spread of urbanization, 3 destructive world-wide military conflicts, and an exponential increase in technological development wiped out many of the tentative gains of the wildlife managers. While biologists were putting up nest boxes, trapping skunks, and planting food patches, the dam builders were flooding whole valleys, agriculturalists were draining swamps, wiping out hedgerows, and applying the newly developed pesticides and herbicides. Hard on their heels were the developers carving up foothill deer ranges for split level homes and filling in wetlands for shopping malls and airports. Highway construction gobbled up another million acres annually, and municipal and industrial pollution despoiled millions more. Each year when the National Wildlife Federation publishes the results of its Environmental Quality Index Poll, wildlife has shown a steady loss, due mainly to habitat destruction.

Simultaneously, we unleased new millions of people onto the surviving acres to play with their snowmobiles, motorcycles, A.T.V.s, R.V.s, Kelty packs, and vibram soles.

Samuel Florman, writing in the October issue of Harper's, discussed a new word "technethics"--"The responsible use of science, technology and ethics in a society shaped by technology." He described it as a happy combination--ethics rejuvenated and applied to technology and technology tempered by ethical considerations. What prompted this alliance, he says, was the technological developments of the post-World War II period that have troubled the American conscience--atomic bombs, acid rain, pesticides, the Alaska pipeline, and oil spills. But he added that..."it was not until the oil embargo and energy panic of 1973 that concern about the effects of technology reached pathological intensity."

Modern technology has been turned against wildlife in many ways--one could recite a litany of evils--echolocators to track down whales, explosive harpoons, processing factories built into diesel-powered ships, purse seines that entrap porpoises, scope-sigted, high-powered rifles, walkie talkies, huge stripping machines used in coal extraction, vast arrays of deadly chemicals, oil spills, etc. Olaus Murie used to say that we never win these battles, we only win an occasional stay of execution.

The spiritual guru of the wildlife profession, (Aldo Leopold), wrote that... "the opportunity to see geese is more important than television." His contempt for gadgeteers, 1940 style, leads me to wonder how he would react to remote sensing, "tattle tale" satellites, and computers. We have a clue in his statement that he could not understand the thunderous goose debates and was well content that it should remain a mystery. "What a dull world if we knew all about geese." He saw a law of diminishing returns in progress and felt that the whole conflict boiled down to a matter of degree, that a land ethic was especially necessary in an increasingly mechanized world. Maybe that's what Mark Twain had in mind when he observed that "man is the only animal that blushes--or needs to."

In a military reversal, the classic procedure is to fall back and regroup, and it appears that that is what we are doing at this symposium. But how can we emphasize the positive aspects of technology in the face of all the obstacles and problems technology precipitates? Instead of acting like a pessimist who rubs limburger cheese on his mustache and says that wherever he goes, the whole world stinks, let's be optimistic. We can imitate the guy who comes home late at night and notes a fresh cigar butt smoldering in the ash tray next to the open window at the head of his wife's bed. "Thank goodness," he murmurs, "Mary has finally quit smoking cigarettes."

Now for the positive uses of technology.

David Carneggie defined remote-sensing in a paper of that title at a Range and Wildlife Habitat Symposium held in Arizona in 1968. He wrote ..."In its broadest context, remote sensing is simply gathering information about objects without coming in contact with them." Sounds like the sort of thing the C.I.A. might be good at--scientific snooping by one or more consenting adults and involving many innocent or unsuspecting animals.

If Stephen Burr, author of "Toward Legal Rights for Animals" is accurate in his analysis and predictions, a permit to use satellites coupled with electronic implants and radio-collars on animals may have to be negotiated in court. Scientists who have adapted the new technology to map vegetation will probably not be hampered by the threat of legal restraints for awhile.

No one registers surprise anymore when they read headlines which announce, "State to use NASA Satellite for Resource Data." A Helena, Montana Associated Press dispatch described how this $50 million satellite will be used to find water, discover insect infestations in forests, identify agricultural lands for tax purposes, and to classify land use patterns for county and local planning. Every 18 days Landsat II floats 600 miles along Montana photographing sections of the state. Landsat data has also been used previously in the Northwest by mining companies for mineral exploration and by Dr. John Craighead for wildlife research--grizzly bear habitat mapping and tracking animal movements. This work continues.

In the late '50s, researchers in Georgia developed the CapChur gun. New, fast-acting drugs used with this dart gun opened a vast new area of wildlife research and allowed studies on wild animals previously impossible to capture and routinely examine. Also in the late 50s Al Erickson developed techniques for anesthetizing wild black bears in Michigan, and his findings were quickly emulated by biologists working on a wide variety of animal species until now mark-recapture studies form a routine research and management tool. Like the gal in the Virginia Slims ads, "We've come a long way, baby."

Researchers at that time also wished to make follow-up observations on captured animals and therefore developed techniques for color marking so that individuals could be recognized. Plastic ear markers and color coded neckbands were employed and are still in widespread use today. As always happens with innovative scientists, they enlarged the scope of their research by wondering what these animals were doing when out of sight of the observers--i.e., in remote areas, in caves, in the dark. And so radio-telemetry was developed. The history of the development and use of this technological achievement is still being written. Durable, lightweight collars were built to withstand the rigors of winter, of immersion in icy seas, and of combat by huge bears. Through miniaturization and the development of batteries with ever improved range and longevity--these developments all demonstrate human ingenuity. The development of receivers has also kept pace--mobile field stations with powerful antennae, elaborate laboratories with sophisticated continuous data recording equipment, satellite tracking, modern computer facilities--all these 20th century wonders are being employed by scientists in their drive to learn and to know. It is said about the scientific creed its workers cannot tolerate disorder, so they strive to find the missing pieces to the biological puzzles.

In a paper written in 1971, Buechner and his associates predicted that within a decade satellites dedicated to ecological research could be available to the scientific community. In addition to basic research, the same satellite systems could be used for tracking marine fish, whales, sea turtles, migratory waterfowl, and other animals to provide a more scientific basis for harvesting and conserving these resources and for improving the control of disease transmitted by migratory animals. These advantages of satellite systems for advancing our understanding of the functioning of ecosystems provide compelling reasons for a major effort to further develop a world-wide satellite tracking and monitoring capability.

Specifically, the following uses of satellite capabilities have already been made:

- to monitor typical physiological parameters such as body temperature of free-ranging animals
- to obtain data on home ranges, movements, behavior, and social interactions
- to survey large, remote areas in short periods of time
- to study endangered or threatened species and their habitats without undue disturbance
- to provide information on dangerous and/or wary animals
- to type map vegetatinn over large areas and to monitor changes caused by fire, drouth, etc.

To reach all these objectives, however, will require the full cooperation of biologists, physicists, engineers, legislators, granting agencies, and even foreign countries.

In addition to achieving these goals we are faced with the inevitable problems of ever-increasing human population, shrinking habitats, and reduced or endangered animal populations. Anti-hunting efforts, emphasis on non-consumptive uses, reduced free hunting privileges, and reduced travel brought on by p edicted energy shortages can only lead to reduced income for resource agencies. That, coupled with California style taxpayer revolts, may well stifle the best laid plans of mice and researchers. To fail in our objective, however, may mean that more species, and even man, may go the way of the mastodons.

Remote sensing technology is not a panacea--it doesn't replace common sense nor does it obviate the need for on-the-ground field work. It can be cost effective, but only in cooperation with other users and at the expense of personnel or staff lines. Finally, it may be far more limited by the skills and understanding of the scientist than by any limitation imposed by the equipment.

It is all too easy to fall into the trap of the tinkerers, or to forget your primary goals in the midst of your secondary, technological goals. The biologist must stay a biologist, he must learn to reach out to specialists in other fields for aid and consultation, but not change his stripes for spots.

"To sum up, wildlife once fed us and shaped our culture. It still yields us pleasure for leisure hours, but we try to reap that pleasure by modern machinery and thus destroy part of its value. Reaping it by modern mentality and thus destroy part of its value. Reaping it by modern mentality would yield not only pleasure, but wisdom as well." Leopold said that also.

All in the Boat Together

Russell W. Peterson

For the past several years about 1,000 canvasback ducks have been wintering on Silver Lake near our home in Rehoboth Beach, Delaware. They are part of the approximately 50,000 who winter in the Chesapeake Bay environs. All day they rest and sleep on Silver Lake, leaving at sundown to fly to their feeding areas where, by diving to the bottom of shallow bays, they fill their stomachs with two kinds of small clams--rangia and macoma.

