Use of Multispectral Aerial Photography for Assessing Takahe Habitat[1]

J A Mills[2] and A D W Fowler[3]

Abstract.-- The habitat of the endangered takahe *Notornis mantelli* in the Murchison Mountains, Fiordland National Park, New Zealand, was assessed from multispectral aerial photography. From correctly colour-balanced false colour composites the tussocks preferred by the bird (*Chionochloa pallens* and *C. flavescens*) were able to be identified from non-preferred species. In territories which were known to be infrequently used, the imagery showed only small amounts of preferred tussocks. Future applications and research are discussed.

INTRODUCTION

The takahe, *Notornis mantelli*, is an endangered flightless rail, endemic to New Zealand. The total population is less than 250 and is restricted to about 650 km^2 within the Fiordland National Park, comprising the Murchison Mountains and a small area to the north (fig. 1). During the snow-free period which extends for 7-8 months of the year, takahe inhabit the alpine snow tussock grasslands, feeding on the succulent basal portions of three tussock species (*Chionochloa pallens*, *C. flavescens* and to a lesser extent *C. crassiuscula*), a mountain daisy (*Celmisia petriei*) and when available, the seeds of tussocks and grasses (Mills and Mark 1977). In winter, when snow covers the grasslands, takahe descend into the adjacent beech forests (*Nothofagus* spp.) and feed primarily on rhizomes of the fern *Hypolepis millefolium*.

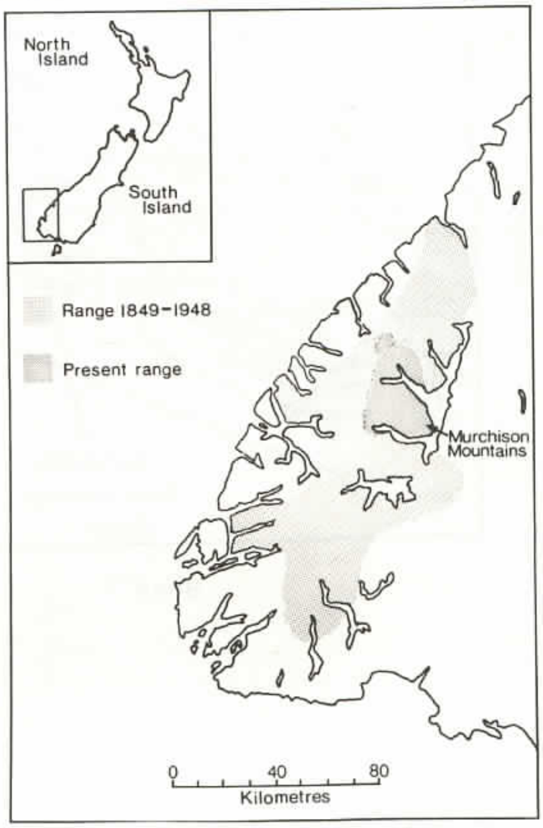

Figure 1.--The south-west of the South Island of New Zealand showing the present and past (1849-1948) distribution of takahe (after Reid 1974).

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Since 1967 the takahe population has undergone two major declines. The first, which occurred between 1967 and 1972 (Reid 1971, Mills 1975) resulted from habitat modification by introduced red deer *Cervus elaphus* (Mills 1977, Mills and Mark 1977). In recent years deer numbers have been reduced by control operations (Parkes *et al* in press), and as a consequence the grassland habitat has markedly improved and takahe numbers have increased very slowly. However, between November 1976 and May 1977 another decline occurred which coincided with a period of exceptionally high stoat (*Mustela erminea*) numbers. Whether this coincidence was fortuitous or not needs further investigation.

One problem in the conservation of takahe is that the species generally has an extremely low survival rate of chicks. (Reid 1969, Mills 1975). Furthermore in some areas there is consistently no breeding success (Mills in press). It is suspected that the quality of the vegetation present may be an important factor in determining chick survival. Management trials are planned (Mills *et al* in press) to assess whether artificially fertilizing the tussocks in "poor" breeding areas will increase fecundity. If successful, fertilizing will be extended to other areas. However, because takahe are found in a National Park the administering authorities may not be very receptive to widespread modification of the vegetation by the application of fertilizers. Therefore fertilizing would have to be confined only to territories which had a history of poor breeding success. It is also planned to shift some birds from poor breeding areas to more promising areas where birds previously occurred prior to the introduction of red deer.

Identification and assessment of suitable takahe habitat over a large area of mountainous country requires a substantial field involvement. In an attempt to reduce this commitment, multispectral aerial photographs have been taken of approximately 65 km^2 of alpine grassland over the area where a population and breeding study of the takahe was conducted between 1972 and 1975.

This paper presents a preliminary analysis of these photographs to determine whether tussock species preferred by takahe can be identified and whether areas temporarily occupied by the bird can be distinguished from permanent territories.

PHYSIOGRAPHY OF THE STUDY AREA

The Murchison Mountains have been extensively glaciated and range in altitude from 213 m (700 ft) to 1706 m (5600 ft). The grasslands are composed of associations dominated by five tussock species - *Chionochloa pallens*, *C. flavescens*, *C. crassiuscula*, *C. teretifolia* and *C.acicularis*. The tussock species may occur together but more often are segregated according to differences in altitude, aspect, slope and degree of soil development particularly as it affects nutrient status and drainage (Mills and Mark 1977). Over a wide elevational range, *C. Pallens* dominates well-drained and often steep slopes, especially on fans and debris slopes with immature soils, but it frequently occurs mixed with *C. crassiuscula*. *Chionochloa teretifolia* and *C.acicularis* typically occupies seepage and other poorly drained sites. The more mature soils on cooler aspect slopes and higher altitudes are covered with *C. crassiuscula*. *Chionochloa flavescens*, usually in association with scrub, occupies moderately drained slopes.

METHODS

The only cloud-free Landsat image of the Murchison Mountains available (No.2824-21214) was enhanced in colour directly from a computer compatible tape using an "Optronics Colorwrite" machine but the subscene was difficult to interpret because of the low resolution and the shadows produced in the mountainous country.

In order to obtain suitable resolution the study area was photographed at scales of 1:8000 and 1:63360 from a twin-engine "Aero Commander" at noon on 6 February 1978. The multispectral camera used was a four camera "Hasselblad" system developed by Physics and Engineering Laboratory (McDonnell *et al* 1977). Nominal Landsat MSS band filters 4,5, 6 and 7 were fitted over the 100 mm matched focal length lenses. The cameras with the MSS 4 and 5 type filters were loaded with Kodak 2403 Tri X aerographic film, and those with MSS 6 and 7 type filters contained Kodak 2424 infra-red film.

Using a stainless steel spiral, the Tri X 2403 film was processed in D-19 developer at 20°C for eight minutes, and ten minutes for the infra-red film, resulting in a gamma of approximately 1.5. This rather high gamma has been found to give a much better colour range when composites are made.

Initially 20 x 20 cm black and white prints were made of all imagery but differentiation of tussock species was not possible and so colour composites were made from the following MSS bands:

MSS band	Spectral range	Printing Filter
4	Green and yellow (0.5-0.6 µm)	Blue
5	Red (0.6-0.7 µm)	Green
7	Near infra-red (0.8-1.1 µm)	Red

Different colour balanced composites were produced and were taken into the field for comparison with a ground test site. The 1:63360 (5 m resolution) imagery proved to be the most useful by "smoothing" unnecessary detail and giving a more synoptic view.

RESULTS

The false colour composites gave an intense red for beech forest and *Hebe* spp. scrub, brown for scrub composed of *Dracophyllum* spp and or *Coprosma* spp., intense blue or cyan for scree and bare rock, and when correctly colour-balanced gave a pinkish-orange for *C.pallens* and *C.flavescens* tussocks, a bluish hue to the pinkish-orange for mixed stands of *C. crassiuscula* and *C. pallens*, and a darker shade of blue for *C. crassiuscula*, *C. acicularis* and *C. teretifolia*. These colour patterns together with differences in texture enabled us to separate those tussocks preferred by takahe (fig. 2). *Chionochloa pallens* and *C. flavescens* could not be differentiated from each other.

A generalized map showing the distribution of *C. Pallens* and *C. flavescens* stands, interpreted from the colour composites is plotted in figure 2 together with the territories of takahe. The distribution and shape of the territories follow closely the configuration of these preferred swards. In those territories which were known to be infrequently used, the imagery showed only small amounts of preferred tussocks.

FUTURE APPLICATIONS AND RESEARCH

More research is needed into the spectral reflectances of tussock species to see whether different filters may give even better results. Work is well advanced with the development of a field spectrometer by the Physics and Engineering Laboratory and this could be used to measure the reflectance of tussock species in situ at different times of the year.

It is planned to extend photographic coverage over other areas to help locate suitable takahe habitat where unknown birds may occur or to which some birds may eventually be translocated.

With further research it is hoped that eventually "good" and "poor" breeding areas may be differentiated.

ACKNOWLEDGEMENTS

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LITERATURE CITED

McDonnell, M.J., I.L. Thomas, P.J.Ellis, A.D. Fowler, R.S. Mason, R.C.Child, and C.T. Nankivell. 1977. Data acquisition and distribution. Final Report Landsat II Investigation Programme No. 28230, Vol. I, pp 36-57. Physics and Engineering Laboratory unpub. report No. 587, DSIR, Lower Hutt, New Zealand.

Mills, J.A. 1975. Population studies of takahe, *Notornis mantelli*, in Fiordland, New Zealand. XII Bulletin of the International Council for Bird Preservation. 140-147.

Mills, J.A. 1977. Red deer as a factor in the decline of takahe numbers. *In* Seminar on science in National Parks 1976. National Parks Series 6. National Park Authority, Wellington, New Zealand.

Mills, J.A. in press. Population studies of takahe. *In* Proceedings of the seminar on the takahe and its habitat 1978. Fiordland National Park Board, Invercargill, New Zealand.

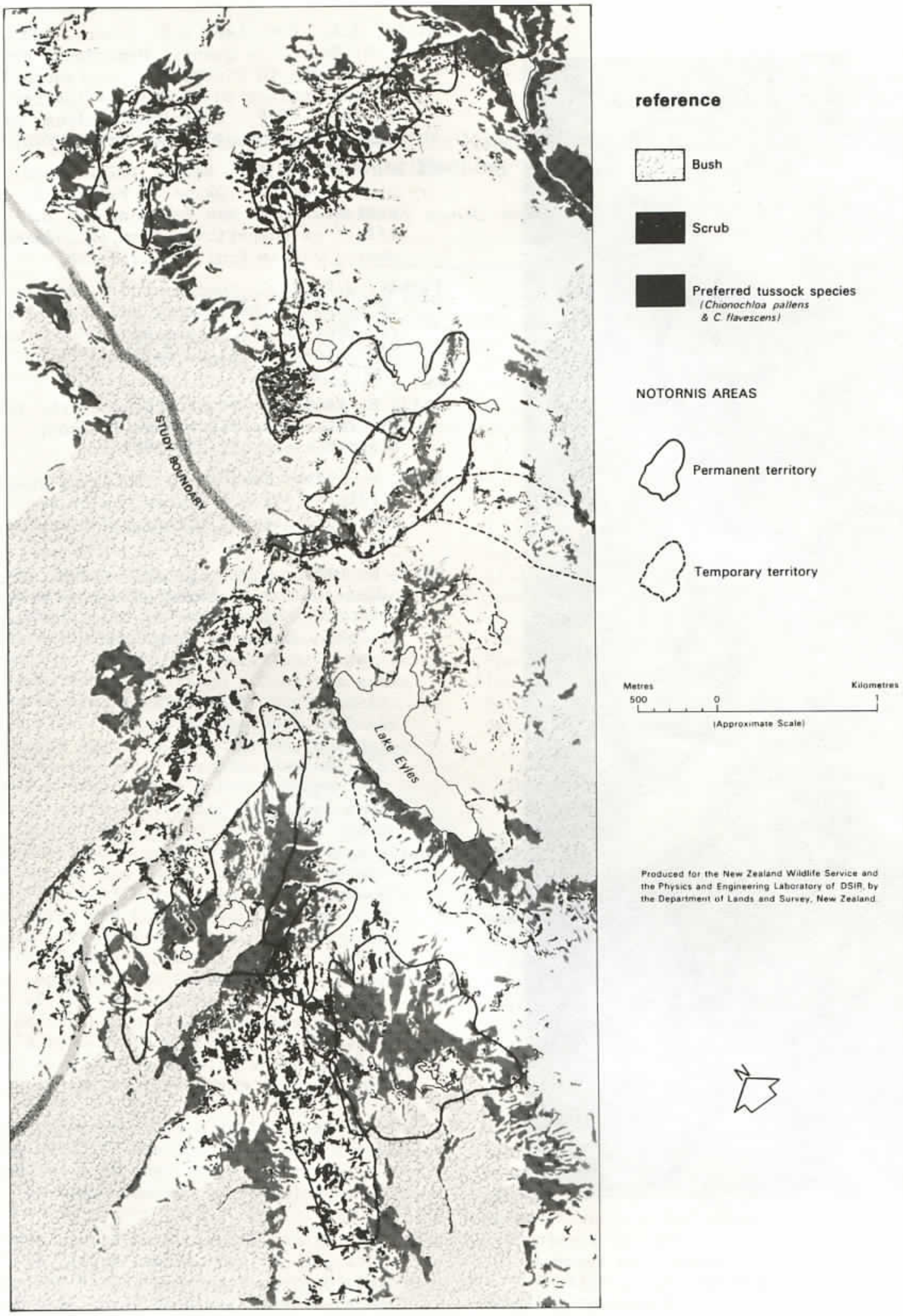

Figure 2.--A Generalized map of the distribution of the tussock species preferred by takahe (*Chionochloa pallens* and *C. flavescens)* interpreted from colour-composites. Superimposed are the territory sizes of takahe for the study area.

Figure 3.--A mosaic of the study area Nominal MSS band 7.

Mills, J.A., W.G. Lee, R.B. Lavers, and P.W. Shaw. in press. Management proposals for takahe in Fiordland. *In* Proceedings of the seminar on the takahe and its habitat 1978. Fiordland National Park Board, Invercargill, New Zealand.

Mills, J.A. and A.F. Mark. 1977. Food preferences of takahe in Fiordland National Park, New Zealand, and the effect of competition from introduced red deer. J.Anim.Ecol. 46, 939-958.

Parkes, J.P., K.G. Tustin, and L. Stanley. in press. The history and control of red deer in the takahe area, Murchison Mountains, Fiordland National Park, N.Z. J.Ecol. 1.

Reid, B. 1969. Survival status of the takahe, *Notornis mantelli*, of New Zealand. Biol. Conserv. 1, 237-240.

Reid, B. 1971. Takahe - a vanishing species. Wildlife 1971 - A Review, pp 39-42. Dept. of Internal Affiars, Wellington, New Zealand.

Reid, B. 1974. Sightings and records of the takahe (*Notornis mantelli*) prior to its "official rediscovery" by Dr G.B.Orbell in 1948. Notornis 21:277-295.

An Inventory and Assessment of Wildlife Habitat in Grand Canyon National Park Using Remote Sensing Techniques[1]

David A. Mouat and R. Roy Johnson[2]

Abstract.--The Grand Canyon Vegetation Mapping Project is designed to provide National Park Service scientists and resource managers with information to help them solve resource management problems. One example of such a problem is the burro controversy. Remote sensing through stepwise discriminant analysis is being used to gather the vegetation information. Correlation of the terrain with vegetation is the specific methodology.

INTRODUCTION

Grand Canyon National Park represents an area of extraordinary environmental diversity. Although the region is especially known for its unique geologic features, it also supports correspondingly striking vegetational complexity. Major vegetation types range across the gamut from desert scrub (dominated by such species as white brittlebush, Encelia farinosa; prickly pear, Opuntia spp.; and blackbrush, Coleogyne ramosissima) to boreal forests (dominated by such species as Engelman spruce, Picea engelmanni; white fir, Abies concolor; and Aspen, Populus tremuloides). Between these two extremes lies a great variety of vegetation types. The habitat types support an equally varied array of wildlife. An understanding of the vegetation and the wildlife of the Park is not only of critical importance to the management of the Park's resources, but it is also of major importance in management considerations for much of the Colorado Plateau of northern Arizona and southern Utah. In this regard, the Park's relatively undisturbed resources represent a control area with which management practices of these other areas can be compared.

This paper presents a methodology for assessing wildlife habitat in an area containing among the most inaccessible terrain in the world: the Grand Canyon. This methodology is being developed by the Applied Remote Sensing Program of the Office of Arid Lands Studies at the University of Arizona in conjunction with National Park Service scientists to map the vegetational resources of the Grand Canyon National Park. The project is being funded in part by the National Park Service (contract #CX821070028) and in part by the National Aeronautics and Space Administration (grant # NGL-03-002-313).

REMOTE SENSING AND WILDLIFE MANAGEMENT

The application of remote sensing techniques to wildlife management presents an exciting challenge to today's wildlife scientists and managers. The field of wildlife management has been utilizing good scientific methods for only a few decades. Earlier attempts to standardize management techniques were plagued by a variety of problems. These included the use of techniques borrowed from other sciences. For example, the idea of "harvesting excess animals" while leaving sufficient "brood stock" to produce the following year's crop, came from range management. However, the inherent problem of trying to keep tallies of wild populations made the task more difficult for the wildlife manager than for the range manager. This led to the development of special techniques such as the Lincoln Index, Kelker technique and other methods of censusing (Trippensee, 1948).

Additional problems in the development of wildlife management as a science are discussed by Carothers and Johnson (1975) and Talbot (1975). More recently, mechanical and electronic

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monitoring techniques have augmented the old visual counts by foot, horse, auto or even low flying aircraft.

A few examples of wildlife management problems in the Grand Canyon might shed some light on how remote sensing might be employed to solve these and other problems.

North Kaibab Deer Herd

The Grand Canyon and adjacent Kaibab plateau has a long and interesting history of wildlife management and mismanagement. The "textbook example" of mismanagement for today's students of wildlife management is still the story of the Kaibab Deer Herd. Those wishing further details on this story are referred to Russo (1964). Since this outstanding example of mismanagement occurred in the area in which we are conducting our project we shall give a brief outline of the problem.

In 1906, Congress set aside part of the Kaibab Plateau on the North Rim of the Grand Canyon as the Grand Canyon Forest Reserve. Between 1906 and 1924 the North Kaibab mule deer herd (Odocoileus hemionus) increased rapidly, from 3,000 or 4,000 to as many as 100,000 animals (Rasmussen (1941). Mann and Locke (1931 fide Russo, 1964) estimated that by 1931 the herd had declined to one-fourth that number, largely through starvation. In spite of the then acknowledged problem of overpopulation some incredible things occurred during the mid to late 1920s. As increasing numbers of deer were found to be dying of starvation, one might have expected a decrease in predator control to allow predators to help curb the increasing numbers of deer. On the contrary; in 1928, the year when predator control agents killed the largest number of large carnivores for the area during that period, federal hunters were hired to kill deer and distribute the meat for consumption. The wolf (Canis lupus) had been exterminated earlier in the decade. In addition to a lack of adequate deer harvest, and an ill-advised predator control program, range mismanagement added to the problem through overgrazing of the region by sheep, cattle and horses. The use of remote sensing techniques in vegetation mapping would have allowed establishment of a carrying capacity for the deer through a) the delineation of vegetation types, b) determination of vegetation condition, and c) distribution and size of vegetation types. The use of this information would help to prevent a repetition of the North Kaibab herd disaster.

Wildlife Management vs. Game Management

Although Aldo Leopold clearly distinguished the difference between game and wildlife management as early as 1933 there is still a tendency by many resource managers to speak of "wildlife management" while actually meaning "game management" (Carothers and Johnson, 1975). The National Park Service, on the other hand, is not concerned with producing game animals any more than it is concerned with nongame animals. Thus, resource managers at Grand Canyon National Park are as concerned with the protection and maintenance of healthy populations of coyotes (Canis latrans), whiptail lizards (Cnemidophorus spp.) and golden-mantled ground squirrels (Citellus lateralis) as they are with mule deer (Ovis canadensis), Abert's squirrels (Sciurus aberti) and mourning doves (Zenaidura macroura). Thus, the NPS is attempting to use the most up-to-date techniques in an attempt to accomplish the best possible practices in wildlife management.

The Kaibab Squirrel will serve as an example of an animal of particular interest to both scientists and managers. This taxon is represented by an endemic population of tassel-eared tree squirrels on the North Rim. It is considered by some authorities to be a separate species from its nearest relative, the Abert's squirrel, to the south (Hall and Kelson, 1959, Hoffmeister, 1971). Others consider it as a subspecies (Cockrum, 1960, Bert & Grossenheider, 1964). Thus, Sciurus aberti and S. kaibabensis or S. a. aberti and S. a. kaibabensis, depending on which school you follow, are separated by the few miles of canyon barrier between the North and South Rims of the Grand Canyon. Several federal and state agencies are interested in the Kaibab squirrel. Because of the rareness of this species it has attracted the attention of the endangered species office of the U. S. Fish & Wildlife Service. The Arizona Game & Fish Department and the U. S. Forest Service are interested in the species as a game animal. Its more plentiful, wider spread relative, the Abert's squirrel is hunted now. The NPS is interested in the Kaibab squirrel because of its uniqueness and its attraction for visitors. In addition several independent investigators have been attracted by the species. Drastic fluctuations from year to year have been of particular interest to scientists such as Dr. Joseph Hall, San Francisco State University (NPS files). Recently, populations have plummeted in the Park but correspondingly drastic drops in populations have not been observed in the adjacent Kaibab National Forest (personal communication with personnel of Arizona Game & Fish Department and U. S. Forest Service). Figure 1 is a Landsat image in which the northern boundary of the Grand Canyon National Park is shown distinctly where it is adjacent to the National Forest. This startlingly visible difference is caused by lumbering on the Forest, in contrast to lack of lumbering in the Park. Some investigators have suggested a cause-effect relationship between lumbering and Kaibab squirrel populations. Others suggest a relationship between the squirrel and the presence of mushrooms, an important component of the squirrel's winter diet. At higher elevations, snow covers those mushrooms for extended periods. Remote sensing "signatures" showing patterns of snow related to time, which could be correlated with population highs and lows, would be extremely desirable.