This current diet of the canvasback is of recent vintage. Formerly, it lived solely on aquatic plants--especially wild celery (vallisneria Americana)--which grows completely submerged in clear fresh water. In view of this, early scientists named the canvasback after the celery plant calling it aythya valisineria.

Aquatic plants have been having a rough time in the Chesapeake Bay area. As erosion poured more and more silt into the Bay and as discharges from sewage treatment plants triggered a dense growth of minute algae, sunlight could no longer reach the plants, causing their demise. This was especially true in the Susquehanna flats where tens of thousands of canvasbacks used to feed. Now the wild celery is gone. And the canvasbacks have switched from a vegetarian diet to a molluscan diet. I hope nothing happens to wipe out the clams.

Canvasbacks are not the only birds experiencing problems with their habitat. Last fall I visited the Bharatpur Bird Sanctuary in India. What a paradise for birders like me. Prince Bernhardt of the Netherlands was there. He told me that he had seen that morning the first three Siberian cranes that had arrived for the winter. Last year, there were only 58 at Bharatpur--way down from earlier years. While talking subsequently with leaders of "Rural Wildlife of India," they pleaded with me to do what I could to stop the draining of wetlands now under way in Afghanistan. Such draining threatens a critical resting place for the Siberian cranes during their long migration from Siberia. Last year there were only 113 of these cranes in the world--in addition to the 58 in India, 55 wintered in China.

There is one other species, however, about which I am more concerned. That is Homo sapiens. I hope this species can adjust as well as the canvasback and better than the Siberian crane.

But there is a limit to adaptability-even for humankind. Couple this with the great changes occurring in the human environment--changes made mostly by Homo sapiens--and you will see the need for our concern. For most of history, change occurred very slowly. One could be reasonably well assured of what his or her lifetime environment would be like. But the rapidly escalating rate of change over the last two centuries makes our lifetime passage today both a challenging and threatening adventure.

None of us knows for sure what the future will be like. But we can be sure that it will be vastly different from the present. The many dedicated persistent people working to alter the course of events will see to that, for better or for worse. Let's hope that we can become architects of change for the better--of change toward the general welfare. But be assured that there will be many others working to maintain the status quo. It has been said that there is only one thing more certain than change--and that is, resistance to change.

Have you noticed how the current energy establishment resists change in the United States and downplays solar energy? This is standard behavior. Never assign a new development to an organization that would feel threatened by success of the new. Almost invariably, they will kill it. Assign it, rather, to those who believe in it, and whose future would be enhanced by by the success of the new venture.

Today we are at a critical juncture in the energy field. The rapidly approaching demise of the oil and natural gas era makes it essential that, in addition to all-out conservation of energy, we develop over the next few decades a major alternative, long-term energy source. The world has only two choices--to go down the nuclear route or rather down the safe energy route based primarily on renewable energy resources.

We need to persuade our governments to back major research and development on alternative sources and to subsidize the private sector in this work as our governments have done so extensively for nuclear energy. The world communities should join together in a massive all-out effort to develop alternatives. Solar energy is already our major source of energy, and the opportunities to expand its use are great indeed.

Recently when I visited Sri Lanka and India, I was downright embarrassed to hear so many people emphasizing the need for conservation of energy in their countries when they use so little, while we squander the world's heritage of fossil fuels, and fight attempts to force us to conserve.

Filling up the gas tank at a Sri Lanka filling station drives home how hard the developing world was hit by the jump in oil prices four years ago. To save the costs of adjusting the meters on the gas pumps, they just multiply the price that shows on the meter by ten. A ten-fold increase in four years.

This is a precursor of what will come in the mid 1990's when the world population of oil peaks out. Do you suppose by this time we in the United States will have made a significant effort to conserve? Certainly as the world's champion waster of energy, we owe it to the rest of the world to do so.

We have been able to avoid facing up to the limits of energy supplies because we have been diverted for over a century by seemingly inexhaustable supplies of fossil fuels. With this expendable gold mine of usable energy at hand, we went on a binge, squandering this capital as fast as we could, building with it a new and wasteful way of life. In so doing, we committed a cardinal economic sin--we spent our capital, our fossil fuel, without replenishing it from earnings.

There is simply no question that we are going to have to make dramatic changes in the way in which we consume and supply energy over the next few decades. The only real issue is whether the transition will be made in an orderly way to a long-term solution we can live with, or whether we will react with panic and confusion when the inevitable occurs and be forced to choose unattractive alternatives simply because we failed to make adequate plans when we had the time.

A particularly exciting finding in Sri Lanka is the work of the Central Research Laboratory at Perydenis in using solar energy and biological processes to produce nitrogen fertilizer. This work is a follow-up of the work done by D. W. Rains at the University of California at Davis, who elucidated the centuries-old practice of the Vietnamese of seeding their rice paddies with a blue-green algae that grew in their irrigation ditches and which markedly increased their yields.

What is involved here is a symbiotic relationship between a blue-green algae (anabaena azolla) and a minature fern (azolla) which does an excellent job of biologically fixing the nitrogen of the air into a useable fertilizer. It reduces the need for chemical nitrogen fertilizen in rice paddies by 50 percent.

I am told by Dr. Sylvan Wittwer of Michigan State University, that by further research on biological nitrogen fixation, it should be possible to select some super strains of rhizobium that would improve the nitrogen fixing of legumes and permit reduction of the amount of chemical nitrogen fertilizer needed for corn and wheat by at least 50 percent if they were rotated with the legumes.

The great significance of this is that by using this solar-energy-powered, biologically produced fertilizer, we could markedly reduce the cost, avoid the serious environmental degradation caused by the 80 percent of the chemical fertilizer that is lost to the environment, and could save the substantial amount of nonrenewable natural gas now going into the production of commercial fertilizer. Today 3 percent of our domestic natural gas goes toward this use, and if today's trend continued, 15 to 20 percent of our rapidly depleting natural gas would be required by the year 2000, as would 500 more nitrogen fertilizer plants at a cost of $50 billion.

Today in the United States, the equivalent of about 11 million metric tons of nitrogen fertilizer is produced by biological fixation. Forty years ago, that was the only source of nitrogen fertilizer. During the intervening period, we have rapidly increased our use of chemical fertilizer until today 11 million tons of it is used at an annual cost of $2 billion. It is incredible that we keep going this way and spend almost nothing on developing the alternative--biological nitrogen fixation.

We who are interested in protecting our environemnt, conserving our scarce natural gas, and saving our dollars must see to it that research and development on biological nitrogen fixation is markedly increased.

To be a good architect of change calls for a holistic perspective--a comprehensive, worldwide, long-range view. It calls for a thorough assessment of the negative as well as the positive impacts of the change contemplated--not just near term, but over the long run. It calls for an understanding and evaluation of the interaction of the proposed change with other forces at work.

At the same time it would do well for all of us to establish the habitat of stepping back occasionally from the immediate task to reflect on what kind of a world we want for our children and grandchildren and consider whether the work we are doing is leading in the right direction. If not, we should have the courage to alter our course, even if it means some near-term personal sacrifice. It requires courage to speak and act effectively against the status quo. But we can bring about the essential changes. We need to work toward worldwide goals. We need to become comprehensivists. Traditionally, we have broken our endeavors down into specific disciplines for our own convenience, and hence have perceived reality from many different perspectives. Such specialization has been necessary, for example, for scientific and technological advance. We have learned much more and learned it quickly by breaking phenomena down into various compartments and studying them from the standpoints of biology, physics, chemistry and so forth. But we must remember that our world does not exist in compartments; it comes in single, interrelated communities, each part of which affects other parts. It does no good, for example, to consider only the effects of oil-shale development when at the same time, in the same region, strip mining and coal gasification are to be conducted. Each will demand extensive water supplies and will contribute to drawing down the water table, thereby affecting the water available for agriculture, grazing, and even human drinking supplies. Each will contribute to population growth, leading to large demands for community services. Not by energy alone does man live.

While we pride ourselves in our perceptions of truth in our areas of specialty, we must widen them to include a holistic perspective. Other wise, what is really important is not always obvious.

Unlike the canvasback duck, we are flying blindly. We have no means of measuring growth in quality of life. We have become enamored with the concept of gross national product--the GNP--and have made a religion out of it...failing to recognize how inaccurate it is for measuring and motivating the movement of human beings toward a higher quality of life.

What we need is an additional concept to help organize our affairs--one which would measure directly the quality of life resulting from our total activities and environment. This would involve the use of some subjective measurements which many economists and businessmen shy away from. Yet I know from personal experience in industry that major ventures have been steered to success by subjective measurements.