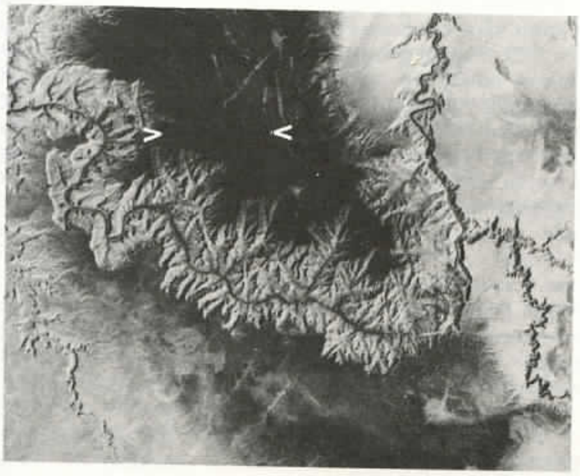


Figure 1.--Landsat scene (25 June 1975) of a portion of the Grand Canyon region. The north boundary of Grand Canyon National Park (arrows) is accentuated by logging practices outside the Park.

Range Management and Burros

Although range management is not a general problem in Grand Canyon National Park, there are several instances where management of non-native herbivores in the Park presents a problem. These include 1) determining the carrying capacity for livestock grazing lands acquired through recent additions to the Park where grazing will be phased-out in the next few years, 2) determining the carrying capacity for Supai livestock to be allowed to graze on "traditional use lands" within the Park (P. L. #93-620), and 3) the most widely publicized problem, to determine the extent of burro (Equus asinus) damage to native ecosystems.

The burro problem in the Grand Canyon has been widely publicized in newspapers and magazines while at least one scientific paper has addressed the problem (Carothers et al, 1976).

Most of the public controversy now raging over the fate of burros in Grand Canyon is highly emotional with little to no scientific reasoning. And, in spite of the furor and "controversy," almost unanimous support for partial control to complete removal has been received from resource management organizations.

This is not to say that there is not some disagreement among managers and other investigators regarding the degree of degredation of native ecosystems by burros, an introduced species. For example, the severity of the impact of burros on bighorn sheep (Ovis canadensis), one of the native mamamals which commonly occur in the same areas with burros has been highly debated. Moehlman, whose work in Death Valley was widely publicized by the National Geographic Magazine (1972), and Welles & Welles (1961) reported that they found bighorn watering holes which had not been fouled by burros, contrary to the findings of other investigators which included observations and photos taken in Death Valley (by Johnson). There is also disagreement regarding the amount of burro damage to vegetation and consequently to native wildlife dependent on this vegetation. Laycock (1974) and Carothers, et al (1976) discuss detrimental effects while Moehlman (1974), again, claims little or no effects in this area.

Remote sensing techniques designed to determine vegetation types, distribution and size of feeding areas, and vegetation conditions would help to answer questions regarding the extent of damage to native ecosystems from burros, cattle or other exotic animals. Current information regarding heavy burro impact on native plants and animals has been demonstrated by photos and scientific analyses of control vs. impact plots. One of the major charges leveled at this research, by opponents of burro control programs, is the perennial question of "side by side" plots vs. "before and after studies" on the same plot. Although rigid standards were followed in the selection to minimize environmental differences between plots it would be much more useful to have documentation from a given plot before and again after burros had been introduced. If sufficient imagery of the Park had been available this analysis would have been possible for some areas.

Resource managers have too long asked for instant answers and "brush-fire" research. Through systematic information gathering and well organized monitoring programs, many of our "burro-like" controversies may be averted.

Adequate information on vegetational resources, therefore, is of paramount importance to the wildlife resource scientist and manager.

The next sections will present a background to vegetation classification and mapping, and remote sensing techniques for their assessment.

VEGETATION CLASSIFICATION AND MAPPING

Through whatever technique is used in the mapping process, vegetation mapping begins with an understanding of intended use and the design and development of an appropriate classification system. This system must fit the factors of vegetation which are pertinent to any of the objectives for which the vegetation map is to be produced.

A considerable literature exists on the subject of vegetation classification. Kuchler (1967) has stated that since vegetation is so heterogeneous and the approaches to classification so numerous, there are, therefore, a number of different avenues to an orderly arrangement of the vegetation mosaic. Kuchler and de Laubenfels (1975) present excellent reviews of the history of vegetation classification. UNESCO (1973) presented a system for an international classification of vegetation. The Biological Services Program of the U. S. Fish & Wildlife Service (1977) published a report on seventy-five classification systems in use in the Western United States. United States Geological Survey Professional Paper 964 (1976) contains a land use and cover system (including vegetation) designed for use in the nationwide mapping program. Poulton (1970 and 1972) and Brown and Lowe (1974) have devised vegetation classification systems designed for Arizona. The system used in our vegetation mapping project is a hierarchical ecologically-based legend involving both of the latter two systems with an adaptation to fit the unique vegetation of the Grand Canyon.

deLaubenfels (1975) states that vegetation is mapped for one of two basic reasons: an interest in learning about the plants themselves--or the study of floristics, and an interest in learning about the physical environment in general. The latter relates the response of plant form to the physical elements of environment.

Methods of vegetation mapping are numerous. At global scales it is often mapped as a correlate of broad climatic regimes (Schimper, 1898) or to physiognomy (Kuchler, 1949). At much larger scales, it may be mapped according to floristics, physiognomy, numerical relations between taxa, or by environmental characteristics (Kuchler, 1967).

Typical sampling techniques for mapping include the transect, quadrat, step-point, and plotless methods (see, for example, Kuchler, 1967, and Daubenmire, 1968). A transect method may involve laying out a tape at given intervals and recording species which touch or shade the tape. A quadrat method might involve a random or systematic selection of sample areas throughout the study area. Sample areas may be, for example, one-meter square plots. A step-point method might involve walking along a predetermined set of lines across the terrain and recording a "hit" for those species at a notch in the toe of the samplers boot or, in some cases, the species which is closest to it. A plotless method might be used to measure density of trees or shrubs by measuring the average distance between the individuals.

With the combination of the classification system and the appropriate sampling procedure the field analysis begins. The mapper begins by thoroughly acquainting himself with the terrain and the flora. The mapper often studies the structure of the vegetation and may try to detect identifiable discrete units of vegetation in the field. From there he may proceed through the sampling procedure selected. Occasionally, field maps are compiled with subjective type lines drawn. In the laboratory a draft of the map is compiled from the field observations. A return to the field is often necessary to clear up uncertainties and doubtful delineations.

VEGETATION MAPPING WITH REMOTE SENSING

Vegetation mapping has progressed considerably in the middle of the 20th century with the assistance of remote sensing technology The use of black and white aerial photography provided the aerial perspective in estimating cover, interpretation of broad types, and delineation of type boundaries on an easily convertible mapping base. The use of stereoscopes, photogrammetric techniques, and other equipment greatly improved the mapping procedure.

Recently, developments in film-filter combinations, sensing systems, sampling techniques, and analytical procedures have added a new dimension in vegetation mapping. Color and color infrared films with the appropriate filter combinations permit a much wider variety of vegetation discrimination than black and white photography. Color infrared photography is particularly well-suited to vegetation discrimination as it is in the near infrared portion of the spectrum that vegetation is most responsive.

Satellite sensing systems, particularly the Landsat satellites, have provided vegetation mappers with an important technique for mapping vegetation resources over extensive regions, for monitoring phenological changes by taking advantage of the Landsat's eighteen day repetitive cycle (nine days with two Landsats), and for analysis through the satellite's radiometric precision. Numerous projects have employed Landsat for inventory and analysis of vegetation resources.

Sampling, as mentioned earlier, is an important tool for providing statistically valid classifications, type delineations, and even type identifications. It certainly provides a rational design framework for ground data collection. Recent developments in multi-stage sampling (see, for example, Langley, 1975) have allowed researchers to use remote sensing more efficiently for resource inventory and analysis. Often, several levels of remotely sensed data are used in the procedure. Landsat, high altitude color infrared photography, low altitude color infrared photography, and ground data collection, for example, in a multi-stage sampling design can provide the appropriate strategy for an intensive vegetation mapping effort.

Perhaps the most radical advance in remote sensing technology for vegetation mapping has been in the field of analytical techniques. Machine-processing of remotely sensed data allows for extremely rapid analysis of data, discrimination of data not possible through visual analysis, processing of data in a manner which can accentuate the spectral characteristics of certain phenomena. Digital classification of data can result in a rapid inventory of vegetation. Certainly, the Landsat system itself would not be possible without some form of machine processing. Again a considerable body of literature exists which describes these and other analytical techniques (for example Phillips, 1973; Swain, 1976; Chavez et al, 1977; Sabins, 1978).

Vegetation Mapping from Terrain Correlation by Remote Sensing

In an environmentally complex area of limited accessibility such as the Grand Canyon, traditional techniques involving direct field mapping are essentially impossible. Remote sensing techniques involving visual analysis of black and white, color, or color infrared photography; and those involving computer-processed imagery or digital classification suffer from a lack of ground data collection including training site definition and verification in these inaccessible areas.

An additional input is needed to achieve suitably uniform standards in the final map. The input being researched to aid in the Grand Canyon Vegetation Mapping Project is the terrain correlate.

A number of studies have been conducted relating vegetation to various terrain features.

One of the earlier attempts to classify biological communities in the Southwest was by C. Harte Merriam (1890). In 1889, Merriam traveled from the San Francisco Peaks to the bottom of the Grand Canyon. He described six separate life zones occurring within this transect. He hypothesized that they were related to different climatic regimes associated with differences in elevation. Five of the six life zones described by Merriam are represented in the Park (see figure 4, a north-south profile of the canyon).

An important study relating vegetation to terrain was conducted by Kassas et al in Egypt. Kassas' major effort was on habitat--plant community relationships in the Egyptian Desert. Kassas found that vegetation follows rather discrete patterns of landforms and moisture availability. Each of a number of geomorphic divisions in his study area had a specific array of community types or "eco-geomorphic systems" (Kassas, 1952 and 1961; Kassas and El-Abyad, 1962).

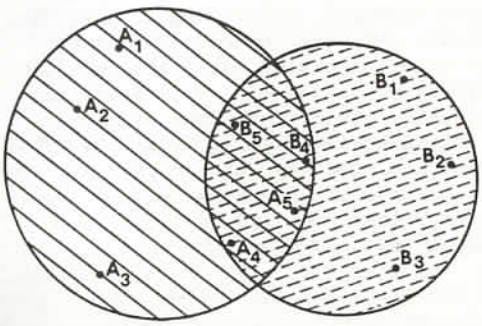
Shreve (1915) stated that the upper limit of species was considerably higher on north-facing slopes than on south-facing slopes. He showed that the influence of slope exposure was greater with increasing elevation and felt that the effect of altitude on vegetation was through moisture, temperature, and light factors. Whittaker and Niering (1965 and 1968) extended Shreve's study by using a gradient analysis to examine the relationships between plant species, elevation, and aspect in the Catalina Mountains of Arizona.

Mouat (1972, 1974a, and 1974b) used stepwise discriminant analysis to analyze vegetation--terrain variable relationships in southern Arizona. In one set of analyses, he found that species could differentiate among parent material groups. In another, he found that some vegetation types could be differentiated on the basis of a set of terrain variables.

Stepwise Discriminant Analysis in the Study of Vegetation

Stepwise discriminant analysis is a program (BMD07M); Sampson, 1968) which performs a multi-discriminant analysis in a stepwise manner. At each step in the program, a variable is entered into the set of discriminating variables (for example, terrain variables). The variable entered is selected if it has the largest F value. This is the same as the variable which gives the greatest decrease in the ratio of within to total generalized variances. A variable is deleted if its F value becomes too low. The program also computes canonical correlations and coefficients for canonical correlations. This is important as the program includes the plotting of the first two canonical variables to give an optimal two-dimensional picture of the dispersion among observations. Each canonical variate is a function of all the original variables.

Terrain variables, properly selected, can be used to separate vegetation types. Occasionally, a vegetation type "defined" or selected by the set of terrain variables is different from the classification an observer would make in the field. A schematic Venn diagram is presented in figure 2 to illustrate how sets of terrain variables may be better correlated with one vegetation type than with another. Two hypothetical vegetation types, A and B, are presented. The set of terrain variables, A, includes all possible combinations of terrain variables which could theoretically exist for the hypothetical vegetation type A. The set of terrain variables, B, includes all possible combinations of terrain variables which could theoretically exist for the hypothetical vegetation type B.



Core of vegetation type A, not much like vegetation type B.

Core of vegetation type B, not much like vegetation type A.

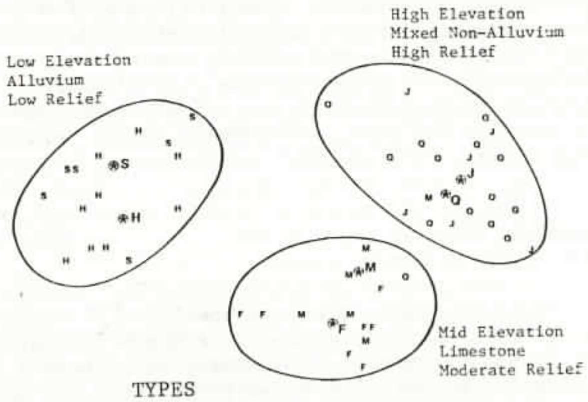
Intersection of vegetation types A and B. Stands A_4, A_5, B_4, and B_5 share a similar set of terrain variables.

Figure 2.--A schematic Venn diagram of two hypothetical vegetation types according to their sets of terrain variables.

The overlap between the two sets means that for that particular subset of terrain variables, two vegetation types can teoretically exist because both have tolerances for similar terrain variables.

In figure 2, vegetation types A and B are considered to have five stands each. Stands A_1, A_2, and A_3 have a set of terrain variables most like the typical set of A terrain variables. Stand A_4 has a corresponding set of terrain variables that are somewhat like the set of terrain variables associated with type B. Still stand A_4 is more like the typical A than B. Stand A_5, on the other hand, is on the very fringe of terrain variables that can have a vegetation type A. Its set of terrain variables is actually more like the "typical" B set.

Stepwise discriminant analysis was used to examine relationships between six vegetation types and eight terrain variables in Arizona (Mouat, 1974). The six vegetation types were from three physiognomic classes: shrubland, grassland, and woodland. The analysis showed that those three physiognomic classes were almost perfectly separated by the terrain features. The vegetation types within each physiognomic class were only partially separated by the terrain features. Figure 3 is a scatter diagram of the first two canonical variates derived from the stepwise discriminant analysis of the six vegetation types and eight terrain variables. The three terrain variables indicated in the figure are those which were found to be the best discriminants of vegetation.



TYPES

H = Hilaria mutica
S = Sporobolus wrightii — Grasslands
F = Fouquieria splendens — Shrublands
M = Mortonia scabrella
Q = Quercus emoryi — Woodland
J = Juniperus deppeana

⊛ = Group means

Figure 3.--A diagram of the first two canonical variates where groups are from six vegetation types and variables are terrain variables.

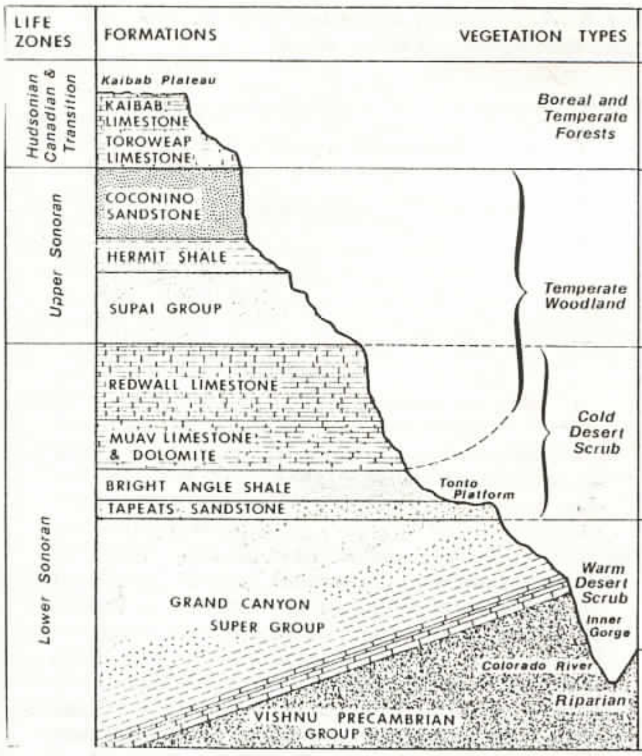
VEGETATION MAPPING FOR THE STUDY
OF WILDLIFE IN THE GRAND CANYON

The vegetation mapping in our on-going project has involved a number of analytical methods. Stepwise discriminant analysis has helped to indicate the terrain variables which are the best discriminants of vegetation. Elevation, parent material, and exposure have been found to be among the best discriminats of vegetation. Associated with the vegetation are unique assemblages of wildlife populations. Figure 4 is a north-south profile of the Grand Canyon from the north rim to the Colorado River. Vegetation is depicted according to dominant and indicator species. Typical wildlife associations with vegetation are also given.

Toroweap Analysis

The Toroweap area occurs in the west portion of the Grand Canyon at an elevation of approximately 4,500 feet. The Supai formation is dominant and the general vegetation is that of a shrubland or open woodland. It is in an extremely inaccessible part of the Park. In an accessible area in what was judged to be representative of the region, 600 samples were collected by a transect method. Information gathered included plant species, slope angle, slope aspect, elevation, parent material, and landform.

One set of analyses will be presented here. In one area landforms consist of undulating topography developed on sandstone and on recent cinders. Elevations were similar. Vegetation differed markedly according to parent material and slope aspect. On the cinder cones, big sage (Artemesia tridentata) dominated the vegetation of north and south-facing slopes. Other key species included desert rue (Thamnosma montana), bladder sage (Salazaria mexicana), and prickly pear (Opuntia spp.). The neighboring sandstone slopes, however, had an entirely different vegetation assemblage.



MAJOR PLANTS	BREEDING BIRDS	MAMMALS
SPRUCE PONDEROSA PINE WHITE FIR, ASPEN GAMBEL OAK	STELLER'S JAY MOUNTAIN CHICKADEE GRAY-HEADED JUNCO	MOUNTAIN LION KAIBAB SQUIRREL MULE DEER
UTAH JUNIPER PINYON PINE UTAH SERVICEBERRY BROOM SNAKEWEED DATIL YUCCA	WHITE-THROATED SWIFT SCRUB JAY PLAIN TITMOUSE	STEPHEN'S WOODRAT CLIFF CHIPMUNK MULE DEER
BLACKBRUSH UTAH AGAVE MORMON TEA RABBITBRUSH HEDGEHOG CACTUS	COMMON RAVEN ROCK WREN BLACK-THROATED SPARROW	WHITE-TAILED WOODRAT CACTUS MOUSE BIGHORN
CATCLAW ACACIA WHITE BRITTLEBUSH BARREL CACTUS PRICKLYPEAR	SPARROW HAWK BLACK-CHINNED HUMMINGBIRD CANYON WREN	RING-TAILED CAT CACTUS MOUSE SPOTTED SKUNK
COYOTE WILLOW SALTCEDAR MESQUITE	BLUE-GRAY GNATCATHER LUCY'S WARBLER BLUE GROSBEAK	WESTERN PIPISTRELLE RING-TAILED CAT BEAVER

Figure 4.--North-south profile of the Grand Canyon from the North Rim to the Colorado River.

On north-facing slopes, broom snakeweed (Gutierrezia sarothrae) was dominant. Associated with it were mormon tea (Ephedra sp.), greasebrush (Glossopetalon nevadense), and galleta grass (Hilaria jamesii). The south-facing slopes were quite different. Scrub live oak (Quercus turbinella) and buckbrush (Ceanothus gregii) were dominant along with broom snakeweed and galleta grass. Cinder cones were readily distinguishable from sandstone hills on color infrared photography as well as on Landsat imagery. North and south-facing slopes were distinguishable only on the aerial photography.

A concomitant bird census was made for both parent materials. The census showed that the vegetation type associated with sandstone had nearly six times the number of birds than the vegetation type associated with cinder cones (see Table 1).

SUMMARY

The Grand Canyon Vegetation Mapping Project is showing that traditional mapping techniques are impractical in inaccessible areas. Even standard remote sensing techniques may give an incomplete survey. Techniques which involve the analysis of terrain variables which are more readily interpreted (by man and machine) than vegetation are called for. The determination of close terrain-vegetation relationships is of paramount importance. Stepwise discriminant analysis is useful for that task.