The Overseas Development Council has developed a physical quality of life index which uses infant mortality, life expectancy and literacy as measures of quality of life. It shows, for example, that Sri Lanka--whose GNP per capita of $130 is near the bottom of the scale--has a physical quality of life index of 83, well above the average of 67 for the upper middle income countries whose average GNP per capita is eight times higher.

The world community must develop other measures of the quality of life than GNP if we expect to steer the world to the goals to which all humanity aspires. Wouldn't it be a good idea if the President combined the Council of Economic Advisors, the Council on Environmental Quality and the Office of Science and Technology Policy into a Council of Holistic Advisors? One of the Council's first assignments might be to develop a means of measuring our nation's success in furthering human development. We might call it the GND--the Gross National Development.

To assist in their efforts to advance human development, to bring a holistic perspective to bear on decision-making and to face up to long-term considerations, the U.S. Congress in 1972 established the Office of Technology Assessment.

OTA has, in my opinion, produced much good work and has the potential to become a key instrument in Congress and in our country for furthering better decision-making on technology-related issues.

OTA's assignment is to advise the Congress on the positive and negative impacts of technological applications on social, economic, environmental and political factors and in so doing provide Congress with early warning.

OTA's job is to tap the most expert knowledge of the broad community on selected technological applications and to integrate such knowledge in a nonbiased, even-handed, authoritative way, and to present such information to the Members of Congress in a manner which will help them make choices for Congressional action on critical problems.

OTA functions with a limited internal staff of 130, but with over 500 consultants, numerous contractors and a series of advisory panels. By this approach OTA can use the best experts in the country on a given issue, readily switch to other expertise as needed for subsequent projects and avoid becoming an inbred, know-it-all agency.

One important source of expertise, particularly on social values and attitudes, is obtained through broad public participation. This activity has been an integral part of OTA since its inception. The Environmental Impact Statement grew out of the technology assessment concept and was siphoned off in 1969 to become a prominent and provocative part of the National Environmental Policy Act.

However, from the outset it was known that technology had political as well as social, environmental and economic impacts and that OTA needed to maintain sensitivity to public opinion. It was the intent of Congress that OTA provide a focus for different points of view and propose options for constructive change to Congress and to citizens on priority issues.

I fully intend to increasingly involve citizen groups such as yours in the OTA process, to make OTA's information available to you and hope that you will make your energy, knowledge and experience available to us. You have actively and persistently cared about the environment and have protested vigorously and effectively when it changed for the worse. You are key members of the vital constituency involved in the process of choosing alternatives, a process that must be informed, competent and open. It is essential that you stay involved. Our children and grandchildren need your continued vigilance.

I have tried tonight to drive home by several vignettes the interdependence of all living things on Earth...the canvasback ducks, the wild celery, the Sri Lankans and Indians, the Siberian cranes, the anabaena azolla, the rhizobia, and you and me. Whether we like it or not, we cannot go it alone. We're all in the boat together.

Overview of Remote Sensing and its Applications to Wildlife Management[1]

Robert N. Colwell[2]

Abstract.--Several of the terms used in remote sensing are defined after which a brief historical account is given of events and discoveries that have led to the present status of remote sensing technology. The most commonly used types of devices are described and the techniques and procedures that can best be used in both the human analysis and the computer assisted analysis of remote sensing data are discussed. Several predictions are made relative to the future of remote sensing. Throughout the paper emphasis is given to the potential applications of remote sensing to wildlife management.

INTRODUCTION

It is recognized that the delegates attending this symposium come from a variety of backgrounds and that their experience in the application of remote sensing to wildlife management may range from minimal to maximal. If the symposium is to be comprehensible to the relatively uninitiated, a certain amount of background material should be made available to them. It is partly in an effort to satisfy this need that the present paper has been prepared. Some of the delegates who already are quite experienced in applying remote sensing to wildlife management very possibly will find aspects of this paper that they would like either to enlarge upon or disagree with. As the symposium proceeds they will certainly be given an opportunity to provide such input, for otherwise one of the most valuable resources to bring to bear in the presentation of this symposium would not be adequately exploited.

[1]Paper presented at the Pecora IV Symposium, Sioux Falls, South Dakota, October 10-12, 1978.

[2]Professor of Forestry and Acting Director of Space Sciences Laboratory, University of California, Berkeley; Director of Berkeley Office, Earth Satellite Corporation.

TERMINOLOGY

It has been aptly stated that a measure of the newness of a science is to be found in its preoccupation with terminology. Such an assertion certainly is applicable to the fast-growing field known as "remote sensing". Therefore several remote sensing-related terms will be dealt with in this brief section. With respect to most of these terms it has been considered adequate--and perhaps even preferable--to define the terms only inferentially here--preferable, because in the fast-growing science with which this study deals, rigorous definitions for some of the most basic terms have not yet been adopted. Our objective in this regard, therefore, will be merely to clear away enough of the terminology "underbrush" so that, throughout the remainder of this conference, we can proceed more expeditiously to a discussion of the relevant concepts of modern-day remote sensing as applied to wildlife management.

The term "remote sensing", as used by wildlife managers and by others working in closely related fields, pertains primarily to the acquiring of information about features on or near the surface of the Earth through the use of aerial cameras or other sensing devices (e.g., optical mechanical scanners and side-looking radar equipment) operated from an aircraft or spacecraft that is situated at a distance (i.e., remotely) with respect to the area being sensed. The property that is being sensed, of course, is the amount of energy that is radiating from the various features that are to be identified, measured, or otherwise analyzed. In most instances it is electromagnetic energy that is being sensed, i.e., energy that is traveling at a velocity of approximately 186,000 miles per second in a repetitive, harmonic, wave-like motion. Within a single beam or bundle of such energy that is traveling toward the sensor from a feature on the ground, some of the wavelengths are as long as several billion microns, while others may be as short as a few millionths of one micron. In between these extremes is an entire "spectrum" of wavelengths radiating toward the sensor from each feature. As will presently be seen, remote sensing commonly is done simultaneously in each of several parts of this electromagnetic spectrum. In most instances the specific characteristics of the energy reaching the sensor will depend primarily upon (1) the nature of the illuminant (e.g., the sun, a radar beam, or a laser beam), and (2) the atomic, molecular, and macro-molecular composition of the matter comprising the feature. The energy reaching the sensor may also be modified somewhat by the medium (e.g. air, water) through which that energy is being transmitted. This is especially true if the medium instead of being clear and transparent, is polluted by various kinds of impurities.

Sometimes the information desired about features on or near the surface of the earth (e.g. information about wildlife or the characteristics of their habitat) is best obtained by sensing in one particular range of wavelengths, known as a wavelength "band", while in other instances the information desired requires sensing in a different band of the spectrum. It follows that more complete information about the total "complex" of features within an area is best obtained by simultaneously sensing in two or more wavelength bands--a process that is variously known as "multispectral sensing", "multiband sensing", "multispectral photography", and "multiband spectral reconnaissance".

Since the material to be dealt with at this symposium includes photography, the need arises to relate conventional photographic terms to certain other terms that are used in the modern field of remote sensing technology. As one example, the term "photography", itself, literally pertains to "writing with light". Visible light, however, is only one small part of the electromagnetic spectrum for which a remote sensing capability now exists. It is true that, until a few years ago, remote sensing of electromagnetic energy was primarily limited to the use of conventional cameras and to "panchromatic" films which were literally sensitive to "all colors" of visible light, but which were not significantly sensitive to any other portions of the electromagnetic spectrum. Eventually, improved technology permitted the development of certain films which had extended red sensitivity at which time the terms "infrared photography" and "infrared imagery" came into usuage. Later, as capabilities were developed for sensing in still other parts of the electromagnetic spectrum, a whole set of new and more inclusive terms had to be developed to replace the corresponding old terms. Four of these new terms are used with sufficient frequency by remote sensing scientists as to merit their being listed, as in Table 1. It should not be inferred from Table 1, however, that the old terms are obsolete. They merely are used incorrectly when one refers to sensing in such exotic parts of the electromagnetic spectrum as the thermal infrared, microwave, and gamma ray regions, even though photo-like images can be acquired in all such regions.

Table 1.--Comparison of Certain New Terms, as Used in this Paper, with their Old Term Counterparts

New, More Broadly Inclusive Term	Corresponding Old Term
1. Remote Sensing	1. Photographic Reconnaissance
2. Imagery	2. Photography
3. Image Analyst	3. Photo Interpreter
4. Analysis of Imagery	4. Photographic Interpretation

Since we often will find it essential to use photography having an ability to resolve ground detail of a certain size, (e.g. some particular kind of animal contributing to the wildlife population of an area) we need also to clarify here the meaning of the term "resolution". While several approaches to defining this term might be used, the following seems most pertinent within the context of the present section: Two objects are said to be "resolved" by a photographic system if that system is able to image them clearly enough so that they are seen "separately and unblurred".

This is a relative term, but one which is readily justified. To illustrate with a hypothetical example: Let us assume that a particular camera is operated at a specified altitude above the Earth's surface and that photographs are thus obtained of a standard "resolution target" (consisting of objects of specified size, shape, spacing, and contrastiness with respect to their background). Let us further assume that the closest spacing of these objects on the ground at which they are imaged as separate and unblurred features on such photographs is, say 10 feet. The photography is then said to provide a Ground Resolved Distance (GRD) of 10 feet. As seen in figure 1, the objects comprising the resolution target commonly consist of either white lines on a black "field" (background) or black lines on a white field, the width of each line being the same as the spacing between it and the next adjacent line. A study of the photographs obtained of this target also permits resolution to be expressed in another way, viz., in terms of the maximum number of "line pairs per millimeter" that can barely be resolved on the photography. As seen in figure 1, the term "line pair" pertains to a line and its adjoining space.

While other terms might be defined in this introductory section, the foregoing should suffice. Later, as the need to define additional terms arises, the same process of defining at least some of the terms inferentially will be employed and for the same reasons as previously indicated.

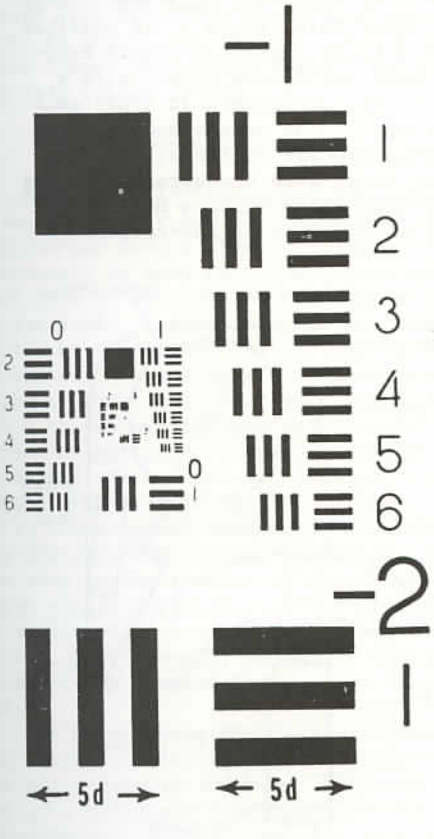

Figure 1.--For explanation of its significance in relation to the remote sensing of wildlife resources, see text.

HISTORICAL DEVELOPMENT

A question might logically be raised as to the possible benefit, in a paper such as this, of our recounting certain salient events that have brought remote sensing to its present status. In answer we submit the following: By so doing we will be better able not only to forecast future progress in the application of remote sensing to wildlife management but also to suggest some of the future activities that should be undertaken in order to maximize that progress.

A scant 4 months ago the present writer prepared a paper, soon to be published, entitled "History and Future of Remote Sensing Technology and Education". (Colwell, 1978). In that paper a rather comprehensive treatment was given relative to the history, present status and future potential of remote sensing as applied to the inventory and management of such natural resources as timber, forage, soils, water, minerals, agricultural crops, wildlife and recreational resources. Among the remote sensing-related developments that are discussed in that 90-page tome are those itemized below:

1. Remote sensing observations of our progenitor, the cave men.
2. Observation regarding the properties of light, as made by ancient philosophers in about 350 B.C.
3. Development of the camera obscura in the 14th century.
4. Development of the first practical photography in about 1840.
5. First successful attempts in the development of aerial photography in the 1850's.
6. The development of roll films and navigable camera platforms (aircraft) at about the turn of the century.
7. The impetus given to remote sensing by World War I.
8. The tremendously increased availability, during the 1930's, of aerial photographs for use by the managers of natural resources.
9. The impetus given to remote sensing by World War II.
10. The development of color and infrared-sensitive films, largely during the 1930's and early 1940's.
11. The post-war surge of interest in photo interpretation throughout the 1940's and early 1950's, and
12. Improvements during the past quarter century in sensor platforms, sensor systems and data analysis capabilities.

In the following sections of the present paper, the last of the above-listed items is developed quite fully as we seek to describe accurately the present status of remote sensing. Furthermore the first 11 of those items are dealt with quite fully in the previously cited article. Hence no further details will be given here.

REMOTE SENSING DEVICES

In the present section emphasis will be placed on describing the construction and method of operation of the six types of remote sensing devices which show greatest promise for the inventory of natural resources. These are (a) the conventional aerial camera, (b) the panoramic camera, (c) the multiband camera, (d) the optical mechanical scanner, (e) the side-looking airborne radar device (SLAR), and (f) the gamma ray spectrometer. Our purpose in describing here the construction and method of operation of these devices is to provide the reader with a better appreciation of how they relate to each other so that he might have a better appreciation of both the uses and the limitations of each.

The Conventional Aerial Camera

The basic components of a modern aerial camera are well known to virtually all of those who are in attendance at this symposium. These components consist of the magazine, drive mechanism, cone and lens.

The magazine is essentially a light-tight box in which the photographic film is held. In most cases it is detachable from the rest of the aerial camera. The film as received from the manufacturer, usually is in the form of a continuous roll, 9-1/2 inches wide and 200 feet long, mounted on a supply spool. Approximately 250 exposures, each 9 inches square, can be taken on such a roll. Both the supply spool and the take-up spool fit snugly inside the magazine.

The drive mechanism is a series of cams, gears, and shafts designed to drive the film from the supply spool to the take-up spool. The film, in passing from one spool to the other, is routed, via guide rollers so constructed as to meter the amount of film passing from the supply spool to the take-up between exposures, thereby assuring a correct and uniform spacing of exposures on the film roll. As a result of this recycling operation, an unexposed portion of film is properly positioned in front of the locating plate between exposures.

The cone is a light-tight element which serves to properly position the camera lens with respect to the exposable portion of the photographic film. The perpendicular distance from the film to the rear nodal point of the lens (of the camera) is known as the focal length. Most aerial photography currently taken for the inventory of natural resources employs focal lengths of either 6, 8-1/4, or 12 inches.

The lens consists of several carefully ground and mounted glass elements which sharply focus on the photographic film the light rays reflected to the lens by illuminated objects on the ground.

On most aerial cameras the shutter is located between the front and rear lens elements and accordingly is termed a "between-the-lens" shutter. In recycling the camera between exposures, the camera drive mechanism automatically re-cocks the shutter at the same time that it draws a new portion of unexposed film into position.

The Panoramic Camera

The principle on which the panoramic camera operates is indicated diagrammatically in Figure 2. With this camera it is possible to photograph a large area in a single exposure at very high resolution (i.e., with a high degree of image sharpness in every part of the photograph). The camera meets a need but creates some special problems. In order to get a sharp image when photographing large areas, one paradoxically needs a narrow angular field so as to minimize aberrations of

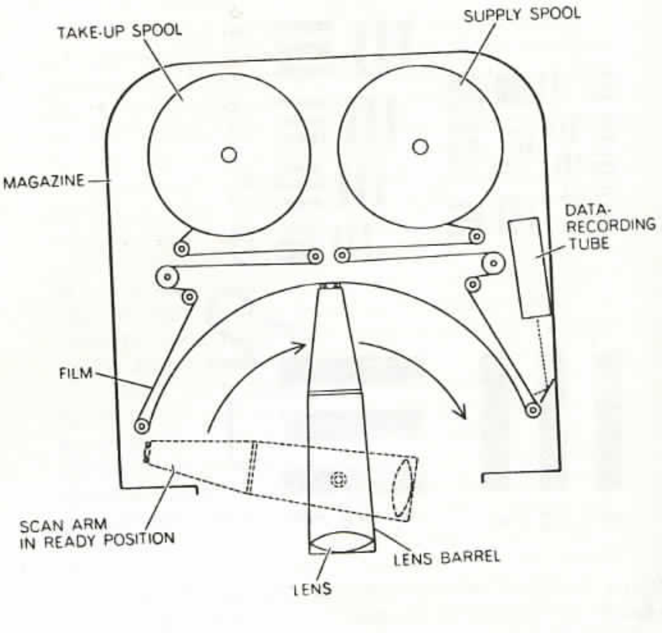

Figure 2.--A Panoramic Aerial Camera

the lens. Such a field is provided in the panoramic camera by a narrow slit in an opaque partition near the focal plane of the camera. The slit is parallel to the camera platform's line of flight. With such a slit, however, one will be able to photograph only a narrow swath of terrain unless the optical train of the camera is equipped to "pan" (move from side to side) as the aircraft advances. The optical train of the panoramic camera is designed to make such movements.