Wildlife management is dependent upon up-to-date accurate baseline information including vegetational resource inventories. Many of the past mistakes in wildlife management occurred from quick and ineffective methods of gathering data on the ground. The Grand Canyon Vegetation Mapping Project is an effective means of obtaining accurate baseline information. Remote Sensing is useful not only for obtaining the vegetation information, but also for change detection operations.

Table 1.--Bird census, April 21, 1978, by R. R. Johnson, designed to traverse opposing exposures, cinders vs. sandstone. Paired plots (57m x 700m).

	CINDERS		SANDSTONE	
	species	individuals	species	individuals
breeding	1	4*	6	16*
transient	1	1	7	11
TOTAL	2	5	13	27

*Number of breeding individuals derived from number of pairs; determined by both birds present, singing male, or an individual on territory.

LITERATURE CITED

Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. U. S. Geol. Survey Prof. Paper 964, 28p.

Brown, D. E., and C. H. Lowe. 1974. A digitized computer-compatible classification for natural and potential vegetation in the Southwest with particular reference to Arizona. Ariz. Acad. Sci. Jour., Vol. 9, Suppl. 2, 11p.

Burt, W. H., and R. P. Grossenheider. 1964. A field guide to the mammals. Boston, Houghton Mifflin Co., 284p.

Carothers, S. W., and R. R. Johnson. 1975. Water management practices and their effects on nongame birds in range habitats. Proc. of the Symp. on Mgt. of Forest and Range Habitat for Nongame Birds. U. S. For. Serv. Gen. Tech. Report WO-1, pp.210-222.

Carothers, S. W., M. E. Stitt, and R. R. Johnson. 1976. Feral asses on public lands: an analysis of biotic impact, legal considerations, and management alternatives. Trans. of the 41st Am. Wildl. and Nat. Res. Conf. pp.396-406.

Chavez, P., L. Berlin, and W. Mitchell. 1977. Computer-enhanced techniques of Landsat MSS digital images for land use/land cover assessment. Sixth Ann. Remote Sensing of Earth Res. Conf., Tullahoma, Tenn.

Cockrum, E. L. 1960. The recent mammals of Arizona: their taxonomy and distribution. Tucson, Univ. of Arizona Press, 276p.
Daubenmire, R. 1968. Plant Communities. New York, Harper and Row, 300p.
deLaubenfels, D. J. 1975. Mapping the world's vegetation. Syracuse Univ. Press, 246p.
Ellis, S. L., C. Fallat, N. Reece, and C. Riordan. 1977. Guide to land cover and use classification systems employed by western governmental agencies. U. S. Fish and Wildl. Serv., Off. of Biol. Serv., FWS/OBS-77/05, 183p.
Hall, E. R., and K. R. Kelson. 1959. The mammals of North America, Vol. 1. New York, Ronald Press Co., 546p.
Hoffmeister, D. F. 1971. Mammals of Grand Canyon. Univ. of Illinois Press, 183p.
Johnson, J. R., B. J. Schrumpf, D. A. Mouat, and W. T. Pyott. 1974. Inventory and monitoring of natural vegetation and related resources in an arid environment, an evaluation of ERTS-1 imagery. NASA Goddard Space Flight Center, Greenbelt, Md., Final Report Type III, NASA Contract 5-21831, 328p.
Johnson, R. R. 1977. Synthesis and management implications of the Colorado River research program. Colorado River Res. Report 17, Grand Canyon National Park, 75p.
Kassas, M. 1952. Habitat and plant communities in the Egyptian Desert, I: introduction. Jour. Ecol., 40(2):342-351.
Kassas, M. 1961. Certain aspects of landform effects on plant/water resources. In: Plant/Water Relationships in Arid and Semi-Arid Conditions, a symposium, UNESCO, Paris, Arid Zone Research 16:71-78.
Kassas, M., and M. El-Abyad. 1962. On the phytosociology of the desert vegetation of Egypt. Ann. Arid Zone 1:54-83.
Kuchler, A. W. 1949. A physiognomic classification of vegetation. Ann. of the Am. Assoc. of Geogr., 39:201-210.
Kuchler, A. W. 1967. Vegetation mapping. New York, Ronald Press Co., 472p.
Langley, P. G. 1975. Multistage variable probability sampling: theory and use in estimating timber resources from space and aircraft photography. Ph. D. Dissertation, Univ. of Calif., Berkeley, 101p.
Laycock, G. 1974. Dilemma in the desert: bighorns or burros? Audubon 76(5):116-117.
Leopold, A. 1933. Game management. New York, Chas. Scribner's Sons, 481p.
Merriam, C. H. 1890. Results of a biological survey of the San Francisco Mountain region and the desert of the Little Colorado, Arizona. U. S. Dept. Agric., No. Amer. Fauna 3:1-136.
Moehlman, P. 1972. Getting to know the wild burros of Death Valley. National Geogr. 141(4):502-517.
Mouat, D. A. 1972. Terrain feature - vegetation relationships in southern Arizona. Proc. 3rd Int. Conf. on Remote Sensing in Arid Lands. Univ. of Arizona, Tucson, pp.152-166.
Mouat, D. A. 1974. Relationships between vegetation and terrain variables in southeastern Arizona. Ph. D. Dissertation, Oregon State University, Corvallis, 242p.
Phillips, T. L. (ed.). 1973. LARSYS user's manual. Lab. Appl. of Remote Sensing, Purdue Univ., W. Lafayette, Ind., Vol. 1,2.
Poulton, C. E., et al. 1970. High altitude photography in the analysis of natural vegetational resources with implications in land use, in: Pettinger, The application of high altitude photography for vegetation resource inventories in southern Arizona. For. Remote Sens. Lab., Univ. of Calif., Berkeley, 147p.
Poulton, C. E. 1972. A comprehensive remote sensing legend system for the ecological characterization and annotation of natural and altered landscapes. Proc. 8th Int. Symp. on Rem. Sens. of Env., ERIM, Univ. of Mich.
Rasmussen, D. I. 1941. Biotic communities of the Kaibab Plateau, Arizona. Ecol. Monographs 3:229-275.
Russo, J. P. 1964. The Kaibab North deer herd: it's history, problems, and management. Az. Game and Fish Dept. Wildl. Bull. 7, 195p.
Sabins, F. F. 1978. Remote sensing, principles and interpretation. San Francisco, W. H. Freeman and Co., 426p.
Sampson, P. 1968. BMDO7M. Biomedical Computer Programs. Los Angeles, Univ. of Calif. Publ. in Automatic Computations No. 2, p.214a-1.
Schimper, A. F. W. 1898. Pflanzengeographie auf physiologischer grundlage. Jena, Fischer Verlag.
Shreve, F. 1915. The vegetation of a desert mountain range as conditioned chiefly by climatic factors. Carneggie Inst. Pub. 217.
Swain, P. H. et al. 1975. Layered classification techniques for remote sensing applications. Proc. of the Earth Resources Survey Symposium, Houston.
Talbot, L. M. 1975. Concluding address: the challenges of management of nongame birds. Proc. Symp. on Mgt. of Forest and Range Hab. for Nongame Birds, U.S. For. Serv. Gen. Tech. Report WO-1, pp.335-337.
Trippensee, R. E. 1948. Wildlife management. New York, McGraw-Hill, 479p.
UNESCO. 1973. International classification and mapping of vegetation. Paris, 93p.
Welles, R. E., and F. B. Welles. 1961. The bighorn of Death Valley. Fauna of the Nat. Parks of the U. S., Fauna Ser. 6, 242p.
Whittaker, R. H., and W. A. Niering. 1965. Vegetation of the Santa Catalina Mountains of Arizona: a gradient analysis of the south slope. Ecology 46:429-452.
Whittaker, R. H., and W. A. Niering. 1968. Vegetation of the Santa Catalina Mountains of Arizona. III. species distribution and floristic relations on the north slope. Jour. Ariz. Acad. of Sci., 5:3-21.

Trend Analysis of Vegetation in Louisiana's Atchafalaya River Basin [1]

Calvin P. O'Neil[2], J. Edward deSteiguer[3], Gary W. North[4]

Abstract.--The purpose of the study was to determine vegetation succession trends; produce a current vegetation map of the basin; and to develop a mathematical model capable of predicting vegetation changes based on hydrologic factors. A statistical relationship of forest and hydrological variables with forest succession constraints predicted forest acreage totals for 16 forest categories within 70% or better of actual values in two-thirds of the cases. Using time-lapsed photography covering 42 years, 23 categories were described. The succession trend of vegetation since 1930, by sedimentation, had been toward mixed hardwoods, except for isolated areas. Satellite MSS Band 7 imagery was used to map the current vegetation into three main categories and for assessment of acreage. Additionally, a geological anomaly was recognized on satellite imagery indicating an effect on drainage and sedimentation.

INTRODUCTION

The Earth Resources Observation Systems (EROS) Applications Assistance Facility located at the National Space Technology Laboratories, in Bay St. Louis, Mississippi, was contracted in May 1973, to conduct a trend analysis of vegetation in Louisiana's Atchafalaya River Basin for the Assistant Secretary for Fish and Wildlife and Parks. The specific objectives of the study, monitored by the U. S. Fish and Wildlife Service, Atchafalaya Land and Water Management Study Group, were to:

1. Determine the trends of vegetation succession within the Atchafalaya Basin by producing a series of vegetation maps, using available 1930, 1952, and 1973 aerial photography covering four rest strips extending east-west across the Basin.
2. Produce a current vegetation map of the entire Atchafalaya River Basin, using imagery from NASA's Land Satellite, formerly Earth Resources Technology Satellite.
3. Develop a mathematical model, using multiple linear regression, to determine the relationships between the hydrologic factors and the vegetation trend analysis acreage data.
4. Expand the mathematical model to produce a Basin-wide model that would be capable of predicting changes in vegetation based on changes in various hydrologic factors.

PHYSICAL DESCRIPTION OF THE BASIN

The Atchafalaya River Basin occupies approximately 1,800 square miles of lowland in south central Louisiana between the cities of Lafayette and Baton Rouge. Consisting mostly of swamps, lakes, streams and forests, this area once served as the flood plain of the Mississippi River; and, the Atchafalaya continues to flow as a distributary of that river today. Figure 1 is an aerial view of this vast, complicated, natural system.

VEGETATION TREND ANALYSIS

Procedures

The vegetation trend analysis data for this study were obtained through systematic sampling of the Atchafalaya River Basin. Trend analysis

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Figure 1.--Low altitude aerial view of the southwestern portion of the Atchafalaya River Basin.

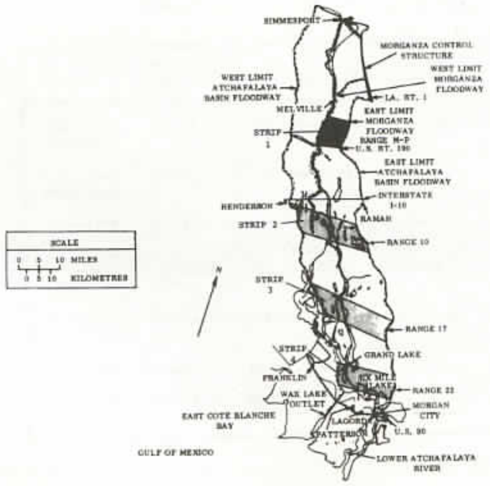


Figure 2.--Map of Atchafalaya River Basin study areas.

as defined in this study refers to changes in acreage of forest types. Four test strips, representing 16 percent of the Basin area, served as the sampling units (see Figure 2). Each of the strips was approximately 4 miles wide and transected the Basin with the flood protection levees serving as the east-west boundaries. The strips were oriented east-west with the exception of strip 3 which was northwest-southeast to include an unknown geologic lineament evident on LANDSAT-1 imagery of the Basin. The strips approximately coincided with the Corps of Engineers sediment profile rangelines shown in Table 1, and depicted in Figure 2. Strip 1 was selected as representative of an area undergoing the most rapid land

Table 1.--Relationship of strip numbers to rangelines.

Strip Number	Rangeline
1	M-P
2	10
3	17
4	22

use changes due to man, while strip 2 was picked to examine the effects of an interstate system on the Basin. Strip 3 was selected to coincide with the geologic lineation, and strip 4 was representative of a dynamic area affected by changes in hydrology and sedimentation.

Available aerial photography covering the four test strips in 1930, 1952, and 1973 was selected for the vegetation mapping and trend analysis. The 1973 coverage of strips 2, 3, and 4 was 1:42,000, color infrared photography taken in January by NASA while the coverage of strip 1 was Corps of Engineers black and white infrared flown in April of the same year. The 1952 photography consisted of panchromatic prints obtained in September and December by the Corps of Engineers. The 1930 strip coverage, also obtained from the Corps of Engineers, was flown in February, March, and October. This photography was also available in panchromatic prints.

Supplemental imagery flown by NASA in October 1971, March 1972, and September 1973, was used to aid in the interpretation of the January 1973 coverage. September 1973 supplemental color infrared coverage was of use in locating the tupelo stands. In September, tupelo had begun to undergo phenological changes and rendered a gray-blue signature while surrounding vegetation had not reached a dormant state and appeared red in contrast to the tupelo. The March 1972 coverage was useful in establishing a photographic signature for cypress. This specie had begun to leaf out, and appeared red on the color infrared photography while surrounding tupelo trees were bare. A detailed description of the imagery used in this study is contained in Table 2.

The photography for each test strip in each year was mosaicked to 1/4-inch Masonite using Lektro-Stik wax base adhesive. The adhesive was applied to the base side of each photograph with a Daige Speedcote Adhesive Wax Coater. The prints were positioned to overlap the same detail on adjacent prints and smoothed into place with a burnishing tool. Image displacement was minimized by using only the center portion of each print. The resulting products were 12 uncontrolled photo mosaics. Examples

Table 2.-- Description of photography

Date	Test Strips Covered	Film Type	Approximate Scale	Acquiring Agency
February, March & October 1930	All	Panchromatic	1:20,000	Corps of Engineers
September & December 1952	All	Panchromatic	1:20,000	Corps of Engineers
January 1973	Strips 2, 3 and 4	Color Infrared	1:42,000	NASA
April 1973	Strip 1	Black-&-White Infrared	1:36,000	Corps of Engineers
[1] September 1973	Strips 2, 3 and 4	Color Infrared	1:47,000	NASA
[1] March 1972	All	Color Infrared	1:120,000	NASA
[1] October 1971	Strips 2 3 and 4	Color Infrared	1:37,000	NASA

[1] Supplemental photography

of the mosaics for test strip 4 are included in the Appendix (Plates 3, 4, 5).[5]

Ground truth surveys of the 1973 aerial coverage were conducted during the winter and spring of 1974 to gain familiarity with vegetation types as they related to photographic signatures and to develop a vegetation classification system for mapping the test strip mosaics. Surveys were conducted through the use of an outboard motorboat and on foot. Information collected during these exercises included tree dendrology and general species identification and location information.

Prior to the field work, the 1973 mosaics were examined for color, tonal and textural anomalies. These anomalies were believed to be related to forest types and, therefore, had a direct affect on the precision with which forest cover could be mapped. Following the preliminary examination, duplicate photographic prints from the 1973 test strip coverage were prepared using mylar drafting film overlays and placed in sealable plastic bags for field use. Selected points in the Basin were visited and the vegetation types noted and recorded on overlays to the photographs.

Ground truth revealed that a number of vegetation associations and land use patterns occupy the Atchafalaya Basin. The northern portion of the Basin supports vast stands of mixed bottomland hardwood species (Figure 3).

Figure 3.--Mixed bottomland hardwood forest

This forest association occupies the better drained areas within the Basin. Much of the northern Basin, because of the improved water drainage, has been cleared for planting of agriculture crops (Figure 4). Swamps in the southern portion of the Basin support cypress and tupelo trees, together (Figure 5) or in pure, dense even-ages stands. Mixed hardwoods dominated by live oak were found on natural levees and ridges throughout the swamp (Figure 6). Within sparse cypress-tupelo stands, newly accreted land was occupied by pure stands of willows (Figure 7). Newly accreted land in lakes and channels also supported pure stands of willow trees (Figure 8).

Figure 4.--Land cleared for farming

With the ground truth effort completed, information gathered in the field was analyzed to establish relationships between photographic anomalies and vegetation types and the following classification system was devised for the vege-

[5] The Appendix is a separate document available from the U. S. Fish and Wildlife Service office at NSTL Station, Mississippi

Figure 5.--Cypress-Tupelo forest.

Figure 6.--A canopy of Live Oak/Mixed Hardwoods.

Figure 7.--Willow trees within a Cypress/Tupelo forest.

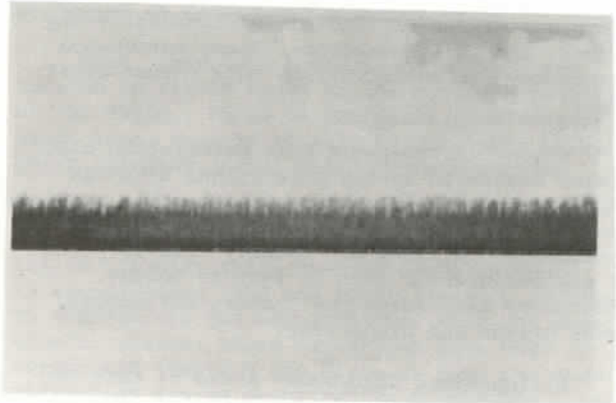


Figure 8.--Willows on newly accreted land.

tation mapping. The common and scientific names for this vegetation are shown in Table 3. In addition to vegetation types, a number of non-vegetation categories were also included in the system. These major classes of vegetation were of specific interest to those scientists interested in mapping wildlife habitat.

Table 3.--Common and scientific names of vegetation

American Elm	Ulmus americana
American Sycamore	Plantanus occidentalis
Bald Cypress	Taxodium distichum
Bitter Pecan	Carya aquatica
Blackberry	Rubus sp.
Black Willow	Salix nigra
Box Elder	Acer negundo
Buttonbush	Cephalathus occidentalis
Cane	Arundinaria tecta
Eastern Cottonwood	Populus deltoides
Green Ash	Fraxinus pennsylvanica
Ladies Eardrop	Brunnichia cirrhosa
Live Oak	Quercus virginiana
Nuttal Oak	Q. nuttallii
Planertree	Planera aquatica
Red Maple	A. rubrum
Sugarberry	Cletis laevigata
Swamp Privet	Forestiera acuminata
Sweet Gum	Liquidambar styraciflua
Water Oak	Quercus nigra
Water Tupelo	Nyssa aquatica
Wax Myrtle	Myrica cerifera

Willow (immature) Black-willow is a pioneer plant, being the first to occup newly accreted land. It is a prolific species with 2 or 3 million seeds per pound disbursed by wind and water, and requires bare mineral soil for germination. This type occurs in virtually pure, even-aged stands. Individual trees are less than 10 years old, 50 feet or less in height, with a diameter of 6 inches or less. Understory associates may include buttonbush, swamp privet, and ladies eardrop. Young cottonwood stands may be present within this forest cover type.

Willow (mature) In this association black willow occurs in nearly pure stands although this type may be interspersed with other species; such as, cypress, bitter pecan, green ash or cottonwood. Willows are usually over 10 years of age and greater than 50 feet in height. Understory associates may include buttonbush, swamp privet and planertree.

Willow-Mixed Hardwoods Areas of this forest association are representative of land in transition to a levee forest due to the deposition of silt and the subsequent increase in land elevation. Willow is usually mature and comprises approximately 50 percent of the stand. Maturity in this case infers that willows are approximately 10 years old and 50 feet tall. The remaining hardwoods may include bitter pecan, Nuttall oak, green ash, cottonwood, red maple, tupelo and sweetgum.

Mixed Hardwoods This forest association is indicative of the levees and bottomland hardwood forests in the subclimax successional stages. Species may include mature cottonwood and willow, red maple, American sycamore, bitter pecan, Nuttal oak, green ash, American elm, sugarberry, water oak and sweetgum. Scattered cypress and tupelo may also be present as remnants of the swamp forests which occupied these sites prior to the levee forests. The mixed hardwood forest is similar in species composition to the live oak-mixed hardwood forest, but live oaks have replaced those hardwoods that are intolerant to competition.

Cypress-Tupelo This forest association is characterized by a nearly homogeneous mixture of the two species. Understory associates may include buttombush, planertree and swamp privet. This community represents the subclimax stage of succession for the swamp areas of the Atchafalaya River Basin.

Cypress This forest association occurs in pure stands or with a few scattered tupelo. Intensive logging in the late 1800's eliminated most mature cypress, but pure stands of limited size now occupy certain areas of the Basin.

Tupelo In this association tupelo occurs in pure stands or interspered with scattered cypress trees. Understory associates may include buttonbush, swamp privet and planertree. Most of the pure tupelo stands are densely stocked and even aged. This species has apparently experienced little commercial exploitation within the Basin. Tupelo represents a subclimax stage of succession for the swamp areas of the Basin.

Tupelo-Willow This forest association represents the early stages of transformation from mature pure tupelo stands to a levee forest. Natural thinning in mature stands and mortality caused by sedimentation provide openings in the canopy that allow sunlight for growth of the willow. Sediment deposition provides the bare mineral soil necessary for the germination of willow seeds.