On the other hand, for the panoramic camera to maintain a uniformly clear focus as the optical train moves, the frame of film being exposed must be held in the form of an arc instead of being kept flat, as in a conventional camera. With the film in an arc the photographic scale becomes progressively smaller as the distance of objects on the ground increases to the left and right of the flight path. In some applications the scale problems outweigh the advantage of a panoramic field of view, so that it is preferable to use a conventional camera. There are many resource managers, however, who are beginning to make very effective use of the panoramic camera to obtain with only a limited number of flight lines, ultra high resolution imagery of very wide swaths of terrain.

The Multiband Camera

As previously indicated, far more information frequently can be obtained about natural resources from a study of images taken simultaneously in each of several wavelength bands than is obtainable from images taken in any one band. Realization of this fact has led to the development of various multiband cameras for the taking of simultaneous photographs in each of several spectral bands. Such a camera permits exploitation of the concept of multiband spectral reconnaissance throughout the visible and very near infrared parts of the electromagnetic spectrum (roughly 400 to 900 millimicrons). With it one can take simultaneous exposures of exactly the same area, using several spectral zones. By proper choice of photographic film and filter, the limits of each spectral zone can be controlled, as necessary, to obtain the maximum amount of the desired information from that zone.

For both conventional cameras and multiband cameras, film transport mechanisms have been significantly improved. Through employment of a principle known as "forward motion compensation", the film can be made to travel, even during the instant of exposure, at a rate commensurate with the rate of travel of images at the focal plane, caused by the camera's forward motion as the aircraft or spacecraft flies along. By this means, sharper images can be obtained since the image of any particular feature is in effect "frozen" to the same spot on the film during the entire time that the exposure is being made. Such a refinement is necessary to minimize "image blur" when taking aerial photos of the Earth's surface from high speed aircraft at low altitudes.

The Optical Mechanical Scanner

In an optical mechanical scanning system, the "collecting optics" is in the form of a mirror, or series of mirrors, rather than a lens. When multiband reconnaissance must include sensing in the thermal infrared region the optical mechanical scanner can provide photo-like images, whereas cameras of the types previously described cannot.

There are at least two reasons why reflective optics rather than refractive optics are used in an optical mechanical scanner, both related to problems of sensing in the thermal infrared part of the spectrum:

1. Relatively few materials can instantaneously transmit energy in any part of the thermal infrared region, and even fewer over the very wide range of wavelengths for which thermal infrared scanning is desired; and
2. Refracting lens systems are unable to sharply focus, in a single focal plane, all radiant energy from a wide spectral band (i.e., one that encompasses a very wide wavelength range, such as the thermal infrared). Both difficulties are overcome through the use of first-surface mirrors as reflecting optics.

An additional problem prevents the obtaining of thermal infrared imagery with a camera of conventional design. This problem pertains to the recording of images in a photo-like form. Thermal infrared sensitive materials can be produced that are similar to the light-sensitive silver halides of a photographic film. However, if such materials are made to respond at ambient (environmental) temperatures, how can they be kept from becoming fogged due to gradual exposure, even as they repose, ready for use, inside the infrared camera? Even the interior of such a camera (the portion facing the film) is continously emitting thermal energy. Therefore, just as the conventional camera must be a "light-tight box" (if it is to prevent light sensitive film from fogging) so a thermal infrared camera would have to be a "heat-tight box" if it were to prevent heat sensitive film from fogging. In fact, the box would have to be cooled to a temperature of nearly absolute zero. Even if the required termperature could be achieved for such a sizable structure, the weight and volume requirements for the cooling equipment which would maintain the system at this low temperature would prohibit its use in most aircraft or spacecraft. Furthermore, at such a low termperature additional problems would be entailed because of brittleness of both the film and certain of the camera components.

The solution which modern science has devised for the problem just described is the optical mechanical scanner. This device consists essentially of three parts:

(1) the energy collector or scanning mechanism
(2) the detecting mechanism and
(3) the recorder.

The design of the energy collector reflects the previously-mentioned fact that no satisfactory means has as yet been found (when working with thermal infrared wavelengths) for simultaneously imaging separate elements in a wide angular field, the way a conventional camera does. Instead, it is necessary to focus on one small element at a time, and the size of this small "instantaneous field of view" determines the pictorial resolution.

All of the photons collected by the scanner within its instantaneous field of view are focused on the detector. There they generate an electrical charge. If sensing is being accomplished in the thermal infrared region, the greater the thermal energy being emitted within this field of view the greater the charge or signal that is generated. This signal is then used to modulate a visible light source such as one "instantaneous element" of a cathode ray tube. The output signal is made to scan the cathode ray tube in the same pattern as the collecting optics scanned the scene beneath the aircraft. The mirror of the collecting optics rotates on an axis that is parallel to the flight line and thus scans a line that is lateral to the flight line. The mirror looks at only one small portion of the terrain at any given instant, and the beam collected illuminates only a correspondingly small spot on the cathode ray tube and on the photographic film placed in front of the tube (Figure 3) at the same instant. The rotating mirror, aided by other elements of the optical train, thus images a swath of terrain across the film. By the time one swath has been painted on the film two events have occurred:

(1) the reconnaissance vehicle has advanced sufficiently so that one of a series of companion mirrors mounted in other positions on the same rotating shaft begins to look at the next continous swath of terrain, and
(2) each piece of film <u>in the multiband installation</u> has advanced sufficiently in its focal place so that this next swath is painted on the film in proper juxtaposition to the first swath. The density of each portion of the exposed film is in direct proportion to the strength of the infrared signal coming from the corresponding terrain. Hence, as the aircraft advances the film advances and a continuous photo-like image (therogram) is formed.

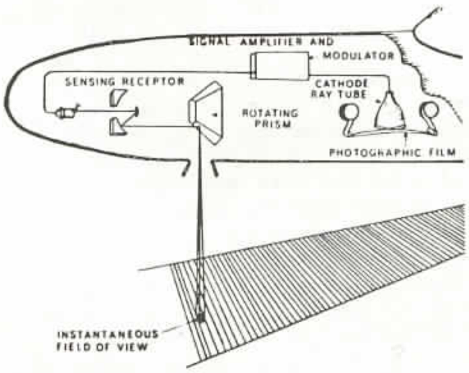

Figure 3.--Principles of an optical mechanical scanner

The Side-looking Airborne Radar Device (SLAR)

Because of its all-weather, day-and-night capability, and its partial ability even to penetrate the vegetation canopy and sense the terrain beneath, radar equipment is of great potential interest to those who seek to inventory wildlife-related resources by means of remote sensing. However, radar devices operate at much longer wavelengths than any of the equipment previously described. Consequently, difficulties arise in acquiring high resolution imagery with such devices because, as with any diffraction-limited system, the longer the wavelength the poorer the resolution.

Tremendous improvements have been made recently in the quality of radar imagery because of the development of SLAR equipment having the characteristics described below.

A transmitting antenna in the reconnaissance aircraft sends out a short pulse of microwave energy to one side of the aircraft and thus illuminates the roughly circular lobe on which points A and B have been annotated in figure 4. This lobe corresponds to the instantaneous field of view in a "diffraction limited" radar system.

A receiving antenna mounted in the same aircraft collects energy reflected back from the illuminated terrain. The greater the distance from aircraft to target, the greater the time delay in return of the reflected signal. Through accurate measurement of the time delay, it is possible for this equipment to differentiate returns from various small concentric "rings". Each ring represents the locus of all points within the illuminated circle that are roughly equidistant from the aircraft. Within any ring there is a spot, just opposite the aircraft, that moves along at the same speed as the aircraft. At any given time the distance from the aircraft to all other points on the ring is either increasing or decreasing. Consequently, through the Doppler effect, the microwave energy reflected back to the aircraft from such points is of a different frequency than that which had been transmitted to them by the radar pulse. The radar receiver is designed to accept those wavelengths which are of approximately the same frequency as the initial pulse, but to reject those of significantly different frequencies.

Because of the two discriminating features just described, the only energy accepted by the radar receiver at any given instant is that which satisfies two conditions:

(1) it is in the narrow ring within which time delay is such that the energy is at that instant striking the receiving antenna and
(2) it is in that particular part of this ring which is directly opposite the aircraft (the area having zero relative velocity with respect to the aircraft and therefore exhibiting no Doppler frequency shift). The combination of these factors effectively provides a "sensing capability" that greatly improves the spatial resolution of the system.