Cypress-Willow Similar to the tupelo-willow classification, this forest association represents the initial transition of cypress stands to levee forests. The mortality of cypress caused by sedimentation provides canopy openings for the establishment of willow. Understory associates may include buttonbush and swamp privet.

Cypress-Willow-Tupelo This association is comprised of a homogeneous mixture of the three species. In 1930 and 1952 much of the Basin was comprised of sparsely stocked stands of cypress and tupelo. Sedimentation within these stands lead to the introduction of willow. This association represents initial transition of swamp forests to levee forests.

Sparse Cypres-Tupleo/Aquatic Vegetation This forest association represents the mature swamp forest of the Basin. As mixed stands of cypress and tupelo mature, natural thinning provides an open canopy. These areas are inundated much of the year and concentrations of aquatic vegetation accumulate. The area west of Hog Island characterizes this vegetation community.

Willow-Blackberry This association occupies a relatively small portion of the Basin. Newly formed spoil banks along canals are the locations for this plant community. Blackberry is eliminated from this association as the forest canopy matures and closes.

Cypress-Mixed Hardwoods This forest association is comprised of cypress and bottomland hardwoods; such as, Nuttal oak, box elder, willow, tupelo and green ash. This association is representative of areas that are developing into levee forests, but are still frequently inundated.

Live Oak-Mixed Hardwoods This forest cover association is regarded as the climax type for the natural and artificial levees and bottomland hardwood areas within the Basin. Bottomland hardwoods common in this association include American elm, sugarberry, water oak and sweetgum. Areas having large concentrations of the live oak climax forest types are Cypress Island and the land between Duck Lake and Grand Lake in the southern portion of the Basin.

Mixed Hardwood-Wax Myrtle Wax myrtle occurs as an understory plant in the early successional stages of the levee forest and is eventually eliminated as the overstory matures and the canopy closes. Overstory associates in the wax myrtle-mixed hardwoods type approximate those of the mixed hardwood with a predominance of the more intolerant tree species.

Water This category includes all surface water such as lakes, bayous, channels, streams and rivers. Open water covered by aquatic vegetation is excluded from this classification.

Aquatic Vegetation Included in this classification is all surface water covered by aquatic plants such as water hyacinth, duckweed and algae. Aquatic vegetation beneath the forest canopy is excluded from this classification.

Bare Soil This category includes newly accreted land or spoil piles prior to the establishment of vegetation or, more commonly, land cleared for development. This category compirses a negligible portion of the Basin as vegetation will become established on bare soil soon after deposition or clearing.

Urban and Built Up Cultural features such as housing developments, oil well drilling platforms and oil storage tanks are included in this category. Single homes or campsites are not included.

Cropland and Pasture Land cleared for cultivation of agricultural crops and pasture are included in this category. A significant portion of the Basin north of U. S. Highway 190 was cropland and pasture by 1973.

Vegetative Mats This plant association is similar in species composition to the Aquatic Vegetation category, however, the floating vegetation proliferates forming thick vegetative mats. This type seems to occur in areas of ponded water that are usually undisturbed by stream flow.

Timber Harvest Areas This category includes all areas of bottomland hardwoods which have been clearcut. The purpose of timber cutting operations within the Basin is usually to provide land for agricultural uses. This category does not include the swamp portions of the Basin that were logged for cypress.

Cottonwood Plantation This category includes managed bottomland areas cleared and planted in cottonwood that will be used for pulpwood. Significant protions of the Basin in the bicinity of U. S. Highway 190 have been converted to cottonwood plantations.

Cane This type consists of bamboo cane located on stream banks in the northern part of the Basin. While it comprises a relatively small area, cane is readily identifiable using color infrared aerial photography.

The forest cover types in the vegetation trend analysis categories represent a more detailed classification than is normally found in standardized land use classification systems. To demonstrate the compatibility with the more general system, these categories have been incorporated (Table 4 and Plate 2) into the classification system described in A Land Use Classification System for Use with Remote Sensor Data. (Anderson, Hardy, and Roach, 1972)

Table 4.--Atchafalaya River Basin vegetation trend analysis categories as part of the Land Use Classification System for use with Remote Sensor Data

Level I	Level II	Level III
01 Urban & Built-Up Land		
02 Cropland & Pastures		
03 Rangeland		
04 Forest Land		
	0401 Deciduous	040101 Willow (Immature)
		040102 Willow (Mature)
		040103 Willow Mixed Hardwoods
		040104 Mixed Hardwoods
		040105 Cypress-Tupelo
		040106 Cypress
		040107 Tupelo
		040108 Tupelo-Willow
		040109 Cypress-Willow
		040110 Cypress-Tupelo-Willow
		040111 Sparse Cypress-Tupelo/Aquatic Vegetation
		040112 Blackberry-Willow
		040113 Cottonwood Plantation
		040114 Cypress-Mixed Hardwoods
	0402 Evergreen	
	0403 Mixed	
		040301 Live Oak-Mixed Hardwoods
		040302 Waxmyrtle-Mixed Hardwoods
	0404 Timber Harvest Area	
05 Water		
06 Nonforested Wetland		
	0601 Vegetated	
		060101 Aquatic Vegetation
		060102 Vegetative Mat
		060103 Cane
	0602 Bare	
07 Barren Land		
08 Tundra		
09 Permanent Snow and Icefields		

The vegetation classification system developed as a result of ground truth efforts was used to classify all the areas delineated on the test strip mosaics. The delineation surfaces for all mosaics were mylar drafting film overlays. A .5 millimetre lead pencil was used to outline and separate the various vegetation types according to the classification system devised.

Interpretation began with the 1973 mosaics which had been ground checked. The color infrared photography covering three of the test strips allowed separation of evergreen species such as live oak and wax myrtle which appeared red on the winter coverage. Delineation of other vegetation types was largely a function of the background element, land or water, and the texture of the bare overstroy vegetation. For example, young willow presented a fine textured appearance over a deep blue or black water background, while mixed hardwoods appeared coarser in texture over a beige background of dead leaves and soil. The relationship between topography and vegetation types is especially significant in alluvial flood plains such as the Atchafalaya Basin. Therefore, the water level, particularly in the winter months, as seen on the January 1973, December 1952 and the February 1930 photography, was a key to locating vegetation types. Water, which occupied the low-lying areas, appeared to outline the extent of certain species such as cypress, tupelo and willow associations, while drier levees were occupied by more tolerant hardwood species.

Delineation of the 1952 and then the 1930 mosaics followed the 1973 mosaics. This involved locating a particular vegetation type on the 1973 mosaics and then examining the earlier mosaics to determine if the type had increased, decreased or remained constant in areal extent. Examples of the strip 4 delineated mosaics are presented in the report Appendix (Plates 3, 4 and 5).

Acreages of the various vegetation categories were determined from the overlays using the H. Dell Foster Digital Planimeter available at the EROS Applications Assistance Facility. Acreage figures and changes were tabulated for each vegetation type, by test strip and by year. The tabulations were then examined to establish the trend in changing vegetation patterns between 1930 and 1973. Acreages are approximate figures only since many of the categories are based on visual judgments as to percentages of specie mixtures and because the mosaics employed in the study are uncontrolled. However, it is believed that since these figures are the result of careful measurement and skilled interpretation that they are more than adequate for the purpose of establishing vegetation trends. The authors estimate that interpretation accuracies range between 80-90 percent while the planimeter accuracies approach 97-98 percent. These figures were confirmed by field checks and comparison with U. S. Forest Service 3-by-3 mile grid coordinate system. The following section deals with the results of the study regarding the trend analysis based on the review of aircraft photography. The vegetation type acreage data as determined from interpretation and mapping of the 1930, 1952 and 1973 aerial photography are presented by test strip. The discussion is confined to significant changes and trends in vegetation types. Changes in selected portions of the test strip are discussed as well as the general trend of the entire sampling area.

All of the test strip mosaics and delineated vegetation overlays are available for study at the EROS Applications Assistance Facility. Only the overlays for test strip 4 in 1930, 1952 and 1973, have been included with the report (Appendix). Acreage data for all the test strips, however, have been included.

TEST STRIP 1

Strip 1, the northernmost test strip, is comprised of a portion of both the West Atchafalaya and Morganza Floodways. The separate management of the two floodways has had differing effects on the vegetation trends; however, the pattern has been one of increased cultural and agricultural development rather than a succession of natural vegetation.

As indicated by Table 5, the predominant forest type of strip 1 since 1930 has been mixed hardwoods. Tupelo and cypress associations have, historically, accounted for only a small portion of the test strip area. The mixed hardwood forests represent a stable, self-perpetuating natural vegetation type for this portion of the alluvial flood plain.

As indicated by Table 6, 1952 to 1973 was a period of intensive development within strip 1. Over 6,000 acres of mixed hardwood forests were cleared and the land diverted to agricultural uses. Most of the development activity took place in the West Atchafalaya Floodway which receives permanent flood protection. The Morganza Floodway is subject to periodic flooding and has experienced less development activity. However, some cottonwood plantations were established within the Morganza.

The Atchafalaya Main Channel is the largest body of water within the test strip and its size has remained almost constant since 1930. Dredging activity has been used to maintain the waterway. Siltation has not decreased the areal extent of the main channel surface water.

Table 5.--Total vegetation acreages of Strip #1 for 1930, 1952 and 1973

Species Group	1930		1952		1973	
	Acres	Percent	Acres	Percent	Acres	Percent
010000 Urban & Built-Up Land	210	0.6	666	2.0	815	2.5
020000 Cropland & Pastures	219	0.7	768	2.3	6,315	19.3
040101 Willow (Immature)	142	0.4	133	0.4	0	0.0
040102 Willow (Mature)	37	0.1	0	0.0	0	0.0
040103 Willow/Mixed Hardwood	0	0.0	0	0.0	112	0.3
040104 Mixed Hardwoods	27,726	84.8	27,257	83.4	21,686	66.3
040105 Cypress/Tupelo	0	0.0	0	0.0	0	0.0
040106 Cypress	0	0.0	0	0.0	0	0.0
040107 Tupelo	1,443	4.4	817	2.5	531	1.6
040108 Tupelo/Willow	998	3.1	825	2.5	0	0.0
040109 Cypress/Willow	791	2.4	929	2.8	693	2.1
040110 Cypress/Willow/Tupelo	390	1.2	530	1.6	455	1.4
040111 Sparse Cypress/Tupelo Aquatic Vegetation	0	0.0	0	0.0	0	0.0
040112 Blackberry/Willow	0	0.0	0	0.0	0	0.0
040113 Cottonwood Plantation	0	0.0	0	0.0	479	1.5
040114 Cypress/Mixed Hardwood	0	0.0	0	0.0	0	0.0
040301 Live Oak/Mixed Hardwood	0	0.0	0	0.0	0	0.0
040302 Waxmyrtle/Mixed Hardwood	0	0.0	0	0.0	0	0.0
040400 Timber Harvest Area	0	0.0	0	0.0	715	2.2
050000 Water	711	2.2	768	2.3	894	2.7
060101 Aquatic Vegetation	0	0.0	0	0.0	0	0.0
060102 Vegetative Mat	0	0.0	0	0.0	0	0.0
060103 Cane	0	0.0	0	0.0	0	0.0
060200 Bare Soil	25	0.1	0	0.0	0	0.0
TOTALS	32,692	100.0	32,693	100.0	32,695*	100.0

*Totals disagree due to scale differences

Table 6.--Comparison of total vegetation acreages of Strip #1 for 1930, 1952 and 1973

Species Group	1930 to 1952		1952 to 1973		1930 to 1973	
	Acres	Percent	Acres	Percent	Acres	Percent
010000 Urban & Built-Up Land	456	217.1	149	22.4	605	288.1
020000 Cropland & Pastures	549	250.7	5,547	722.3	6,096	2,783.6
040101 Willow (Immature)	-9	-6.3	-133	-100.0	-142	-100.0
040102 Willow (Mature)	-37	-100.0	0	0.0	-37	-100.0
040103 Willow/Mixed Hardwood	0	0.0	112	0.0*	112	0.0*
040104 Mixed Hardwoods	-469	-1.7	-5,571	-20.4	-6,040	-21.8
040105 Cypress/Tupelo	0	0.0	0	0.0	0	0.0
040106 Cypress	0	0.0	0	0.0	0	0.0
040107 Tupelo	-626	-43.4	-286	-35.0	-912	-63.2
040108 Tupelo/Willow	-173	-17.3	-825	-100.0	-998	-100.0
040109 Cypress/illow	138	17.4	-236	-25.4	-98	-12.4
040110 Cypress/Willow/Tupelo	140	35.9	-75	-14.2	65	16.7
040111 Sparse Cypress/Tupelo Aquatic Vegetation	0	0.0	0	0.0	0	0.0
040112 Blackberry/Willow	0	0.0	0	0.0	0	0.0
040113 Cottonwood Plantation	0	0.0	479	0.0*	479	0.0*
040114 Cypress/Mixed Hardwoods	0	0.0	0	0.0	0	0.0
040301 Live Oak/Mixed Hardwoods	0	0.0	0	0.0	0	0.0
040302 Waxmyrtle/Mixed Hardwoods	0	0.0	0	0.0	0	0.0
040400 Timber Harvest Area	0	0.0	715	0.0*	715	0.0*
050000 Water	57	8.0	126	16.4	183	25.7
060101 Aquatic Vegetation	0	0.0	0	0.0	0	0.0
060102 Vegetative Mat	0	0.0	0	0.0	0	0.0
060103 Cane	0	0.0	0	0.0	0	0.0
060104 Bare Soil	-25	-100.0	0	0.0	-25	-100.0

*First occurrence

In 1930, approximately 1,000 acres of tupelo/willow were present. By 1973 this type had succeeded to mixed hardwood forests. Pure stands of tupelo decreased from 1,443 acres to 531 over the same period while the cypress/willow and cypress/tupelo/willow remained fairly stable. The trend of forest associations within the swamp areas appears to be gradully towards a mixed hardwood forest.

A complete analysis of test strip 1 extends beyond vegetation trends. The effects of sedimentation have been overpowered by man's activities on the land; clearing forests for agriculture and cultural development is the trend within the mixed hardwood regions.

TEST STRIP 2

The overall trend of vegetation succession evident within strip 2 during the period 1930 to 1973, as indicated by Table 7 has been a large decrease in the extent of the mature, sparse cypress/tupelo forests and an increase in the acreage of willows, mixed hardwoods and cultural development. Sedimentation has played a significant role in strip 2 vegetation succession patterns. The heavy deposition of silt has constricted the area of surface water, reduced the extent of swamp forest types, increased the size of natural stream levees and provided a seedbed for vast stands of willows.

Table 7.--Total vegetation acreages of Strip #2 for 1930, 1952 and 1973

Species Group	1930		1952		1973	
	Acres	Percent	Acres	Percent	Acres	Percent
010000 Urban & Built-Up Land	136	0.3	112	0.3	823	2.0
020000 Cropland & Pastures	0	0.0	0	0.0	0	0.0
040101 Willow (Immature)	3,385	8.4	1,441	3.6	2,075	5.2
040102 Willow (Mature)	580	1.4	3,896	9.7	5,129	12.8
040103 Willow/Mixed Hardwoods	3,095	7.7	1,569	3.9	2,576	6.4
040104 Mixed Hardwoods	1,764	4.4	5,694	14.2	7,204	17.9
040105 Cypress/Tupelo	25	0.1	0	0.0	0	0.0
040106 Cypress	0	0.0	0	0.0	0	0.0
040107 Tupelo	45	0.1	275	0.7	261	0.6
040108 Tupelo/Willow	507	1.3	478	1.2	440	1.1
040109 Cypress/Willow	8,772	21.8	7,569	18.9	8,407	20.9
040110 Cypress/Willow/Tupelo	2,810	7.0	3,351	8.3	2,142	5.3
040111 Sparse Cypress/Tupelo Aquatic Vegetation	7,489	18.7	1,369	3.4	229	0.6
040112 Blackberry/Willow	0	0.0	0	0.0	121	0.3
040113 Cottonwood Plantation	0	0.0	0	0.0	0	0.0
040114 Cypress/Mixed Hardwoods	0	0.0	0	0.0	523	1.3
040301 Live Oak/Mixed Hardwoods	0	0.0	0	0.0	422	1.1
040302 Waxmyrtle/Mixed Hardwoods	2,434	6.1	4,769	11.9	3,371	8.4
040400 Timber Harvest Area	0	0.0	0	0.0	0	0.0
050000 Water	7,628	19.0	6,258	15.6	4,949	12.3
060101 Aquatic Vegetation	1,374	3.4	1,334	3.3	1,044	2.6
060102 Vegetative Mat	0	0.0	2,035	5.1	440	1.1
060103 Cane	0	0.0	0	0.0	0	0.0
060200 Bare Soil	104	0.3	0	0.0	0	0.0
TOTALS	40,148	100.0	40,150	100.0	40,156*	100.0

*Totals disagree due to scale differences

In 1930, the area within test strip 2 was dominated almost equally by cypress/willow, sparse cypress/tupelo and by water, as indicated by Table 8. By 1952, the stands of sparse cypress/tupelo had decreased in size by almost 82 percent. At the same time, the area of mixed hardwoods and willows had increased substantially. Finally, in 1973, the trend of vegetation succession had placed mixed hardwoods and cypress/willow as the dominant forest types. Willow trees and water accounted for about 12 percent each of the total land area within strip 2.

Table 8.--Comparison of total vegetation acreages of Strip #2 for 1930, 1952 and 1973

Species Group		1930 to 1952		1952 to 1973		1930 to 1973	
		Acres	Percent	Acres	Percent	Acres	Percent
010000	Urban & Built-Up Land	-24	-17.6	711	634.8	687	505.1
020000	Cropland & Pastures	0	0.0	0	0.0	0	0.0
040101	Willow (Immature)	-1,944	-57.4	634	44.0	-1,310	-38.7
040102	Willow (Mature)	3,316	571.7	1,233	31.6	4,549	784.3
040103	Willow/Mixed Hardwoods	-1,526	-49.3	1,007	64.2	-519	-16.8
040104	Mixed Hardwoods	3,930	222.8	1,510	26.5	5,440	308.4
040105	Cypress/Tupelo	-25	-100.0	0	0.0	-25	-100.0
040106	Cypress	0	0.0	0	0.0	0	0.0
040107	Tupelo	230	511.1	-14	-5.1	216	480.0
040108	Tupelo/Willow	-29	-5.7	-38	-7.9	-67	-13.2
040109	Cypress/Willow	-1,203	-13.7	838	11.1	-365	-4.2
040110	Cypress/Willow/Tupelo	541	19.3	-1,209	-36.1	-668	-23.8
040111	Sparse Cypress/Tupelo Aquatic Vegetation	-6,120	-81.7	-1,140	-83.3	-7,260	-96.9
040112	Blackberry/Willow	0	0.0	121	0.0*	121	0.0*
040113	Cottonwood Plantation	0	0.0	0	0.0	0	0.0
040114	Cypress/Mixed Hardwoods	0	0.0	523	0.0*	523	0.0*
040301	Live Oak/Mixed Hardwoods	0	0.0	422	0.0*	422	0.0*
040302	Waxmyrtle/Mixed Hardwoods	2,335	95.9	-1,398	-29.3	937	38.5
040400	Timber Harvest Area	0	0.0	0	0.0	0	0.0
050000	Water	-1,370	-18.0	-1,309	-20.9	-2,679	-35.1
060101	Aquatic Vegetation	-40	-2.9	-290	-21.7	-330	-24.0
060102	Vegetative Mat	2,035	0.0*	-1,595	-78.4	440	0.0*
060103	Cane	0	0.0	0	0.0	0	0.0
060200	Bare Soil	-104	-100.0	0	0.0	-104	-100.0

*First occurrence

Dredging, channelization and sedimentation have divided the land within this test strip into a complexity of vegetation types in various stages of succession. The following is a discussion of several portions of test strip 2 and the pattern of vegetation succession within each area.

In 1930 the area to the east of the main channel on strip 2 was dominated by the cypress/willow and the cypress/tupelo associations. Pure stands of tupelo were evident as were stands of willows. In 1952, the forest associations were similar to those seen in 1930. Noticeable, however, pur stands of willos had increased their areal extent. By 1973, mature willow had become a dominant forest association although the previously mentioned forest types were present.

With the construction of Whiskey Bay Pilot Channel, the area immediately to the est succeeded to a mixed hardwood and wax myrtle/mixed hardwood forest as evident in 1952. Continued dredging activity increased this area of hardwood forest types in 1973, and willows were also naturally introduced.

The area between Whiskey Bay Pilot Channel and Upper Grand River succeeded from a cypress/tupelo association in 1930 to a virtually pure stand of willows in 1952. By 1973, this area was predominantly willows with peripheral stands of mixed hardwoods evident.

In 1930, the area to the south of Upper Grand River was a mixed hardwood forest adjacent to the levees and a cypress/tupelo/willow association in the swampy areas. By 1953 the area was, principally, mixed hardwoods although some cypress and tupelo were present. By 1973, the area was predominantly mixed hardwoods.

The area to the northwest of Butte La Rose presents a classic example of accretion within a swamp area. In 1930, the area was swamp dominated by a cypress/tupelo association having a sparse crown cover. In 1952, the area had succeeded to pure stands of young willows; and, by 1973, the area vegetation consisted of mature willows with hardwood stands near the stream levees.

Southwest of Butte La Rose the forest associations have remained relatively the same since 1930. The area is predominantly willow and mixed hardwood forest types.

TEST STRIP 3

The most significant fact evident from analysis of the historical vegetation type data (Table 9) for this area is the increasing rate at which changes are occurring. Additionally, the data in Table 10 indicate that in 1930, almost half of the test strip areas was tupelo/cypres forests and nearly 20 percent of the region was sparse cypress/tupelo. By 1952, the cypress/tupelo forest had decreased slightly in extent, while the cypress/willow/tupelo had increased. This change was due to the initial deposition of sediment and establishment of willows within the cypress/tupelo forests.

The change from 1952 to 1973 is dramatic. The vast tupelo/cypress stand present in 1930 and 1952 had been completely transformed into the typress/willow/tupelo type by accretion of new land. Over the 1930-1952 period, the extent of surface water had been maintained by dredging. This was evidenced by numerous spoil piles seen on the photography. Also, from 1930 to 1973 the succession of willow stands to willow/mixed hardwood is evident.

Table 9.--Total vegetation acreages of Strip #3 for 1930, 1952 and 1973

	Species Group	1930		1952		1973	
		Acres	Percent	Acres	Percent	Acres	Percent
010000	Urban & Built-Up Land	0	0.0	6	0.0	18	0.0
020000	Cropland & Pastures	0	0.0	0	0.0	0	0.0
040101	Willow (Immature)	3,690	7.3	3,185	6.3	586	1.2
040102	Willow (Mature)	0	0.0	4,651	9.2	5,392	10.6
040103	Willow/Mixed Hardwood	0	0.0	261	0.5	1,395	2.8
040104	Mixed Hardwoods	0	0.0	0	0.0	951	1.9
040105	Cypress/Tupelo	22,831	45.1	18,108	35.7	0	0.0
040106	Cypress	0	0.0	0	0.0	0	0.0
040107	Tupelo	2,859	5.6	3,024	6.0	3,274	6.5
040108	Tupelo/Willow	0	0.0	19	0.0	0	0.0
040109	Cypress/Willow	0	0.0	0	0.0	221	0.4
040110	Cypress/Willow/Tupelo	4,854	9.6	7,311	14.4	21,898	43.2
040111	Sparse Cypress/Aquatic Vegetation	9,904	19.5	7,735	15.3	5,386	10.6
040112	Blackberry/Willow	0	0.0	0	0.0	0	0.0
040113	Cottonwood Plantation	0	0.0	0	0.0	0	0.0
040114	Cypress/Mixed Hardwoods	0	0.0	415	0.8	3,137	6.2
040301	Live Oak/Mixed Hardwoods	0	0.0	0	0.0	25	0.0
040302	Waxmyrtle/Mixed Hardwoods	0	0.0	0	0.0	1,205	2.4
040400	Timber Harvest Area	0	0.0	0	0.0	0	0.0
050000	Water	5,597	11.0	5,519	10.9	6,741	13.3
060101	Aquatic Vegetation	939	1.9	419	0.8	207	0.4
060102	Vegetative Mat	0	0.0	0	0.0	234	0.5
060103	Cane	0	0.0	0	0.0	0	0.0
060200	Bare Soil	0	0.0	24	0.0	0	0.0
	TOTALS	50,674	100.0	50,677	100.0	50,670*	100.0

*Totals disagree due to scale differences

Table 10.--Comparison of total vegetation acreages of Strip #3 for 1930, 1952 and 1973

	Species Group	1930 to 1952		1952 to 1973		1930 to 1973	
		Acres	Percen	Acres	Percen	Acres	Percent
010000	Urban & Built-Up Land	6	0.0*	12	200.0	18	0.0*
020000	Cropland & Pastures	0	0.0	0	0.0	0	0.0
040101	Willow (Immature)	-505	-13.7	-2,599	-81.6	-3,104	-84.1
040102	Willow (Mature)	4,651	0.0*	741	15.9	5,392	0.0*
040103	Willow/Mixed Hardwood	261	0.0*	1,134	434.5	1,395	0.0*
040104	Mixed Hardwoods	0	0.0	951	0.0*	951	0.0*
040105	Cypress/Tupelo	-4,723	-20.7	-18,108	-100.0	-22,831	-100.0
040106	Cypress	0	0.0	0	0.0	0	0.0
040107	Tupelo	165	5.8	250	8.3	415	14.5
040108	Tupelo/Willow	19	0.0*	-19	-100.0	0	0.0
040109	Cypress/Willow	0	0.0	221	0.0*	221	0.0*
040110	Cypress/Willow/Tupelo	2,457	50.6	14,587	199.5	17,044	351.1
040111	Sparse Cypress/Tupelo Aquatic Vegetation	-2,169	-21.9	-2,349	-30.4	-4,518	-45.6
040112	Blackberry/Willow	0	0.0	0	0.0	0	0.0
040113	Cottonwood/Plantation	0	0.0	0	0.0	0	0.0
040114	Cypress/Mixed Hardwoods	415	0.0*	2,722	655.9	3,137	0.0*
040301	Live Oak/Mixed Hardwoods	0	0.0	25	0.0*	25	0.0*
040302	Waxmyrtle/Mixed Hardwoods	0	0.0	1,205	0.0*	1,205	0.0*
040400	Timber Harvest Area	0	0.0	0	0.0	0	0.0
050000	Water	-78	-1.4	1,222	22.1	1,144	20.4
060101	Aquatic Vegetation	-520	-55.4	-212	-50.6	-732	-78.0
060102	Vegetative Mat	0	0.0	234	0.0*	234	0.0*
060103	Cane	0	0.0	0	0.0	0	0.0
060200	Bare Soil	24	0.0*	-24	-100.0	0	0.0

*First occurrence

As with strip 2, this test strip warrants a discussion of selected areas within the sampling area to gain an accurate picture of vegetation succession.

The area to the east of Little Bayou Pigeon in 1930 was principally cypress/tupelo interspersed with stands of pure typelo. Also present was an area of sparse cypress/tupelo and some cypress/willow/typelo. The latter was an indication that increased sedimentation was occurring. In 1952 this area was still predominantly cypress/tupelo interspersed with pure tupelo stands. The sparse cypress/tupelo stands had decreased while the cypress/willow/tupleo had become more extensive. By 1973, the area was predominantly cypress/willow/tupleo and all stands of the sparse cypress/tupelo type had been eliminated.

In 1930, Hog Island was forested with sparse cypress/tupelo except for a natural levee covered with cypress/willow/tupelo that bordered the island. In 1952, the center of the island remained sparse cypress/tupelo, while the levees had succeeded to mixed hardwood forests. By 1973, a vegetative mat was established in the center of the island and the area of sparse cypress/tupelo had decreased in size yielding to mixed hardwood forests.

The area between Grand Lake and Little Bayou Piegeon was principally cypress/tupelo and cypress/willow/tupelo in 1930 and 1952. However, in 1952 some pure willow stands were evident. By 1973, this region was predominantly cypress/willow/tupelo and mixed hardwood forests were established on the banks of Grand Lake.

Turkey Island, in the vicinity of the Atchafalaya Main Channel, represents a succession from a swamp forest to mixed hardwood forest. In 1930, the area was cypress/willow/tupleo with some pure stands of willow established on newly accreted land. In 1952, extensive stands of mature willows were present. By 1973, the area had evolved to mixed hardwood stands with some willow present.

The Buffalo Cover area west of the main channel is one of contrasts in that it has supported a mature swamp forest surrounded by extensive willow stands established on newly accreted land. From 1930 to 1973 this region has maintained an extensive sparse cypress/tupleo forest. First evident in 1952, willows became established as sedimentation occurred. In 1973, the results of increasing siltation were evident as the willow stands incresed in areal extent.

TEST STRIP 4

This test strip presents marked contrasts in its patterns of vegetation succession. The swamp areas in the eastern portion of the strip exhibit a stable cypress/tupelo association. This association is the major vegetation type as shown in Table 11, while Table 12 indicates that this forest type has changed little since 1930.

Table 11.--Total vegetation acreages of Strip #4 for 1930, 1952 and 1973

Species Group		1930		1952		1973	
		Acres	Percent	Acres	Percent	Acres	Percent
010000	Urban & Built-Up Land	24	0.1	30	0.1	6	0.0
020000	Cropland & Pastures	62	0.2	87	0.2	0	0.0
040101	Willow (Immature)	0	0.0	877	2.4	7,710	10.0
040102	Willow (Mature)	0	0.0	0	0.0	121	0.3
040103	Willow/Mixed Hardwood	0	0.0	0	0.0	51	0.1
040104	Mixed Hardwoods	0	0.0	0	0.0	0	0.0
040105	Cypress/Tupelo	16,221	43.9	15,683	42.4	16,318	44.1
040106	Cypress	210	0.6	132	0.4	108	0.3
040107	Tupelo	6,215	16.8	5,093	13.8	5,181	14.0
040108	Tupelo/Willow	0	0.0	0	0.0	0	0.0
040109	Cypress/Willow	0	0.0	0	0.0	0	0.0
040110	Cypress/Willow/Tupelo	0	0.0	0	0.0	0	0.0
040111	Sparse Cypress/Aquatic Vegetation	36	0.1	50	0.1	0	0.0
040112	Blackberry/Willow	0	0.0	11	0.0	531	1.4
040113	Cottonwood/Plantation	0	0.0	0	0.0	0	0.0
040114	Cypress/Mixed Hardwoods	383	1.0	231	0.6	279	0.8
040301	Live Oak/Mixed Hardwoods	656	1.8	800	2.2	1,059	2.9
040302	Waxmyrtle/Mixed Hardwoods	0	0.0	0	0.0	12	0.0
040400	Timber Harvest Area	0	0.0	0	0.0	0	0.0
050000	Water	12,573	34.0	13,503	36.5	9,457	25.6
060101	Aquatic Vegetation	561	1.5	491	1.3	158	0.4
060102	Vegetative Mat	0	0.0	0	0.0	0	0.0
060103	Cane	0	0.0	0	0.0	0	0.0
060200	Bare Soil	47	0.1	0	0.0	0	0.0
	TOTALS	36,988	100.0	36,988	100.0	36,991*	100.0

*Totals disagree due to scale differences

The western portion of the test strip supprots an increasing area of pur willow stands established on newly accreted land that has decreased the surface of water.

The forest coer type of test strip 4 in 1930 was predominantly the cypress/tupelo association. Intensive logging activity prior to 1930 had substantially decreased the number of mature cypress in the area, but enough young cypress remained to justify the classification of the predominant forest type as cypress/tupelo. Pure stands of tupelo were located within the vast cypress/tupelo swamp, while one young stand of pure cypress/mixed hardwoods occupied some of the natural river levees, principally in the area of Bayou Sorrel. Natural river levees on Cypress Island and Tiger Island were the site of some of the most extensive live oak/mixed hardwood forests in the Basin. Noticeable within test strip 4, there were no stands of willow trees in 1930.

Table 12.--Comparison of total vegetation acreages of Strip #4 for 1930, 1952 and 1973

Species Group		1930 to 1952		1952 to 1973		1930 to 1973	
		Acres	Percent	Acres	Percent	Acres	Percent
010000	Urban & Built-Up Land	6	25.0	-24	-80.0	-18	-75.0
020000	Cropland & Pastures	25	40.3	-87	-100.0	-62	-100.0
040101	Willow (Immature)	877	0.0*	2,833	323.0	3,710	0.0*
040102	Willow (Mature)	0	0.0	121	0.0*	121	0.0*
040103	Willow/Mixed Hardwood	0	0.0	51	0.0*	51	0.0*
040104	Mixed Hardwoods	0	0.0	0	0.0	0	0.0
040105	Cypress/Tupelo	-538	-3.3	635	4.0	97	0.6
040106	Cypress	-78	-37.1	-24	-18.2	-102	-48.6
040107	Tupelo	-1,122	-18.1	88	1.7	-1,034	-16.6
040108	Tupelo/Willow	0	0.0	0	0.0	0	0.0
040109	Cypress/Willow	0	0.0	0	0.0	0	0.0
040110	Cypress/Willow/Tupelo	0	0.0	0	0.0	0	0.0
040111	Sparse Cypress/Tupelo Aquatic Vegetation	14	38.9	-50	-100.0	-36	-100.0
040112	Blackberry/Willow	11	0.0*	520	4,727.3	531	0.0*
040113	Cottonwood Plantation	0	0.0	0	0.0	0	0.0
040114	Cypress/Mixed Hardwoods	-152	-39.7	48	20.8	-104	-27.2
040301	Live Oak/Mixed Hardwoods	144	22.0	259	32.4	403	61.4
040302	Waxmyrtle/Mixed Hardwoods	0	0.0	12	0.0*	12	0.0*
040400	Timber Harvest Area	0	0.0	0	0.0	0	0.0
050000	Water	930	7.4	-4,046	-30.0	-3,116	-24.8
060101	Aquatic Vegetation	-70	-12.5	-333	-67.8	-403	-71.8
060102	Vegetative Mat	0	0.0	0	0.0	0	0.0
060103	Cane	0	0.0	0	0.0	0	0.0
060200	Bare Soil	-47	-100.0	0	0.0	-47	-100.0

*First occurrence

In 1952 the forest cover types within test strip 4 were much the same as in 1930. The area was still predominantly cypress/tupelo interspersed with pure stands of tupelo and the single stand of cypress north of Flat Lake continued to mature. The cypress/mixed hardwood forests along Bayou Sorrel were decreasing slightly, while the live oak/mixed hardwood forests on the levees of Cypress and Tiger Islands had increased. Despite the seeming stability in forest cover types, a significant change did occur. The newly accreted land in the area of Grand Lake and Six Mile Lake became the site of extensive pure stands of young willow trees.

The 1973 forest associations were essentially the same in 1952. The dominant cover type remained cypress/tupelo. The area of pure stands of tupelo had increased slightly. Cypress/mixed hardwood hardwoods still bordered Bayou Sorrel and the live oak/mixed hardwood forests of Cypress and Tiger Islands were approximately the same size as in 1952. The significant change occurring within the area was again the emergence of new stands of willows in the Grand Lake and Six Mile Lake region. The trend, first evident in 1952, has continued at an increasing rate. As large areas of newly accreted land appeared, extensive stands of pure willows became established and dominated the vegetation type of the western portion of the test strip.

BASIN-WIDE VEGETATION ANALYSIS

Procedures

In order to complete a vegetation map of the Atchafalaya River Basin, a comprehensive review was made of the best available photography and imagery covering the Basin. Several criteria were used in the selection of these data which included its availability, areal extent, quality, detail and timeliness. The Landsat-1 band 7, black-and-white infrared (0.8 to 1.1 micrometres) imagery was deemed the best data to satisfy the criteria. Landsat-1 frames 152116104 (26 December 1973) and 155616035 (30 January 1974) were selected for analysis.

Landsat-1 acquires coverage every 18 days over the Basin and is easily accessible from the EROS Data Center in Sioux Falls, South Dakota. The quality of the imagery used was very good, and the late December or mid-January scenes were selected since they were taken during the same months as the aircraft photography used in the trend analysis. In addition, it was found that there was a wider range of forest type signatures on these data. On spring coverage the forest types showed up as a solid red tone on the color infrared coverage.

Landsat-1 imagery was enlarged to 1:250,000 scale positive paper prints. The two frames were mosaicked on a masonite board using hot wax. This uncontrolled mosaic was then covered with frosted acetate and delineated.

The vegetation was grouped into four categories which represented a composite of the vegetation categories used in the aerial photographic analysis (Table 13 and Plate 2). Since the groupings were different from those presented in USGS Circular 671, a separate identification system was employed for this portion of the study.

The interpretation of the Landsat-1 black and white band 7 imagery was carried out using conventional photo interpretation methods. Each of the tonal anomalies was delineated using a mechanical pencil (Demi-5, .5mm lead) on frosted acetate. The range of observed tones included white, black and several shades of gray. Mixed hardwoods, for example, had a bright gray tone while water appeared as a black tone. The Landsat-1 band 7 image (0.8 to 1.1 micrometres) is sometimes referred to as the "water band" since surface water absorbs the electromagnetic energy and therefore clear, non-turbid water appears black on the imagery. Vegetation, however, reflects the solar energy and is depicted on the images as a gray to white tone. The vegetation was easier to interpret on band 7 because of the sharp intricate outlines, traces and tones seen on the image even though the imagery used showed much of the vegetation in the dormant stage. It appears that during December and January the most noticeable vegetation "signature" on the Landsat-1 imagery was the leafless crown canopy. The water in most cases provided a contrasting background to the bare crowned vegetation. As was evident on the aerial color infrared photography, the water helped to demarcate most of the vegetation categories. For example, the mixed hardwoods had a different tone than the swamp mixed hardwood due to the presence of water under the swamp hardwood canopy and little, if any, under the mixed hardwoods.

Table 13.--Basin-wide vegetation classification and related vegetation trend analysis classification

1. Mixed Hardwoods	040301 Live Oak/Mixed Hardwoods 040302 Wax Myrtle/Mixed Hardwoods 040104 Mixed Hardwoods
2. Swamp Mixed Hardwoods	040103 Willow/Mixed Hardwoods 040108 Tupelo/Willow 040109 Cypress/Willow 040114 Cypress/Mixed Hardwoods
3. Cypress/Tupelo	040111 Sparse Cypress/Tupelo Aquatic Vegetation 040106 Cypress 040107 Tupelo 040105 Cypress/Tupelo 040110 Cypress/Willow/Tupelo[1]
4. Willow/Cottonwood	040101 Willow (Immature) 040102 Willow (Mature) 040112 Blackberry/Willow
5. Water (Surface)	0500 Water
6. Non-Forested	040113 Cottonwood Plantations 0100 Urban & Built-Up 0200 Cropland and Pasture 0602 Bare Soil

[1]Cypress/Willow/Tupelo classification belongs in the Swamp Mixed Hardwood classification instead of the Cypress/Tupelo classification, but the Cypress/Willow/Tupelo stands could not be separated from the Cypress/Tupelo groupings.

The delineation of the vegetation was checked with aircraft data from the strip analysis. Table 2 listed the aerial photography used to "ground truth" the Landsat interpretation. In addition, the ground truth efforts carried out during the vegetation trend analysis were also used to help confirm some fo the satellite imagery observations. The willow/cottonwood classification proved to be the most difficult to interpret and delineate while mixed hardwoods were the easiest. Turbidity patterns in the water also made delineation of surface water in some areas difficult. This caused the analyst to over extend some of the vegetation boundaries and miscalassify them as surface water. This problem, however, did not greatly affect the totals for each species of vegetation in the Basin.

After the completion of the delineation all the vegetation types were planimetered using an H. Dell Foster Digital Planimeter. The planimeter automatically computed the acreage (Table 14) after the scale factor was registered and the delineated area outlined with a movable glass vernier.

Table 14.-- Basin-wide vegetation classification and acreage table (Keyed to Plate 6)

Vegetation Classification	Acres
1. Mixed Hardwoods	275,000
2. Swamp Mixed Hardwoods	144,400
3. Cypress/Tupelo	204,800
4. Willow/Cottonwood	93,800
5. Surface Water	53,100
6. Non-Forested	62,600
TOTAL	833,700

Results

One of the most significant results of this study is the distribution pattern of the various vegetation types shown on Plate 6 in the Appendix. As this vegetation map indicates, mixed hardwoods and non-forested areas predominate from just north of Interstate 10 to the vicinity of Simmesport. Swamp mixed hardwoods, the transitory vegetation type, are principally located from Highway US-190 to approximately the Bayou Pigeon and Bayou Eugene areas. Willow/cottonwood is the dominant type on the west side of the Atchafalaya River Basin in two areas from north of Interstate 10 to Butte La Rose and from Grand Lake to Six Mile Lake. The cypress/tupelo type dominates the eastern areas of the Basin from Interstate 10 to Morgan City.

The Landsat analysis showed that much of the Basin has been bisected with bayous, channels, canals, levees, streams and pipelines forming unique units or compartments of vegetation. This in effect has created sections of differing rates of vegetation dynamics or change. In some of the western areas of the Basin where the effects of the Atchafalaya River have been restricted to its flood levees, the rate of change in vegetation has been slowed down or almost stopped. However, the areas which are influenced by Grand and Six Mile Lake areas (southwestern part of the Basin). This area of the Basin appears to receive perhaps the greatest amount of sediment deposition and is covered by the willow/cottonwood species. Apparently east-west trending stream banks, channels, canals or bayous impede some of the sediment. The banks rise as the silt load is deposited and as a result a change in vegetation begins to take place in favor of vegetation which can take advantage of the higher and drier sites. Some areas which seem to reflect this change are located along the eastern portion of Interstate 10, Cow Bayou, Upper Grand River, Little Bayou Sorrel, Little Bayou Pigeon, Big Bayou Pigeon, the area between Bayou Eugene and Bayou Chene, and the area between Lake Long and Lake Round.

One of the most apparent results of this sediment deposition is in the Flat Lake area. To the north of Flat Lake lies a vast area of cypress/tupelo, but as the river water infiltrates through this area apparently most of the sediment is fileterd or drops out. This phenomena was noted on band 5 Landsat-1 data over Flat Lake. At this point a relatively clear effluent emerges from the cypress/tupelo stand and enters Flat Lake, heading for the Atchafalaya River Basin outlet. The sediment load is apparently being deposited in the cypress/tupelo stand probably creating changes in elevation. Little and Big Bayou Pigeon, Bayou Sorrel and Upper Grand River show a drier site vegetation. Sequential coverage of the Basin by satellite and aircraft have shown the plume in detail during most of the year.