In order to record this accepted energy in photo-like form, two other radar components are used: a cathode ray tube and a roll of photographic film. The strength of the signal determines the brightness of a dot. The position of this dot on the cathode ray tube changes synchronously with the antenna scan. Thus, for any given scan line, the signal that first returns is that from the inner edge of the illuminated area and is imaged at the bottom of the cathode ray tube. As time goes on, the return signals come from farther and farther away and are directed farther and farther up the scan line on the cathode ray tube. At the time the signal is returning from the farthest point illuminated, the spot on the tube has moved all the way from the bottom to the top. Photographic film which (as in the optical mechanical scanner) is in juxtaposition to the tube is exposed by this means, one line at a time. By the time the next pulse is transmitted, the film has advanced slightly and so has the aircraft. The density of each portion of the exposed film is in proportion to the brightness of radar signal coming from the corresponding spot on the terrain. As the aircraft advances, the film advances and thus a continous photo-like record of the terrain is produced.

Although the five devices which have just been described are the primary ones used for imaging the terrain, certain others are in the process of being developed. One of these is for the sensing of passive microwaves (in contrast with radar which is an active microwave sensor). It relies on thermal differences emanating from the terrain and, because of the long wavelengths which it employs, can produce a discernible image of a fire even through dense clouds.

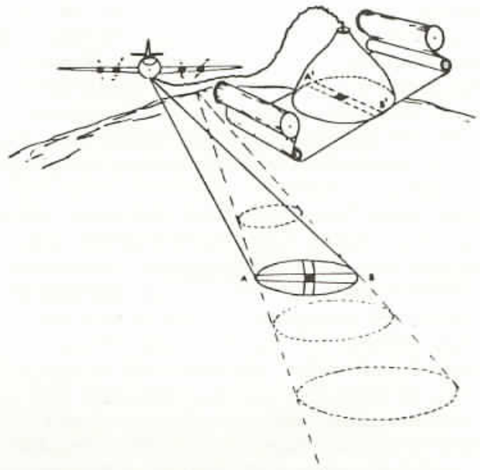

Figure 4.--Side-Looking Airborne Radar (SLAR) equipment

The Gamma Ray Spectrometer

This device is designed to exploit the fact that many minerals sought by the geologic prospector emit gamma rays because they are either naturally radioactive or are chemically combined with components which, in turn, are radioactive. When airborne, this device measures incoming gamma radiation primarily from that portion of the earth's surface that is beneath the flight path of the aircraft. It can measure both the total gamma ray output and the spectral output of gamma rays in as many as 400 channels or spectral bands, each of which may contribute to the identifying signature of some radioactive substance.

The energy of each gamma ray given up within the detector provides a proportional electrical pulse which is sorted out by a multichannel analyzer to provide radiation spectra. Such a device ordinarily will be of less interest to the manager of wildlife resources than are the 5 which were previously described. We can readily envisage one notable exception, however. If the gamma ray spectrometer were to establish that large deposits of radioactive ore occurred within a particular wildlife refuge, we could be virtually certain that miners would seek authority to extract this ore, however severe the damage to the refuge were likely to be.

PHOTOGRAPHIC FILMS

Three of the devices described in the preceding section (viz., the conventional camera, the panoramic camera, and the multiband camera) form images on film that is placed directly in the focal plane of the "collecting optics" or lens system. Some rather delicate choices sometimes must be made by the wildlife manager when deciding exactly which type of black-and-white or color film will be used when photographing specific wildlife areas.

As the term "panchromatic" implies, these black-and-white films are about equally sensitive to all parts of the visible spectrum, although with some modification as indicated in the preceding paragraph. The human eye also is "panchromatic" in the same sense. Consequently, the relative tones or brightness values of objects are essentially the same on panchromatic photography as those seen directly by the human eye. The resulting natural appearances of features may greatly facilitate their photo identification. Herein lies one of the primary advantages of panchromatic photography for those wishing to interpret natural resource features on aerial photographs.

The spectral sensitivity of infrared-sensitive black-and-white films is from about 0.36 to 0.90 microns. Consequently, to obtain pure infrared effects with it, the ultraviolet and visible wavelengths to which it is sensitive should be screened out by use of a Wratten 89B filter, or equivalent. In various multiband camera systems, the fact that this film also is sensitive throughout the visible spectrum is fully exploited. Specifically, many multiband camera systems are designed to register the several multiband scenes (including bands in both the visible and near-infrared regions) on a single piece of film to facilitate the subsequent registration of the scenes when they are optically combined and color coded.

Healthy broad-leaved vegetation has very high infrared reflectance and therefore photographs very light in tone on this film. When such vegetation becomes unhealthy (e.g. due to damage done by diseases, insects, drought, fire, mineral deficiency or mineral toxicity) it is likely to undergo a loss in its ability to reflect infrared light, even before any other change in its spectral behavior occurs. Consequently, it is of more than passing interest to the manager of wildlife-related resources that infrared photography may provide him with "previsual symptoms" of unhealthy conditions that are developing on the broadleaved vegetation within certain parts of a landscape that he seeks to evaluate. Conversely, if the broadleaved vegetation registers only in light tones on infrared photography, the resource manager can be reasonably sure that it is not suffering from any of these maladies.

Aerial color films are of three types:

(1) color positive films
(2) color negative films, and
(3) false color films

Each is potentially useful to the natural resource manager for specific purposes. However, the cost of obtaining such photography, when compared to that of black-and-white photography, is not always justified by the additional information which it provides. Many of the papers that are to be given at this symposium will describe the properties, uses and limitations of various kinds of color films. Hence no further details will be given here.

PHOTOGRAPHIC INTERPRETATION

Remote sensing in its broadest sense, pertains not only to the acquisition, but also to the analysis of aerial photos, space photos and related data. If the analysis is done by humans rather than by machines, it is called photo interpretation, which is defined as the act of examining photographic images for the purposes of identifying objects and judging their condition or significance.

Most photo interpretation is done from vertical photographs, and the vertical view presents objects on the Earth's surface in an unfamiliar aspect. To work with the vertical view, the photo interpreter must revise his ideas of the external world and acquire new habits of observation. Moreover, objects are imaged on aerial and space photography at very small scales. Because of the vertical view and the small scale, some elements of appearance assume greater importance in aerial and space photography than in the ground view.

The interpreter of aerial or space photography must learn to pay special attention to the following characteristics of photographic images: size, shape, shadow, tone or color, texture, pattern and association. These attributes and their uses are fully discussed in many books, including those of the American Society of Photogrammetry (1960, 1966, 1975). This and related topics are updated in an article by Colwell, Poulton and Schrumpf (1978).

Many image characteristics may provide clues to the identity of an unknown object. None of the clues is infallible by itself; but if all or most of the clues point to the same conclusion, the conclusion is probably correct. Photo interpretation, then, is actually an art of probabilities. The principle involved here, known as "convergence of evidence" requires the interpreter first to recognize basic features or types of features and then to consider their arrangement (pattern) in the areal context. Several interpretations may suggest themselves. With the aid of photo interpretation keys critical examination of the evidence usually shows that all interpretations but one are unlikely or impossible.

Photo interpreters can measure the exact dimensions of images by means of scales and other instruments. Generally, however, measurement in photo interpretation consists of a visual estimate of the size and shape of an object; reasonably correct estimation of dimensions is essential to correct identification. Such further activities as plotting and drawing to known scales may also be regarded as a particular form of measurement.

The arrangements of images in photographs admit of systematic photo interpretation because the orderly way in which the objects are arranged on the Earth's surface permits important deductions to be made. From these deductions then, the interpreter communicates his response to a stimulus by labeling (naming or describing) the identified image.

A large body of knowledge about photo interpretation has been accumulated by patient correlation of photographic images with the corresponding features as viewed on the ground. Many established correlations are taught as basic knowledge in the various fields of photo interpretation. Nevertheless, in almost every job of interpretation there will be unknowns or uncertain conclusions which must be checked in the field. The interpreter must accept the responsibility of field checking whenever it is feasible, in order to make sure his work is right or, if it is wrong, to find out why. Some types of work require field correlation before and after the office interpretation. The amount of field work which will be necessary varies with the intensiveness and accuracy requirement of the study, the complexity of the area, the quality of the photographs, and the ability of the interpreter.