In the area above Interstate 10, the major species changes have occurred in the large commercial non-forested areas. Generally, this activity involves the removal of mixed hardwoods, which are the culmination of the overstory forest cycle in the Basin. In some instances the commercial non-forested areas are situated on other than mixed hardwood sites and are almost continually flooded each year.

Basin-Wide Cleared Land Statistics

One of the critical elements in determining wildlife habitat and documenting vegetation trends is to determine how many areas of land have been cleared. A special exercise was carried out to arrive at such a figure for the Atchafalaya Basin. A 1:20,000 scale black line ozalid copy of an uncontrolled aerial mosaic was interpreted and planimetered to produce the figures. The photography for the mosaic was collected by the Corps of Engineers in February 1974. Cleared land acreages were computed on a digital planimeter for the West Atchafalaya Floodway, the Morganza Floodway, and the lower Atchafalaya Floodway from Simmesport in the north to Interstate 10 in the south. Cleared lands were defined as those that supported agriculture, cottonwood plantations, timber clearnings, oil development facilities, river and transportation developments, or urbanized areas.

It should be noted that the cleared land figures in Table 15 are greater than the non-forested category shown in Table 14. This difference is due to the fact that only during this special exercise was the upper portion of the West Atchafalaya Floodway studies in any great detail.

Table 15.--Basin-wide cleared land statistics

Area	Cleared Land (Acres)
West Atchafalaya Floodway	51,720
Morganza Floodway	13,015
Lower Atchafalaya Floodway	8,844
TOTAL	73,579

FOREST ACREAGE TREND MODELING

Several recent studies have focused on the problem of forest simulation. The work of Botkin and Miller (1974), using conceptually based algorithms relating forest growth to approximately 10 environment factors, resulted in the development of a northwestern forest-growth simulator. A similar study on simulation of southern wetland forests using a plot of 0.1 acre (0.04 ha) is underway by Phipps (1974, written communication).

Because of the large and diverse nature of the Atchafalaya Basin and the need to consider all or most of the Basin, detailed investigations of the above kind could not be undertaken in this study. Instead, an empirical model based on statistical methods and forestry concepts using observed forest acreage and available hydrologic data was selected.

The model predicts forest acreage transitions (approximately 21-year acreage changes) on a quadrat basis using data from 24 quadrats. A forest acreage transition is defined as a discrete change in acreage of a given forest type during a time period of 21 years. The quadrat size of 8 mi^2 (20.74 km^2) is an arbitrary choice representing a balance between expected accuracy of the model and data definition capability. The objectives of the analysis is not to simulate vegetation change by use of all factors correlated with vegetation distribution, but to determine how accurately factors associated with hydrologic change can predict vegetation change. In future simulation studies, approximately 150 quadrats will be used to simulate forest trends under alternative Basin management plans.

Data Used in the Study

The data base for the statistical model includes 4 basic hydrologic variables and 16 forest types and related variables. Figure 2 and Plate 1 are maps of the Atchafalaya Basin study area and show the location of test strips on which vegetation acreages were sampled. The test strips (shown shaded) are 4 mi (6.44 km) wide and span the Basin from levee to levee.

Three sets of aerial photography for years 1930, 1952, and 1973 were available for each test strip. The test strips are associated with Corps of Engineers sedimentation range lines 10, 17, and 22, along which hydrologic information is available for approximately the same times as the available aerial photography.

The test strips were subdivided into 26 quadrats, each 2 mi (3.22 km) by 4 mi (6.44 km), except for quadrats near levees which contain less than 8 mi^2 (20.74 km^2). Hydrologic data were available for 24 of the 26 quadrats. Thus, observed data from 24 quadrats, or environmental sampling units, were available for analysis.

Forest Acreage Data

Forest types are defined, for the purpose of this study, as vegetation units composed of one or more forest species distinguishable on aerial photography. The forest types are listed in Table 16. Forest type data for each quadrat were identified and obtained from aerial photography by planimetry. The sets of aerial photogrpahy acquired from the National Aeronautics and Space Administration and the Corps of Engineers varied in scale from 1:120,000 to 1:20,000 and included panchromatic, black and white infrared and color infrared photography.

Table 16.--Forest Types

Forest Type Number	Forest Type
33[1]	Urban and Built-Up Land
34[1]	Agricultural Land
35	Willow (Immature)
36	Willow (Mature)
37	Willow/Mixed Hardwoods
38	Mixed Hardwoods
39	Cypress/Tupelo
41	Tupelo
42	Tupelo/Willow
43	Cypress/Willow
44	Cypress/Willow/Tupelo
45	Sparse Cypress/Tupelo-Aquatic Vegetation
46	Blackberry/Willow
48	Cypress/Mixed Hardwoods
49	Live Oak/Mixed Hardwoods
50	Wax Myrtle/Mixed Hardwoods
52	Water
53	Aquatic Vegetation

[1]Delineated, but not used in statistical model.

Field investigations were undertaken to obtain a key for use in identifying each forest type on the aerial photography. Both beginning and ending acreages for each type representing a forest transition were tabulated. Table 17 is a matrix of observed forest type data for the 16 types to be predicted by the forest-trend simulation model.

Table 17.--Observed forest type data

Year	Number Quadrat	35	36	37	38	39	41	42	43	44	45	46	48	49	50	52	53
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Hydrologic Data

Hydrologic variables used in the statistical calculations are defined and listed in Table 18. The set of hydrologic variables reprsents those quantities which will undergo change as the result of proposed alternative water-management plans for the Basin. Thus, while other environmental factors undoubtedly affect vegetation change, the marginal vegetation change due to hydrologic change (either natural or manmade) is of primary interest in these studies.

As previously mentioned, hydrologic data are available at ranges 10, 17, and 22. Using data from Corps of Engineers publications (see references), including sedimentation range and river-stage data, the following four hydrologic quantities were obtained for each quadrat: (a) average land elevation as determined along applicable range line; (b) maximum land elevation as determined along applicable range line; (c) average number of days per year quadrat was inundated; and (d) average annual depth of inundation in quadrat. Several utility computer programs were used to process and prepare the cross section (available from sedimentation range plots) and river-stage (available from published records at nearby gaging stations) data. The first variable was obtained by averaging interpolated ground elevations (msl) at 100 ft (30.48 m) intervals across the 2 mi (3.22 km) quadrat widths. The second variable was the highest ground elevation (msl) in 2 mi (3.22 km) quadrat width along the range line. The third variable was obtained by comparing average quadrat land elevation with annual river stage hydrographs from a nearby gaging station. The number of days within the year in which river stage exceeded average land elevation was tabulated. Five determinations using annual hydrographs for years near 1930, 1952, and 1973 were then averaged to define the variable. The fourth variable is the corresponding average annual depth determined as river stage minus average land elevation.

Table 18.--Hydrologic variables used in study

Variable number	Hydrologic variables
1[1]	Change in average land elevation in quadrat
2[1]	Change in maximum land elevation in quadrat
3[1]	Change in average number of days inundation per year in quadrat
4[1]	Change in average annual depth of inundation in quadrat
5	Average land elevation in quadrat at end of a forest transition
6	Maximum land elevation in quadrat at end of a forest transition
7	Average number of days inundation per year in quadrat at end of a forest transition
8	Average annual depth of inundation in quadrat at end of a forest transition
9	Aera of surface water in quadrat at end of a forest transition, in acres

[1]Change in hydrologic variables corresponds as closely as possible to 1930-52 or 1952-73 forest transition periods.

The four basic hydrology variables were then used to create four additional variables based on difference between ending and beginning values which represent hydrologic change during a forest transition. A ninth hydrologic variable, obtained by planimetry, was the acreage of surface water present in each quadrat.

Statistical Analyses

The statistical component of the forest-trend simulation model is linear regression analysis using stepwise multiple linear regression methods. Only one set of forest-type data was available for use in the study.

Recalling the strip-quadrat system as shown in Figure 2, let $Y(i,j,k,t)$ denote the number of acres occupied by the ith forest type in the jth quadrat of the kth strip in year t. Let $X(l,j,k,t)$ denote the value of the lth basic hydrologic variable in the jth quadrat of the kth strip in year t. Hydrologic change variables are created by setting

$$\Delta X(l,j,k,t) = X(l,j,k,t) - X(l,j,k,t-1)$$

Thus, a regression equation for estimates $\hat{Y}(i,j,k,t)$ can be written for each $i = 1,2,...16$,

$$\hat{Y}(i,j,k,t) = \beta(0,i) + \sum_{l=1}^{5} \beta(l,i)X(l,j,k.t)$$

$$\pm \sum_{l=1}^{4} \gamma(l,i)\Delta X(l,j,k,t) + \delta(i)Y(i,j,k,t-1) \qquad (1)$$

for all values of j,k,t for which data are available. The last term in equation 1 represents an autoregressive component.

Becuase of the nature of hydrologic and forest type data, data vectors used in the final regression equations will not be independent in time or space. This fact will limit the validity of statistical reliability tests. The coefficients β, γ, and δ, as well as the standard error of estimate, are determined as a result of the regression computation.

A feature of the regression problem is the constraint that $\Sigma \hat{Y}(i,j,k,t)$ for $i = 1,2,...16$ for each jth quadrat must equal 8 mi^2 (20.74 km^2). While an approach based on multivariate statistical processes may offer a solution to the problem, an interim empirical approach was selected. The approach uses individual regression analysis based on equation 1 and forest category type constraint relations based on relationships between forest types as distinguished on aerial photography.

A computer program, BMD02R, Stepwise Regression (BMD, Biomedical Computer Program, University of California, Los Angeles, 1968) was used to perform the analyses. The program computes a sequence of multiple linear regression equations in a stepwise manner. At each step, one variable is added to the regression equation. The variable added is the one which makes the greatest reduction in the error sum of squares. Equivalently it is the variable which, if it were added, would have the highest F value. The use of the F value in this analysis is limited to that of a control variable for entry and exit of independent variables. The program allows variables to be forced into the equation, and also, will automatically remove nonforced variables when their F values become too low. F values for inclusion of variables were set at 0.01; F values for variable deletion were set at 0.005. In addition, the program contains a feature for forcing the regression intercept through the origin and for fixed regressions both of which were utilized in the computer runs.

Several regression runs were made using the model of equation 1 with and without the autoregressive component. These included: (a) log transformation of variables, (b) individual regressions for each strip, (c) regressions using riverine and backswamp quadrats separately, and (d) the basic untransformed model with the autoregressive component. Log transformation of dependent and independent variables offered no improvement in standard error of estimate, the parameter used to measure accuracy. Individual strip regressions were unsatisfactory because of a small number of data items and consequent loss of statistical significance. Regressions using data sorted into data from quadrats in predominantly riverine and predominantly backswamp areas yielded no substantial improvement in results. Therefore, final regression results were based on combined data from all strips using the model of equation 1 including an autoregressive component. The autoregressive component is simply the last forest type acreage for the type being predicted included as an additional independent variable.

The first phase of regression runs made using the stepwise option in an effort to find the most important independent variables. Four of the nine independent hydrology variables were identified as explaining most of the variance when the set of forest acreage prediction equations was compared. These were: (a) change in maximum land elevation in quadrat, (b) change in average number of days inundation per year in quadrat, (c) average land elevation in quadrat at end of a forest transition, and (d) last acreage of forest type variable. Therefore, the final phase of regression runs used these four variables without the stepwise option.

Regression results using each of the 16 forest type variables regressed against these four variables are given in Table 19. The order of significance of each independent variable is also shown in Table 19.

Table 19.--Summary of regression results

Forest type number 1	Multiple correlation coefficient	Standard error of estimate, acres times 1,000	Regression constants of independent varibles			
			Independent variable 2	Independent variable 3	Independent variable 5	Independent variable, last acreage
35	.6129	.3777	-.00262 (4) 2	-.00105 (2)	.00282 (3)	.37988 (1)
36	.7197	.7318	.05612 (3)	.00112 (4)	.01776 (1)	.64372 (2)
37	.9103	.2965	-.03413 (2)	-.00050 (4)	.02969 (1)	.19567 (3)
38	.9554	.3418	-.01588 (3)	.00029 (4)	.05433 (1)	.67032 (2)
39	.8908	1.0604	-.02105 (4)	.01728 (2)	.29166 (3)	.57012 (1)
41	.9793	.1528	-.00555 (2)	-.00015 (4)	.00241 (3)	1.02520 (1)
42	.8285	.0591	.00168 (4)	.00024 (2)	.00583 (1)	-.25087 (3)
43	.8593	.7787	-.00849 (2)	-.00065 (2)	-.00640 (3)	.80852 (1)
44	.7710	1.1542	.02695 (4)	-.00823 (2)	-.01324 (3)	.96858 (1)
45	.4969	.2509	.00221 (3)	.00102 (2)	.01390 (1)	-.01367 (4)
46	.7111	.1888	.03739 (1)	.00152 (4)	-.00520 (2)	-8.93693 (3)
48	.7547	.2039	-.00666 (3)	-.00246 (1)	.00655 (4)	.57042 (2)
49	.9590	.0493	-.00069 (3)	.00007 (2)	.00000 (4)	1.05780 (1)
50	.7621	.4208	-.01597 (2)	.00069 (3)	.05032 (1)	.00000 (4)
52	.9409	.3114	.01427 (3)	-.00075 (4)	.00907 (2)	.60320 (1)
53	.8023	.0081	-.00072 (4)	.00031 (3)	.00628 (2)	.39050 (1)

1Refer to Table XVI for forest type.
2Number in parenthesis is rank of significance of independent variable.

Within the subset of four independent variables, the most significant were generally last acreage and average land elevation at the end of a forest transition period. This fact suggests the dominant effect on forest type change of sedimentation superimposed on a natural forest succession.

The standard error of estimate in units of acres ranged from ±49.3 acres (20.0 ha) for forest type variable 49 to ±1,154.2 acres (467 ha) for forest type variable 44. In general, forest type variables which experienced least erratic transitions were best predicted. All equations included one or more transitions to or from a zero acreage, and most equations appeared capable of computing this situation.

Forest Trend Simulation

The regression relations alone are not adequate for long-term forest trend predictions. For example, they include no interrelationships among forest types. Also due to significant error potential, depending on the equation, they are capable of negative or unreasonable large acreage predictions. Because the forest trend simulation model is likely to be used for predictions of up to 5 forest transitions (over 100 years), a study of forest succession for the Atchafalaya Basin, in the light of observed behavior as shown in Table 16, is necessary.

As sedimentation occurred within a test strip evidenced by the land accretion within streams and lakes, a natural and predictable succession of vegetation could be observed by study of the sequential aerial photography. These trends are depicted in Figure 18 (in the Conclusions section), a flow chart of forest succession for the Atchafalaya River Basin.

Two climax forests are depicted in Figure 18: cypress for the swamp regions, where land floods frequently for long duration, and the oak type for areas with raised land elevations. Within the swamp areas, the succession of forest types toward a climax forest is interrupted when silt deposition results in the raising of land and improving of drainage. In such instances, willow and cottonwood become established in areas of sparse crown cover; while in areas of dense cypress and tupelo crown cover, the more competitive hardwood species, such as red maple, bitter pecan, and green ash, become established. The forest types and associated numbers are also shown in Figure 18.

Based on forest succession concepts and observed forest transitions, several constraints were put on regression equation estimates. These are: (a) constraint based on an inverse relationship between the sum of forest type numbers 35-38 (willow/mixed hardwoods) and type 39 (cypress/tupelo); (b) a constraint based on inverse relations between forest types 35 and 36 (willow) and forest type 41 (tupelo); and (c) a constraint such that forest acreage changes during any transition period were set to observed maximum or minimum changes if a computed value exceeded these limits for a given forest type. The inverse relations of (a) and (b) can be seen in the data matrix of Table 17 and are consistent with forest succession concepts. The constraint relations are expressed as upper limits of one type for a given value of another type or set of types. For example, in relation (a), if the willow/mixed hardwood group sums to more than 3,200 acres (1,295 ha), the computed value of cypress/tupelo is set to zero acres. These relations, called willow/tupelo I and II and willow/mixed hardwoods - cypress/tupelo, are given in Table 20.

Table 20. Forest type constraint relations

If	Then
Tupelo/willow relation I	
Var 41 > 300 acres (121 ha)	Var 35 = 0
300 acres (121 ha) ≥ var 41 > 50 acres (20 ha)	Var 35 ≤ 100 acres (40 ha)
50 acres (20 ha) ≥ var 41	Var 35 as computed
Tupelo/willow relation II	
Var 41 > 400 acres (161 ha)	Var 36 = 0
400 acres (161 ha) ≥ var 41 > 100 acres (40 ha)	Var 36 ≤ 200 acres (81 ha)
100 acres (40 ha) ≥ var 41	Var 36 as computed
Willow/mixed hardwoods - cypress/tupelo	
W/HW > 3,200 acres (1,295 ha)	Var 39 = 0
3,200 acres (1,295 ha) ≥ W/HW > 1,920 acres (777 ha)	Var 39 ≤ 320 acres (130 ha)
1,920 acres (777 ha) ≥ W/HW > 640 acres (259 ha)	Var 39 ≤ 1,920 acres (78 ha)
640 acres (259 ha) ≥ W/HW	Var 39 ≤ 4,480 acres (1,813 ha)

Additional constraints on computed values of the regression equations are: (a) negative values are set to zero, and (b) if computed quadrat area exceeds 8 mi^2 (20.74 km^2), the error in area is distributed to individual computed forest type acreages in proportion to standard errors of estimate for each type given in Table 19.

In some cases, the quadrat area is reduced to account for areas of agriculture, urban land, or other constant quantities not predictable by the forest trend simulation model. The computation sequence of the model is summarized in Figure 9.

Test of Simulation Method

The simulation method or model was further tested using data on two observed forest transitions, 1930-52 and 1952-73. An example computation for quadrat 5 of range 17 is shown in Table 21. In addition to observed and computed total acreages of each forest type, Table 22 also gives mean and standard deviation of observed and computed values for comparison. Of the 32 cases, observed and computed total forest type acreages agree within 10 percent for 6 cases, within 20 percent for 16 cases, and within 30 percent for 23 cases. In nine cases, forest type totals were in error by greater than 30 percent.

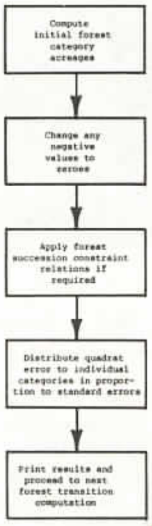


Figure 9.--Forest trend simulation model

Table 21.--Example simulation for range 17, quadrat 5

	Forest transition 1930-52				Forest transition 1952-73			
Forest type number[1]	Computed 1952 acreage times 1,000--unadjusted	1952 observed acreage times 1,000	Computed adjusted 1952 acreage times 1,000	Acreage error times 1,000	Computed 1973 acreage times, 1,000--unadjusted	1973 observed acreage times 1,000	Computed adjusted 1973 acreage times, 1,000	Acreage error times 1,000
35	0.0	0.0832	0.0	0.0832	0.1898	0.0	0.2163	-0.2163
36	0.5089	0.0	0.4224	-0.4224	0.2029	0.0	0.2542	-0.2542
37	0.0	0.0	0.0	0.0	0.0291	0.0896	0.0499	0.0397
38	0.0755	0.0	0.0351	-0.0351	0.1143	0.0320	0.1383	-0.1063
39	2.5593	2.7712	2.4340	0.3372	0.1430	0.0	0.2173	-0.2173
41	0.0048	0.0	0.0	0.0	0.0048	0.0832	0.0151	0.0681
42	0.0342	0.0	0.0272	-0.0272	0.0	0.0	0.0041	-0.0041
43	0.0	0.0	0.0	0.0	0.0025	0.0	0.1372	-0.1372
44	1.7113	1.8048	1.5749	0.2299	2.9908	4.1600	3.0717	1.0883
45	0.0642	0.0	0.0346	0.0346	0.0	0.0	0.0176	-0.0176
46	0.2722	0.0	0.2499	0.2499	0.0	0.0	0.0132	-0.0132
48	0.0	0.0	0.0	0.0	0.3677	0.1216	0.3820	-0.2604
49	0.0	0.0	0.0	0.0	0.0	0.0	0.0035	-0.0035
50	0.0581	0.0	0.0084	-0.0084	0.0353	0.0440	0.0648	-0.0208
52	0.3630	0.4600	0.3262	0.1346	0.5069	0.5632	0.5287	0.0345
53	0.0215	0.0	0.0111	-0.0111	0.0	0.0256	0.0062	0.0194
Sum of acreage	5.6730	5.1200	5.1237	-0.0037	4.6667	5.1200	5.1200	0.0000

[1] Refer to Table XVI for forest type

Table 22.--Summary of forest trend model simulation results

(Mean and standard deviation are computed using 16 quadrats for 1952 and 24 quadrats for 1973)

	1952 results						1973 results					
Forest type number[1]	Acreage times 1,000		Mean acreage times 1,000		Standard deviation times 1,000		Total acreage times 1,000		Mean acreage times 1,000		Standard deviation times 1,000	
	Computed	Observed	Computed	Observed	Computed	Observed	Computed	Observed	Computed	Observed	Computed	Observed
35	2.33	2.56	0.15	0.16	0.20	0.23	1.23	5.53	0.05	0.24	0.07	0.43
36	6.41	7.95	0.40	0.50	0.30	0.79	7.03	5.71	0.31	0.25	0.35	0.40
37	2.24	1.52	0.14	0.10	0.14	0.22	3.39	3.53	0.15	0.15	0.20	0.30
38	6.19	5.47	0.38	0.34	0.41	0.52	8.33	7.41	0.36	0.32	0.54	0.62
39	22.70	17.81	1.41	1.11	1.22	1.54	20.54	16.32	0.89	0.71	0.99	1.21
41	2.89	3.08	0.18	0.19	0.38	0.40	8.03	8.51	0.34	0.36	0.57	0.62
42	0.67	0.48	0.04	0.03	0.03	0.06	0.84	0.10	0.03	.004	0.03	0.02
43	6.01	7.28	0.38	0.45	0.76	0.89	6.88	8.16	0.30	0.36	0.55	0.83
44	6.92	10.06	0.43	0.63	0.60	0.72	20.92	23.61	0.91	1.03	0.99	1.47
45	1.58	2.35	0.10	0.15	0.10	0.30	2.57	0.23	0.12	0.01	0.13	0.04
46	1.92	0.0	0.12	0.0	0.10	0.0	2.43	0.65	0.10	0.03	0.11	0.07
48	0.49	0.42	0.03	0.03	0.05	0.07	5.03	3.82	0.22	0.17	0.17	0.23
49	0.07	0.0	0.0	0.0	0.0	0.0	0.96	1.09	0.04	0.05	0.12	0.12
50	4.61	4.59	0.28	0.28	0.28	0.48	4.57	4.33	0.20	0.19	0.21	0.36
52	8.81	10.03	0.55	0.63	0.33	0.36	14.90	19.06	0.65	0.83	0.44	0.49
53	1.46	1.65	0.09	0.10	0.09	0.16	1.53	0.97	0.07	0.04	0.07	0.05

[1] Refer to Table XVI for forest type

Because the same data were used to test the forest trend simulation model as were used to define the regression relations, this test cannot be considered as a model verification. Model prediction errors for applications in other areas of the Basin may be significantly larger.

GEOLOGIC LINEAMENT

Discovery

During the course of the analysis conducted during this study a suspected geologic lineation was recognized on the May 5, 1974, Landsat-1 imagery. At the time of discovery, a set of 70 millimetre (mm) black and white positive transparencies of multispectral scanner (MSS) bands 4, 5, and 7, were being analyzed on a color additive multispectral viewer. The lineation (a) was first noted on this color infrared composite and the scene is shown as Figure 10. On the enlarged black and white band 7 Landsat-1 image (Figure 11), the west to southeast trending lineament (arrows) was observed cutting across the entire Atchafalaya Basin in the vicinity of Lake Faussee Pointe (B), Hog Island (C), Big Bayou Pigeon (D), and Bayou Postillion (E). It was noted that it extended beyond the leveed areas (F) of the Basin.

Figure 10.--Landsat-1 color infrared composite of Atchafalaya Basin

Several color enhancements were made of the Landsat-1 scene to accent the geologic feature. Figure 12 is an example of one of these color enhancements. The suspected lineament (arrows) was depicted better on an enhanced band 7 image (Figure 13) than on the band 5 image (Figure 14) which showed little evidence of the lineament.

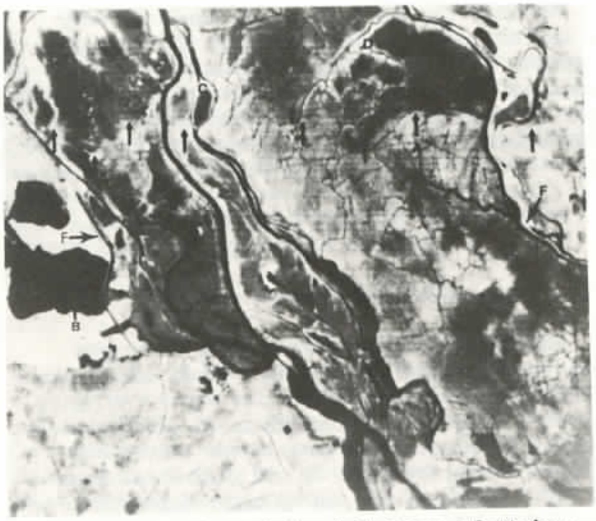


Figure 11.--Landsat-1 band 7 image of Atchafalaya Basin lineation

Figure 12.--Landsat-1 color enhancement of the geologic lineation

Figure 13.--Color enhancement of the Landsat-1 band 7 image of the geologic lineation

Figure 14.--Landsat-1 band 5 image of the geologic lineation

At the time the image in Figure 14 was taken there way heavy flooding in the Mississippi River Basin and along its tributaries. The Morzanza Spillway gates, near Baton Rouge, had been opened for the first time in history and some of the flood waters of the Mississippi were being channeled into the Atchafalaya Basin. The huge sediment plume emerging from the mouth of the Atchafalaya River into the Gulf of Mexico at (A) is evidence of the tremendous volume of water going through the Basin at this time. The band 7 enhancement in Figure 13 showed that the flow of the water was being partially blocked by the lineation causing it to back up north of the anomaly. (Also shown in Figure 11, north of arrows.)

Field Check

Since this feature was discovered early in the study, test strip 3 was orientated to include as much of the geologic feature as possible. A ground check was made of the area at several points during the vegetation field trips. In the vicinity of Postillion Bayou it was noted that the area had a northwesterly trending ridgeline topped with willows (Figure 15). To the south of this ridgeline was a row slough or bottom interspersed with bald cypress (Figure 16). In another area, along the southern tip of Hog Island, a depression was noted traversing the area in the same direction as the lineament. On the east side of the island the depression was filled with willows while mixed hardwoods were observed to the north and the south.

Analysis

Because of the tremendous importance of water to the Basin and the fact that little is known of the ground water system it was decided to further investigate this lineation. On the

Figure 15 and 16.--Ground truth photographs near lineament

aircraft photography used in the trend analysis, the geologic feature followed closely the cypress/mixed hardwood category on the east side of the Basin while the mixed hardwoods and willow/cottonwood category appeared to follow the geologic feature on the west side of the Basin.

Further analysis of additional aircraft photography showed little evidence of the lineation. On some photography portions the lineation could be seen during the comparative analysis, but only on the April 1973 Landsat-1 coverage could the feature be seen in its entirety.

In analyzing the Landsat-1 imagery the investigators checked to see if the line could be a defective scan line on the imagery. It was found that MSS band 6 did have defective scan lines that could create the illusion of an east-west lineament, but this band was not used to generate the color composite. In addition, it should be noted that the lineation is not truly a straight line throughout its enire course. Therefore, it is highly unlikely that it is a spacecraft malfunction.

In discussions with USGS and EROS Program geologists the theory was advanced that the lineament was possibly a beach ridge or a remnant of a former shoreline of the Gulf of Mexico. Analysis of the Landsat-1 band 7 mosaic of the United States (Figure 17) does present some evidence to support this theory. The mosaic has been annotated with a dashed line to highlight what might have been an old beach line. The annotation appears just north of the beach line and the Atchafalaya lineation (A) has been included as part of this line.

Figure 17.--Landsat-1 mosaic of Gulf Coast, scale 1:5,000,000

Summary

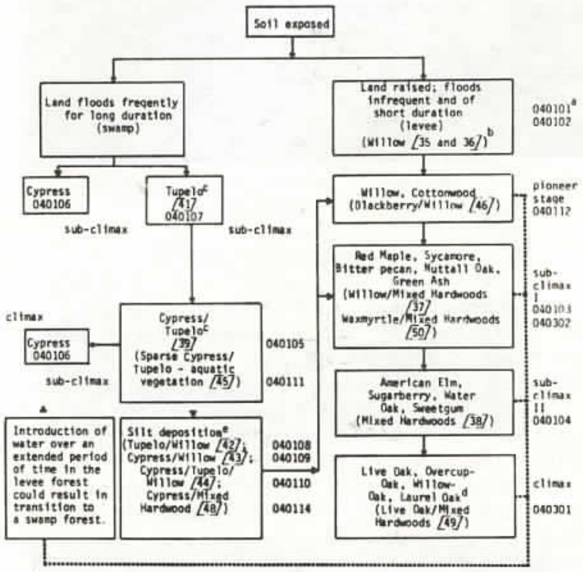
In summary, the team working on this study feels that it has discovered a new geologic feature which does affect the hydrology of the Atchafalaya Basin. It is believed that: 1) it is probably a beach ridge and that 2) the vegetation on either side of the lineation is different because of accretion, and 3) that the flooding conditions in the Basin at the time of the Landsat-1 pass, provided the background for accenting the lineament on the data. Further, it is concluded that core samples and further geologic field investigations should be conducted to determine what effects this lineament currently has on the Basin and what effect it would have on proposed development activities within the Basin.

CONCLUSIONS

Vegetation Trend Analysis

A study of the combined vegetation trend analysis test strips allows certain broad statements to be made regarding vegetation trend patterns within the entire Basin from 1930 to 1973. During this time period, the areal extent of surface water was decreased substantially. Sedimentation, responsible for the decrease in surface water, gave rise to extensive stands of willow trees. Natural levees increased in size as flats and swamps were filled in by increased siltation that resulted in an increase in the extent of mixed hardwood forest types. Additionally, the sedimentation within swamp areas decreased the areal extent of the cypress and tupelo forest associations. Vast hardwood forest acreages in the northern portion of the Basin were cleared for cultural development and agricultural activities.

As sedimentation occurred within a test strip, evidenced by the land accretion within streams and lakes, a natural and predictable succession of vegetation could be observed by study of the sequential aerial photography. These trends are depicted in Figure 18, a flow chart of idealized forest succession for the Atchafalaya River Basin.



[a]Forest type classification number (Table IV)

[b]Forest type category number used in mathematical model (Table XVI)

[c]The Tupelo and Cypress/Tupelo forest types may persist as a climax type, but Cypress is considered the climax forest type because it is more tolerant to competition.

[d]Live Oak appears to be the dominant climax forest type south of an east-west line approximated by the U.S. Highway 90 transect of the basin, while the Overcup, Willow and Laurel Oak climax forest type dominates the area to the north of the line.

[e]Silt deposition within swamp areas will result in transition to a levee forest.

Figure 18.--Forest succession in the Atchafalaya River Basin

Two climax forest types are depicted in the flow chart; cypress for the swamp regions, where land floods frequently for long duration, and the oak type for areas with raised land elevations. Within the swamp areas, the succession of forest types toward a climax forest is interrupted when silt deposition results in the raising of land and improving of drainage. In such instances, willow and cottonwood become established in areas of sparse crown cover, while in areas of a dense cypress and tupelo crown cover the more competitive hardwood species such as red maple, bitter pecan, and green ash become established.

The relationship of vegetation to topography is illustrated in Figure 19. Data collected during ground truth were used to reconstruct an idealized typical Basin cross-section. Sedimentation, over time, led to changes in the topography that resulted in changing vegetation types as evidenced on the aerial photography.

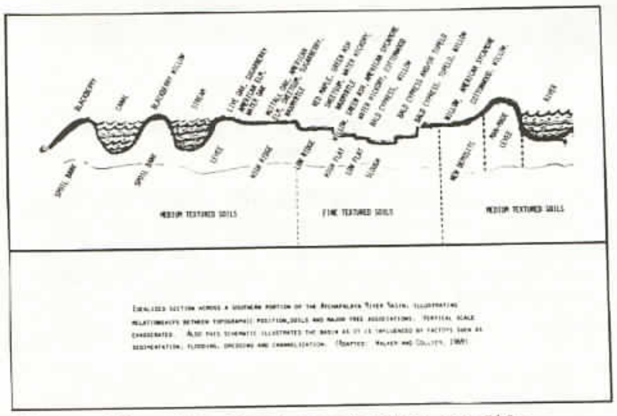


Figure 19.--Idealized vegetation profile

The results of the vegetation trend analysis are substantiated by the work of others. Putnam, Furnival, and McKnight noted that, within the southern bottomland hardwood region, forests exhibit extreme variation in species and sites. Nevertheless, there is an order to this diversity; certain species occur on certain sites. Some grow in evenaged stands that are almost pure, and others are mixed, many-aged communities. (Putnam, Furnival and McKnight, 1960, pp. 4-7)

Walker and Collier found within the Mississippi Alluvial Plains that slight differences in land elevation caused significant changes in species composition. Natural levees, flats and ridges supported a diverse mixture of bottomland hardwood species; "new" land was the site of pure willow and cottonwood stands, while in poorly drained swamp regions cypress and tupelo occurred. (Walker and Collier, 1969, pp. 32-33)

The four test strips selected for the vegetation mapping and trend analysis (see Plate 1) were each representative of different physiographic and vegetative regions of the Atchafalaya River Basin. Therefore, each strip serves as a sample of vegetation trending within the various regions of the Basin. Analysis of these regions reveals that each has singular characteristics that warrant their treatment as separate management units.

The broad introductory statements on vegetative trending may not apply to a specific region in the Basin. The northern portion of the Basin is nearing an oak type climax forest. Here, the vegetation succession is, more or less, stabilized. Clearing of the vast mixed hardwood forests for agriculture is now the evident pattern of land use.

The southern portion of the Atchafalaya Basin contains one of the more stable areas of the Basin. The extensive cypress and tupelo forests on the eastern side of the main channel remain in 1973, much as they were in 1930.

The Grand Lake area, however, also located in the southern portion of the Basin, is one of the least stable areas. Heavy sediment deposition now supports large areas of willows that were not present in 1930.

Vegetation, particularly forest associations, is a component of the Atchafalaya ecosystem that has been permanently recorded through time by aerial photography. Examination of these aerial photographs allows an accurate description of Basin vegetation types in years past and the capability of determining patterns of succession. However, vegetation serves only as an indicator of changing physiography; therefore, it is the factors effecting physiographic change that must be manipulated if present forest conditions are to be maintained.

Basin Wide Vegetation Analysis

The Atchafalaya River Basin contains 833,700 acres of land shown on the Basin wide vegetation map (Plate 5). Mixed hardwoods occupy 275,500 acres or 33 percent of the area, followed by cypress/tupelo which covers 204,800 acres or 24.6 percent. The third largest vegetation group is the swamp mixed hardwoods extending over 144,400 acres or 17.3 percent. The willow/cottonwood type embraces 93,800 acres or 11.2 percent. Special note should be made of the nonforested category, which includes some of the commercial activities in the Basin. This category covers 62,600 acres and comprises 7.5 percent of the total area.

Forest Acreage Trend Model

Current studies on the Atchafalaya River Basin include mathematical modeling of flow and sediment movement in the Basin below Simmesport, Louisiana. The results of these modeling studies for various alternative Basin management plans will provide sets of estimates of hydrologic variables shown in Table 23 for all quadrat areas in the Basin. Estimates of required initial acreages of forest types can be made from existing semi-detailed Basin vegetation maps. Thus, the forest trend simulation model can be applied for forest trend prediction and ecosystem analysis under different Basin water management alternatives.

The results of this study, based on one set of data, show that forest trend predictions for total forest type acreages were within 70 percent or better of actual values in two-thirds of the cases. The estimates appeared to be unbiased. Predictions of forest trends within individual quadrats are subject to somewhat larger errors that may approach the standard error of estimates for given forest types.

Several uses of the forest trend simulation model are indicated. For example, comparisons of forest trends at selected quadrats or on a Basin wide basis for proposed Basin alternatives could be made. Forest management units could also be designed in certain areas of the Basin by inspection for favorable hydrologic conditions and by use of forest succession concepts. Such management units could then be simulated to ensure that they would be maintained under a given Basin water management plan. Because such forest management units form the basis for stable ecosystems, models of understory vegetation trends, key animal populations, and aquatic environments could be appended to the basic forest trend simulation model.

LITERATURE CITED

Anderson, James R., Ernest E. Hardy, and John T. Roach. 1973. A Land Use Classification System for Use with Remote-Sensor Data. U. S. Geol. Survey Circ. 671. 16 p.

Botkin, D. B. and Miller, R. S. 1974. Complex Ecosystems: Models and Predictions. Am. Scientist, v. 62, July-August. pp. 448-453.

Comeaux, Malcolm L. 1972. Atchafalaya Swamp Live Settlement and Folk Occupations. v. 2, Baton Rouge. 111 p.

Corps of Engineers. Atchafalaya River element study. U. S. Army Engineer Dist., New Orleans, LA, app. II-2-A. Basic Hydrologic Data, Sedimentation Ranges, app. B, plates 55-73.

Corps of Engineers. Stages and discharges of the Mississippi River and tributaries and other watersheds in the New Orleans district. U. S. Army Engineer Dist., New Orleans, LA. (Data for calendard year 1930-1969.)

Dixon, W. J., ed. BMD. 1968. BMD, Biomedical Computer Programs. Univ. California Press. 600 p.

Draper, N. R., and Smith, H. 1966. Applied regression analysis. John Wiley and Sons, Inc. 407 p.

Fowells, H. A. 1965. Silvics of Forest Trees of the United States. Agr. Handbood No. 271. 762 p.

Gagliano, Sherwood M. and Johannes L. von Beek. 1970. Geologic and Geomorphic Aspects of Deltaic Processed, Mississippi Delta System, v. 1. Baton Rouge. 140 p.

Preston, Richard J., Jr. 1970. North American Trees. Mass. Inst. Tech. Press. 395 p.

Putnam, John A., George M. Furnival and J. S. McKnight. 1960. Management and Inventory of Southern Hardwoods. Agr. Handbood No. 181. 102 p.

Spurr, Stephen H. 1964. Forest Ecology. The Ronald Press, New York. 352 p.

U. S. Department of Agriculture. 1941. Climate and Man. Yearbook of agr., Washington, D. C. 1248 p.

Walker, Laurence C. and G. Lloyd Collier. 1969. Geography of Southern Forests. Stephen F. Austin State Univ., Nacogdoches, TX. 31-36 p.

Walker, Laurence C. and Kenneth G. Watterson. 1972. Silviculture of Southern Bottomland Hardwoods. Stephen F. Austin State Univ., Nacogdoches, TX. 77 p.

Quantitative Evaluation of Deer Habitat[1]

Norman E.G. Roller[2]

Abstract.--Two techniques for obtaining quantitative habitat condition information from remote sensing data are discussed. The first technique discussed provides a means of identifying the trend of habitat condition for a given area, based on the interpretation and comparison of current and historical aerial photography. The second technique described was developed in response to the general need for a way to objectively and rapidly assess habitat quality over large areas. It is characterized by the use of a computer model which generates numerical ratings of habitat quality, based upon analysis of digital cover type maps.

INTRODUCTION

Determining habitat quality over large areas and monitoring trends in habitat condition are activities essential to the development of effective strategies for the preservation and management of wildlife. This paper presents two techniques involving the use of remote sensing that can aid in accomplishing these goals. The first technique discussed provides a means of identifying the trend of habitat quality in a given area, based on the interpretation and comparison of current and historical aerial photography. It is useful for wildlife-habitat interaction studies or management treatment effectiveness evaluation. The second technique discussed is one that has been developed in response to the general need for a quantitative way to rapidly assess habitat quality over large areas. It is characterized by the use of a computer model which generates numerical ratings of habitat quality for units of land corresponding approximately in size and shape to the home range of a wildlife species of interest. The ratings produced by the model are based upon a computer analysis of the characteristics of the habitat, as represented in digital cover type maps of the area derived from remote sensing.

The application of these techniques is demonstrated by a study of white-tailed deer (Odocoileus virginia) habitat in southern Michigan. The principles upon which these techniques are based are general enough, however, so that with some modifications the techniques will also be useful for the study of other species and geographic areas.

HABITAT CONDITION TREND ANALYSIS

A major objective of most wildlife management efforts is the elimination or mitigation of both external factors and wildlife habitat interactions that cause long-term downward trends in habitat quality. Yet in many cases the exact nature of these factors and deleterious interactions is often unclear, or at least the cause-effect mechanism remains unquantified. As a result, corrective action cannot be effectively undertaken because the most appropriate remedial measures are not obvious, given present understanding. At the same time, we often cannot afford, ecologically or monetarily, to conduct long-term studies to get these answers. Thus, an alternative, short-term method of obtaining these insights is needed. Fortunately, such an alternative method does exist that, in most cases, can be implemented quickly and inexpensively.

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

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Medium-scale airphotos are available from a number of government agencies in the U.S. at nominal cost. For a particular site as many as five sets of photo coverage often exist, in many cases providing observations of habitat condition at roughly five-to-eight year intervals over the last forty years. By analyzing these photos with standard visual-interpretation procedures requiring only simple equipment, resource managers can extract what amounts to point-in-time habitat condition information for several dates.

Trend of habitat condition information can then be generated by comparing this sequence of habitat condition estimates. Quantifying the nature of external factor habitat impact or wildlife habitat relationships is then accomplished by correlating cause (e.g., wildlife population data, management treatment application, or external factor presence) with the observed effect (trend of habitat condition).

Vegetation Change Detection

The Edwin S. George Reserve is a natural studies area administered by the University of Michigan. It consists of 464 hectares located in the inter-lobate moraine zone of southeastern Michigan. It is enclosed by a 3.7 m high fence, and a herd of white-tailed deer has been maintained on the Reserve since 1928.