Photo interpreters need equipment for three general purposes: viewing, measuring, and transferring or recording detail. Viewing instruments provide either stereoscopic or two-dimensional views; measuring instruments may be used on single photographs or stereoscopic pairs; instruments which record or transfer detail do so through the use of the "camera lucida" principle, by projection, or by means of a pantograph.

The stereoscope, which provides the three-dimensional view of photographic images, is one of the most important instruments used in photo interpretation. The stereoscopic principle is exploited in many measuring and plotting instruments as well as those which are designed principally for viewing photographic images. The design of stereoscopic viewing instruments utilizes lenses or a combination of lenses, mirrors, and prisms.

The amount of useful information that can obtained by the image analyst may be increased if the imagery is first "enhanced" by such means as <u>density slicing, color coding, improving the signal-to-noise ratio, and combining multiple images into a single composite</u>. Some scientists advocate the use of multiple lantern slide projectors or other <u>optical</u> devices for this purpose. Others prefer the use of closed-circuit color television equipment or other <u>electronic</u> devices. A combination of optical and electronic devices, however, usually produces the greatest amount of useful information, especially when several multidate and/or multiband images of the same area are available, each containing different kinds of information.

THE "MULTI" CONCEPT

During recent years progress in the field of remote sensing has been characterized by the development of <u>multiple</u> data acquisition capabilities and <u>multiple</u> data analysis techniques. This progress has, in turn, given rise to the need for more clearly understanding both the advantages and the limitations that are inherent in what tentatively might be termed the "multi" concept as applied to the acquisition and analysis of remote sensing data. This concept is of great significance in relation to the potential usefulness of both aerial and space photographs for the inventory of wildlife and related resources.

Remote sensing scientists are compiling an ever increasing and highly impressive list of examples which demonstrate, collectively, that:

(1) More information usually is obtainable from multiband photography than from that taken in only one wavelength band.

(2) More information usually is obtainable from multidate photography than from that taken on only one date.

(3) More information usually is obtainable from multistage photography than from that taken from only one stage or flight altitude.
(4) More information usually is obtainable through the multienhancement of this photography than from only one enhancement.
(5) More information usually is obtainable by the multi -disciplinary analysis of this photography than if it is analyzed by experts from only one discipline; and
(6) The wealth of information usually derivable through intelligent use of these various means usually is better conveyed to the potential user of it through multi thematic maps, i.e., through a series of maps, each dedicated to the portraying of one particular theme, rather than through only one map.

All of the foregoing principles of the "multi" concept are illustrated and fully discussed in Chapter 1 of the "Manual of Remote Sensing". (Amer. Soc. Photogram., 1975)

As remote sensing scientists attempt to define the proper interaction between humans and machines they appear to agree, more and more, on the following two broad generalizations:

(1) the delineation of major ecological entities and/or "land systems" is best based upon spatial patterns and related texture differences and hence is better done by humans;
(2) the identification of sub-elements within each such delineated area, however, is best based upon multiband tone signatures, (readily expressed in digital form) and hence is best done by machines.

A LOOK TO THE FUTURE

In a previously cited paper (Colwell, 1978) several predictions with respect to the future of remote sensing are listed and amplified upon. Suffice it here merely to list certain of these predictions that are likely to be of greatest interest to those who will seek to inventory and manage wildlife resources in the future:

(1) There will be very substantial progress toward the development of a globally uniform information system, based primarily upon remote sensing-derived data.
(2) There will be a very appreciable reduction in the presently intolerable delay between data acquisition by remote sensing satellites and the supply to users of needed information derivable from such data.
(3) Great progress will be made with respect to the "compression" of remote sensing data.
(4) Great progress will be made in an area of remote sensing data reduction that is known as "change detection".
(5) There will be a very significant increase in the amount of high-resolution remote sensing data of the type now being acquired by various military satellites that will be released and made available to non-military users.
(6) Space photography will largely replace "orthopotography", as presently produced, when the need is for a product that provides both the plan view and a large amount of photographic detail.
(7) There will be a significant resurgence of interest in improving the ability of humans to extract information from remote sensing data by direct visual means.
(8) There will be increased efforts to define the roles of humans and machines as they function as a team in the derivation of information from remote sensing data.
(9) There will be a better realization that the feasibility of using remote sensing techniques in any geographic area depends on whether that area is simply or complexly structured.
(10) There will be a better realization that the feasibility of using remote sensing techniques can be assessed in terms of several other considerations also, as discussed on the next page.
(11) There will be a greater borrowing by future remote sensing scientists of various applicable techniques and procedures that have been developed in other disciplines.
(12) "Synthetic stereo" will be used to an ever-increasing extent as an aid to the interpretation   space photography.
(13) "Shadow parallax" also will be exploited in the future as a means of perceiving on space photographs the three-dimensional characteristics of features.
(14) Future improvements in sensor capabilities and resource classification schemes will better conform to the requirements imposed by resource policy decisions and management objectives.
(15) Intelligent exploration of the "Multi" concept will greatly increase the amount of information derivable through use of modern remote sensing techniques.

By way of summarizing much of what has been said in this "overview" paper, the following are the main questions that one should ask when trying to predict the usefulness of remote sensing for the inventory and management of wildlife resources in a given geographic area: (1) Is the area simply structured, or is it complexly structured in terms of topography, geology and the associated number of vegetation types, soil types and differences in slope, aspect and elevation? (2) Are clouds, dust storms or other atmospheric conditions such that there are very few opportunities, year in and year out, for acquiring remote sensing data of the area? (3) Is there likely to be a long delay after the acquisition of remote sensing data before such data can be made available for analysis? (4) Is only one data analyst available, and is he inexperienced, poorly trained, poorly funded, poorly equipped, littled appreciated and poorly motivated? (5) Is it legally possible to implement, on this particular property, management decisions that will improve the habitat and the wildlife resources, or must efforts be limited to preserving the area in its present state? (6) Is it financially possible to implement those management decisions which are deemed most suitable, once consideration has been given to the relative cost-effectiveness of the various resource management alternatives?

The extent to which favorable answers can be given to these questions will govern, in very large measure, the extent to which remote sensing can facilitate the inventory and management of an area's wildlife resources.

LITERATURE CITED

American Society of Photogrammetry. 1960. Manual of Photographic Interpretation. George Banta Co., Menasha, Wisconsin. 944 pp. Illus.

________1966. Manual of Color Aerial Photography.

________1975. Manual of Remote Sensing. Keuffel and Esser. 2144 pp. Illus.

Colwell, Robert N. 1978. History and Future of Remote Sensing Technology and Education. In Proceedings of Conference of Remote Sensing Educators. NASA Western Regional Applications Program. In Press.

Colwell, Robert N., Charles E. Poulton, and Barry L. Schrumpf. 1978. The Reduction of Remote Sensing Data by Visual Means. In Proceedings of Conference of Remote Sensing Educators. NASA Western Regional Applications Program. In Press.

Remote Sensing for Regional Habitat Analysis in the United States[1]

H. Dennison Parker[2]

The U.S. FWS, Western Energy and Land Use Team has investigated the use of LANDSAT and color infrared aerial imagery for application to regional wildlife habitat analysis. LANDSAT data was deemed useful although difficult to quantitatively evaluate. Color infrared imagery is being used routinely by manual analysis methods, while automatic techniques are under study.

A major part of the goal of the FWS Western Energy and Land Use Team is the development of rapid assessment methodologies for regional wildlife habitat assessment. The reason for our attention to regional analyses is the increasingly rapid development of fossil fuel energy resources in the western U.S. These include the lignite region of North Dakota, the coal regions of Montana and Wyoming, the oil shale and coal areas of NW Colorado, and coal in Utah and New Mexico.

In these states, Five Regional Ecological Test Areas (RETA) were established by the Office of Biological Services in 1975, based on the distribution of known fossil fuel reserves. Because of the high degree of interest in Montana and Wyoming, those states are where we have concentrated most of our effort. Our RETA encompasses the Powder River Basin and is about 9,000 square miles in area.

Early in the planning stages for assessment of these test areas, remote sensing technologies were targeted as prime candidates for methods by which region wide assessments might be accomplished. We knew that the key to assessment of land for wildlife production is habitat value, and therefore concentrated on inventory mapping and evaluation of the habitat components in the study areas. The data being acquired will be stored in a geographic information system, which will also be capable of generating certain model outputs and indices to habitat value.

In looking at the various types of remote sensing methods that were available for our use, it was apparent that really only two basic media were feasible. One was color infrared (CIR) aerial imagery at a variety of scales; the other was LANDSAT data. In 1975, we decided to investigate both of these tools via contract research. A contract was awarded to the Bendix Aerospace Systems Division in Ann Arbor, Michigan, to classify the landcover on three of the five test areas using digital LANDSAT data. The purpose of the project was to attempt to determine the utility of a single digital LANDSAT data set for producing a regional classification of wildlife habitat. Rather than being a basic research effort, this project was directed at looking at an off-the-shelf, standard maximum likelihood classifier applied to operational problems. The study produced classifications of the Montana/Wyoming, Colorado, and Utah test areas which are now being used to stratify the area further for intensive analysis with color infrared imagery.

The Montana/Wyoming classification produced only 12 landcover classes. The work was hampered by a lack of adequate ground truth data, a problem which was subsequently corrected for the Colorado and Utah test areas. In Colorado, we generated 44 classes, and in Utah, 15 classes.

---

[1]Paper presented at the Fourth William T. Pecora Memorial Symposium, Sioux Falls, South Dakota, October 10-12, 1978.

[2]Manager, Data Support Group, U.S. Fish and Wildlife Service, Western Energy and Land Use Team, Fort Collins, Colorado 80526.

We planned to determine classification accuracy on randomly selected pixels for all test areas based on the ground truth acquired from the field exercise and from color infrared imagery. We specifically excluded the option of making accuracy estimates based on training area tests, since this approach doesn't yield accuracy estimates in an operational sense. What it produces is a test of some of the assumptions in the classification algorithm.

Because of CIR imagery interpretation problems and slight misregistration of the LANDSAT maps with ground truth data, the analysis aggregated several different error sources which we can identify but can't partition. As a result of these problems, it was not possible to quantitatively estimate the accuracy of these classifications.

Our approach to the use of color infrared imagery followed two courses. First, we believed that the primary drawback to the use of film data for regional applications was the time required for manual analysis. Therefore, we initiated a contract research project in 1976 to investigate the feasibility of computer classification of color infrared imagery after conversion to a digital format. This project, now nearing completion, was a joint effort of the HRB Singer Company with support from Colorado State University and the University of Wisconsin.

The approach followed was to first digitize selected frames of color infrared imagery with a drum scanner. The resulting digital data were then subjected to computer classification with a standard maximum likelihood classifier. Although not yet finished, the study is producing some interesting results which may have application to future regional assessments.

The development efforts on LANDSAT and CIR imagery begun in 1976 have provided information on the potential use of remote sensing techniques in the long term. However, they are not of immediate use for assessment of the test areas for wildlife habitat. In 1977 a new group was formed in the Western Energy and Land Use Team to commence operational application of remote sensing and computer technologies, the Western Data Support Group (DSG). The DSG has two missions, one developmental, and the other operational.

First, the DSG is establishing a capability for applying advanced technologies to Fish and Wildlife Service goals throughout the Western U.S. Operationally, we are applying these technologies to wildlife characterization of the ecological test area in Montana and Wyoming. We have a staff of approximately 20 people mostly provided by the support contractor, HRB Singer, Inc.

DSG developmental activities over the past year have been largely confined to establishment of operational computer and remote sensing laboratories. On the operational side, we are applying color infrared imagery to a habitat inventory of the Montana/Wyoming test area. This inventory data will be used to characterize the test area for wildlife habitat values. The color infrared imagery being used is 1:31,680 scale obtained in 1976.

To reduce the mapping effort to one of manageable size on this 9,000 square miles, a spatial resolution of 40 acres was decided upon for aereal features; point features are being mapped as detected. The classification scheme being used was designed by the DSG specifically for the purpose of providing input information for wildlife habitat characterization. (See Table 1 in paper by Craig Tom, this proceedings.) It is an experimental classification system which is subject to modification as we proceed with our investigations.

The analyses are being performed on conventional stereoscopic interpretation equipment to produce overlays of each image at image scale. These overlays are transferred to a standard USGS quad with zoom transfer scopes. The resulting map separates are scribed, paneled, photo reduced to 1:100,000 scale, and color-coded to produce the final map.

Field studies of the accuracy of the analysis results were conducted this summer for portions of the test area on which the mapping was complete. Results of the analyses to date have indicated 83% to 85% correct overall accuracy at a 95% confidence level. The image analysis work for this project will be completed in November 1978, and the mapping, in April 1979.

The general application of remote sensing techniques to regional wildlife habitat inventory is a very broad subject and includes a wide array of sensors, processing methods, and approaches. Our experience over the past two years has highlighted some of the considerations involved, and has also indicated areas where new research is needed.

Probably the most important consideration in applying remote sensing to regional wildlife habitat inventory is not technical at all. It is the definitive specification of the questions that need to be answered by the data that you gather. In many cases the remote sensing data alone will answer few if any questions. Rather, it will constitute a data resource which, when considered along with other types of information, can yield answers to the questions posed. In our case, the information alone, landcover maps, is of little use in assessing the value of the landscape for wildlife. Considerable manipulation and study of the data in a regional context, by wildlife biologists, is required to convert the basic landcover map to a true habitat map. In essence, we are not mapping habitats, we are mapping habitat components. These components, when integrated in terms of particular wildlife species or groups of species, can lead to production of habitat maps.

Advance specification of the questions to be answered, the reasons for the study, can also lead to detailed specifications for the needed data. One of the most important of these is spatial resolution, the minimum size of land units that will appear in the final map. In the case of digital data, that decision is made for you by the pixel size. But in manual interpretation of CIR imagery, or other types of data, it is necessary to specify the desired resolution in advance.

On most regional applications one is required to settle for less than the full complement of data he would like to have. Even with remote sensing methods, the time and cost involved in wide area assessments can be prohibitive. Therefore, considerable attention should be paid to the number and size of land units to be inventoried, especially if manual analysis of image data is the analytical method chosen. In some cases, statistical sampling is indicated rather than complete coverage of the area being investigated. In our case we opted for complete coverage but chose 40 acres as a minimum area to be mapped. Therefore, with the exception of certain point and linear features of great importance, the inventory will not record any landcover units smaller than 40 acres in size. In other, more restricted studies during the same period, we've specified resolutions of 1 to 5 acres where more detail was required.

In any case, the resolution specified should, (1) Be adequate to satisfy the needs of the study and, (2) Be achieveable within the time and cost constraints involved. If these two considerations prove to be mutually exclusive, a statistical sampling approach will probably be necessary.

The resolution, time, and cost of a project may well dictate the remote sensing medium to be used, although there may be no choice. As a practical matter, only two media are available for application on a regional scale which are within the budgets of most studies--aerial photography and LANDSAT data.

In the category of aerial photography, color infrared film is clearly superior to other film types due to its utility for vegetational analysis. The scale chosen is a function of the information requirements of the project. In our case, medium scale (1:31,680) imagery was obtained because of our need for both site-specific and regional information. However, high altitude, small scale imagery may be adequate for many regional investigations. The Fish and Wildlife Service, National Wetland Inventory is using high altitude CIR imagery almost exclusively.

In its simplest form, film imagery, LANDSAT data is probably the most economical medium available for regional wildlife habitat mapping. Enlarged LANDSAT transparencies or prints of full scenes cover approximately 10,000 square miles. In multi-band color composites, they portray major vegetation groupings well enough for interpretation by the naked eye. However, maps produced by this method may be generalized to the point where utility in the continental U.S. may well be questionable. In areas of the world less well known, such a product may be of substantial use. A series of maps interpreted from LANDSAT imagery depicting habitat distribution change over time may also be of considerable value.

It is apparent to us that digital LANDSAT data is far superior to film data, in terms of ground resolution. However, as has been shown by our experience, the accuracy of the maps produced may be difficult to evaluate. Also, optimal use of LANDSAT data may only be realized where facilities exist which will permit use of some of the more advanced data processing methods. These include various types of pre and post processing, registration of the data against previous LANDSAT data sets, and registration to accurate cartographic map bases. In addition, LANDSAT data should not be used for any application unless adequate provision is made for the acquisition of adequate ground truth data.

In summary, remote sensing methods are definitely useful for regional wildlife habitat evaluation. Some methods like basic film image analysis are here now and are being applied operationally. Others await further development. In terms of cost effectiveness, remote sensing methods may have the edge over ground techniques. Our LANDSAT classifications of approximately 16,000 square miles in the western U.S. cost about $9 per square mile, including ground truth costs. The color infrared image analysis is costing about $11 per square mile.

While imperfect in many respects, remote sensing methods are clearly advantageous for habitat assessments over thousands of square miles in reasonable time periods. They can provide data obtainable in no other way. Our emphasis now must be on the difficult biological questions to which this data can be applied.