1:20,000 B&W ASCS airphotos of the Reserve were obtained for the following years: 1937, 1949, 1955, 1963 and 1971. A photo-interpretation key was constructed for the identification of vegetation cover types on the photos, and the vegetation of the Reserve was cover type mapped for all five dates (Roller 1974). In general, the Reserve was found to consist of a patchwork arrangement of old-field grasslands, upland hardwood forest and mixed wetlands (see Figures 1 and 2).

A "digital" change detection technique was then used to obtain the data required to assess changes in the relative abundance and arrangement of the vegetation cover types found on the Reserve. This technique has been described previously by Istvan and Bondy (1977) for use directly with airphotos. In this study the procedure was modified by overlaying a grid on the cover type maps, instead of directly over the original photographs; this procedure was used because the cover type maps were geometrically correct, and using them eliminated any change of grid misregistration, due to distortions in the photography.

The major change that was found to have occurred in the relative abundance and spatial distribution of the Reserve's cover types occurred on the uplands. Here, reforestation of old-fields resulted in a 60% loss (approximately 80 hectares) of grasslands. The wetlands, in contrast, did not change in areal extent, although one cover type, swamp was found to have changed significantly in tree species composition. Specifically, areas of swamp characterized by an aspen-dogwood mixture at the beginning of the study period (1937) were found to be dominated by tamarack in 1971.

The rate of old field reforestation was then examined and it was discovered that a significantly higher than average rate of invasion of the grasslands by trees occurred during the middle of the study period, from 1956 to 1963 (see Table 1). In attempting to explain this dramatic increase, the hypothesis was advanced that reduced browsing pressure by the Reserve's enclosed herd of deer allowed old field reforestation to accelerate during this period. To investigate this hypothesis, a second study was initiated in which the character and temporal pattern of old field reforestation was compared to deer herd size.

Table 1.--Rate of Old Field Reforestation

t_1-t_2	Loss of Old Fields (%)	Rate (%/yr)
1937-1949	7.4	.61
1950-1955	9.4	1.88
1956-1963	22.0	3.14
1963-1971	8.5	1.21

Relation of Vegetation Changes to Deer Herd Size

Assessment of the effect of deer browsing on old field reforestation was made using tree count data derived from photo-interpretation of test and control plots and deer herd size data from an annual census. From the photo-interpretation analysis it was possible to reconstruct the chronological pattern of tree seedling establishment on plots located in two old fields, one inside and one adjacent but outside the Reserve's fence. The data from study plot A, located outside the Reserve, was considered to represent a control of sorts, since it is known that this field has been browsed only lightly by free-ranging deer in the past. The pattern of seedling establishment for the study plot outside the Reserve is one of steady increase for all tree species (Fig. 3). On study plot B, inside the Reserve, however, many of the tree species found outside the Reserve are absent, and a pattern of

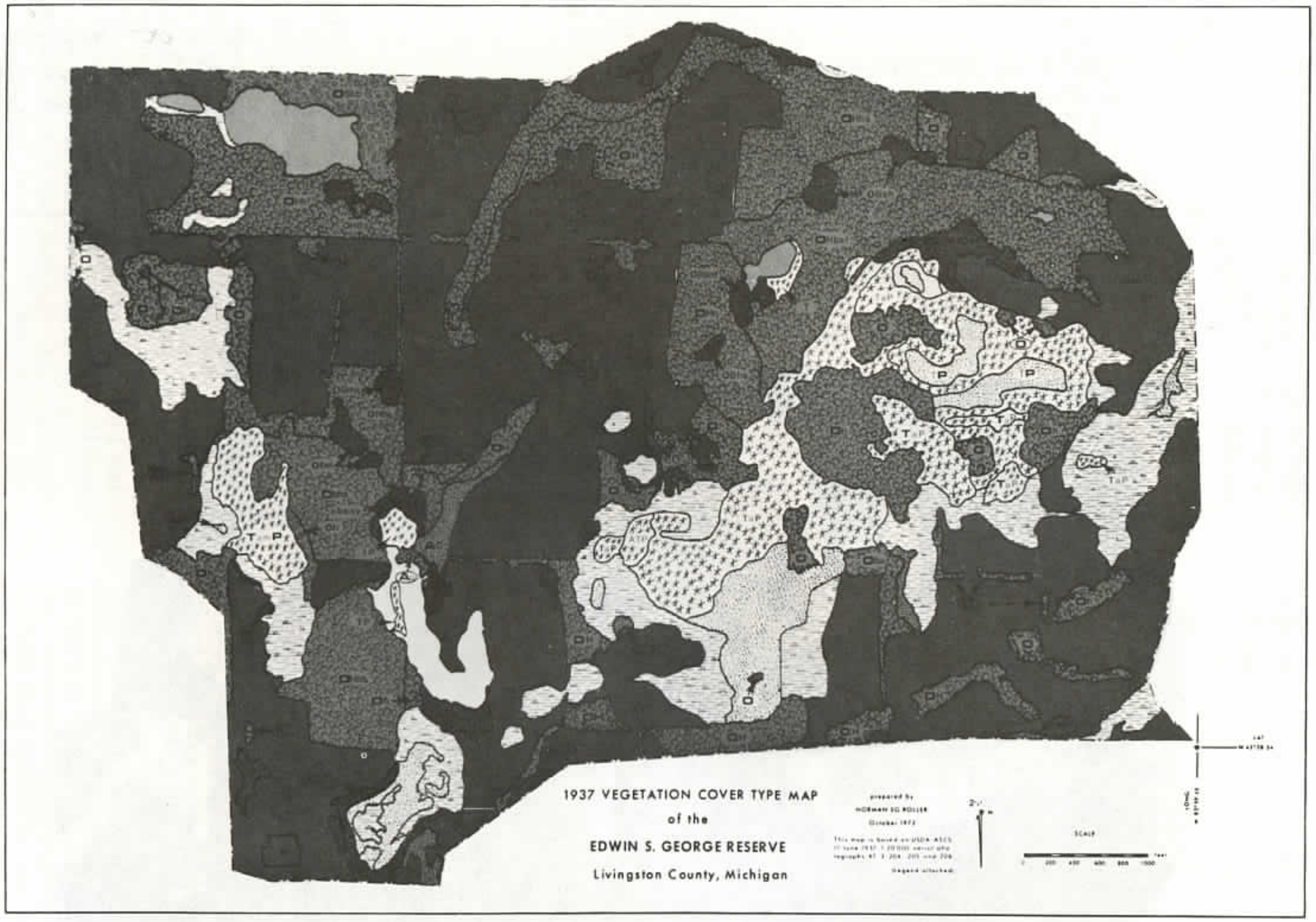


FIGURE 1

very light gray = open water, marshes and swamps

light gray = bogs

medium gray = forest

dark gray = grasslands

very dark gray = forest/grasslands ecotone

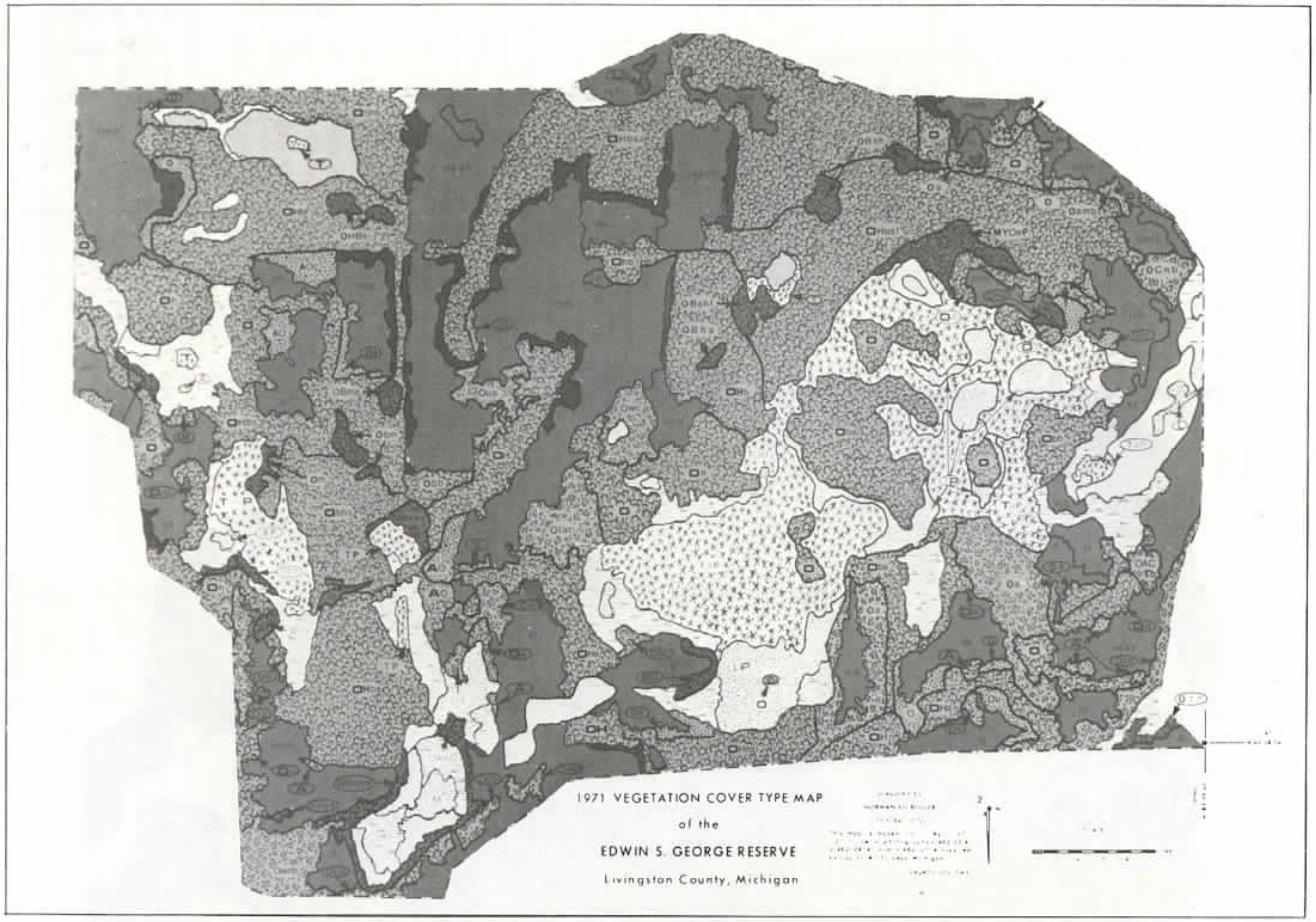


FIGURE 2

very light gray = open water, marshes, and swamps
light gray = bogs
medium gray = forest
dark gray =grasslands
very dark gray = forest/grasslands ecotone

CHRONOLOGICAL INCREASE OF TREE SPECIES INCREASE ON DEER BROWSING STUDY PLOTS, 1937-1971.

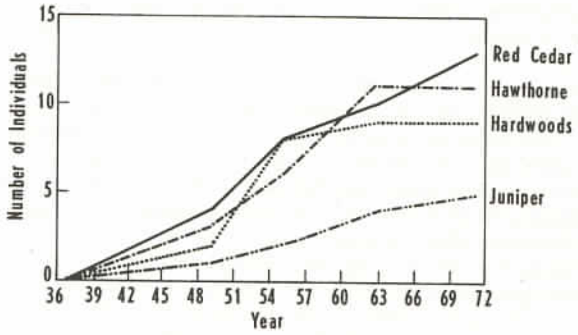


FIGURE 3. PLOT A: OUTSIDE RESERVE

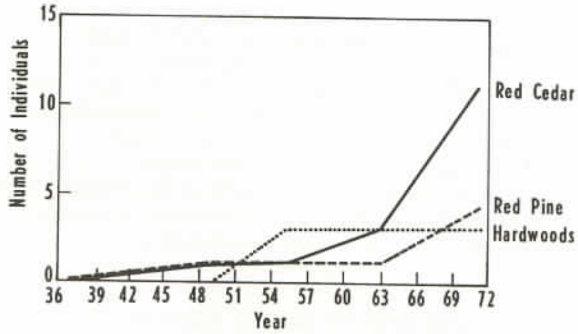
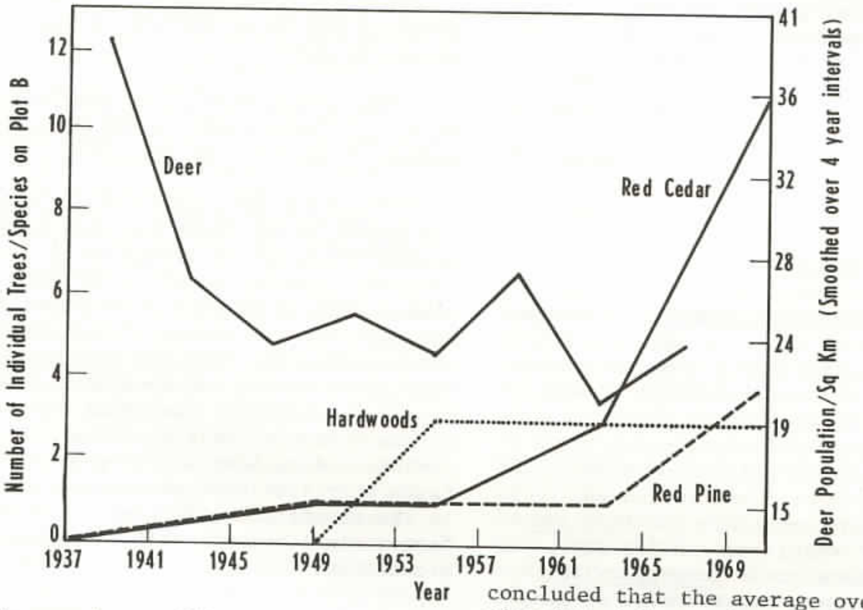


FIGURE 4. PLOT B: INSIDE RESERVE

FIGURE 5. CHRONOLOGICAL COMPARISON OF INCREASE IN TREE SPECIES ABUNDANCE ON DEER BROWSING STUDY PLOT B AND RESERVE DEER HERD.



significantly increasing seedling establishment is evident only for roughly the last quarter of the study period (1963-1971)(Fig. 4).

When the census data describing the changes in the annual size of the deer herd was compared with the pattern of seedling establishment observed on study plot B (Fig. 5), a strong correlation was observed between the reduction of the over-winter size of the deer herd and the increase in both the number of seedlings and tree species showing up on study plot B. This relationship may indicate that the later size of the deer herd (20-25 deer per sq km) is much nearer to the carrying capacity of the habitat than it has been in the past. However, since some very palatable tree species are still not found on the plot inside the Reserve, it is concluded that the average over-winter herd size for at least the last eight years of the study period may still have been exceeding the carrying capacity of the habitat.[1]

The uncertainty here arises from two sources. First, a time lag exists between when a seedling actually establishes itself on a site and the point at which its crown becomes big enough to be detectable on a medium-scale aerial photograph. Secondly, the crown structure and leaf morphology of different tree species is such that, for seedlings of the same age, some tree species have denser and/or darker foliage than others (e.g., red cedar vs. black cherry). As a result, these species are detectable on airphotos at an earlier age.

[1]Continued observation from 1971 to the present indicate that 10-15 deer/sq.km. may be optimal.

Conclusion

On the basis of this study, it was concluded that vegetation maps derived from the interpretation of standard U.S. government agency historical aerial photography can provide useful trend of habitat condition data. Furthermore, when ancillary data is available, it may also be possible to draw meaningful conclusions regarding the cause-effect relationships between the agents responsible and the pattern of change observed in a modified pattern of vegetation development.

HABITAT QUALITY RATING MODEL

State and federal agencies concerned with multiple-use management of large tracts of land require comprehensive and timely information on the value of given areas for proposed uses, in order to effectively set priorities and optimally allocate resources. The synoptic Wildlife Habitat Quality Rating technique described here has the potential to provide such information to managers by virtue of its ability to consistently and objectively evaluate wildlife habitat quality over large areas.

Approach

This technique generates numerical ratings of habitat quality based upon the analysis of digital remote sensing data by a computer model. The model integrates the contributions toward habitat quality made by components of the habitat whose presence and condition are known to affect the survival and welfare of wildlife. These components are (1) the vegetation and terrain features which constitute the food and cover requirements of wildlife, and (2) the manner in which the pattern of interspersion and juxtaposition of these key elements of the habitat affects their usefulness to wildlife.

Because this technique is based on the quantitative description and spatial analysis of the habitat, in order for it to be useful for evaluating large areas, a synoptic mapping capability such as remote sensing is a necessary source of raw data. Categorized Landsat data and digitized, type-mapped high-altitude aerial photography are, thus, useful sources of input data for the model; but, note that any map based cover type data could be used, including the results of field work.

General Form of the Model

Habitat quality, as the term is used here, relates to the potential of a unit of land to attract and maintain a population of wildlife over time. It is not intended to convey a measure of actual animal production, but rather, the relative production potential of one area versus another.

The quality of wildlife habitat depends on the abundance and arrangement of food, water, and cover that exists within the seasonal movement pattern and daily radius of activity of wildlife. This realization has led wildlife biologists from Leopold (1933) to Dasmann (1964) to emphasize the theoretical importance of analyzing the following basic components of habitat quality:

(1) The presence and relative abundance of key vegetation and terrain cover types[1] which supply the food and cover[2] requirements of wildlife;

(2) The spatial distribution, or interspersion, of these key cover types in relation to the seasonal radius of activity (home range) of wildlife; and

(3) The accessibility, or juxtaposition, of these key cover types in relation to the daily radius of activity of wildlife.

Obtaining data that effectively summarizes the condition of these components of habitat quality in order to assess local habitat carrying capacity requires not only extensive measurement of physical characteristics of habitat like the amount of "edge" present and the presence and relative abundance of certain vegetation types, but even more difficult, it requires a means of analyzing the significance of their spatial relationships. Because of the obvious tediousness and complexity of these tasks very little consideration has been given to the quantitative incorporation of these factors in standard habitat evaluation procedures.

It is expected that the general form of the model will vary somewhat with species of wildlife, geographic area and source of input data. Nevertheless, the basic variables, which represent the building blocks of the model and the manner in which they are calculated, will probably remain the same or at least similar to what they are now. Thus, there is the desire to remain general in terms of discussion here to

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[1]When known to be significant, different condition classes and/or stand densities of the same plant community are considered as separate cover types.

[2]Necessary water supplies are also included under the term "food and cover".

avoid getting bogged down in detail, while at the same time realizing that a specific demonstration of the model is perhaps the best way to illustrate its usefulness. As a compromise, the remaining discussion of the model will be general regarding how the variables are calculated, but the form of the model used will be one developed for the evaluation of white-tailed deer habitat in southern Michigan. Thus, although a specific model is presented, based on the best biological information available, it is intended to serve primarily as an illustration of the nature and usefulness of such a model, in the hope that such a demonstration will stimulate interest in the technique and the generation of additional biological information, so that an even better model for deer can be constructed.

Based on the literature and discussions with professional wildlife biologists, several factors were found to generally be thought to influence deer habitat quality. The perceived role of these basic factors determined the general form of the model, yet the specific relationships between these factors were not known in any detail. As a result, a semi-empirical approach had to be used to develop quantitative expressions for these relationships. These expressions were developed based on observation of the relationships between the basic factors of habitat quality for examples of habitat of known quality.

Since habitat quality was being evaluated on a per unit area basis in relation to the radius of daily activity of deer, the physical size of the basic habitat unit had to correspond approximately to a deer's home range. Home range is approximately 1 mi^2 for deer in southern Michigan somewhat resembling a section. Furthermore, the topographic maps of the study area are gridded into sections. It was therefore found convenient and reasonable to demonstrate the concept of evaluating deer habitat quality by generating ratings on a section-by-section basis. Although this procedure imposes an artificial grid system on the natural characteristics of the study area, it also characterizes habitat on the basis of readily definable land ownership and management units, a significant advantage. Ultimately, some averaging of the section-by-section ratings over a larger unit of area may prove desirable.

The general form of the model used was as follows:

$$WHQ = k_1 \cdot FC[(k_2 \cdot INT) + (k_3 \cdot JUX)]$$

where, FC = Wildlife Habitat Quality rating,
INT = Interspersion of cover types,
JUX = Juxtaposition of cover types,
k_1, k_2, k_3 = specific calibration coefficients that eliminate any redundancy between variables.

Note that a multiplicative relationship between FC and INT and JUX is used. Thus, without the necessary food and cover, an area's rating must be zero,

Model input data consists of objective assessments of how effectively the vegetation cover types and other terrain features actually present in a given area compare with an ideal composition and arrangement in which the components of habitat quality achieve their maximum potential. These assessments are based on measurements of (a) the presence and relative abundance of vegetation cover types and other terrain features (FC), (b) the distribution and complexity of their perimeters (INT), and (c) the prevalence of certain "edge" combinations of various vegetation cover types and/or terrain features (JUX).

These measurements are made by computer in three submodels.

Habitat Component Submodels

Food and Cover

In this submodel the computer tabulates the vegetation cover types present in each habitat unit and then calculates their relative abundance. The relative abundances of the vegetation cover types that are actually present in the habitat unit are then compared with experts' opinions of the optimum variety of cover types required by that species of wildlife, and what their relative abundance should be. A score is calculated as shown below, based on this comparison, which indicates how closely the cover types found on a specific habitat unit match what is considered to be high quality habitat:

$$FC = \sum_{i=1}^{N} \left[\frac{(T_i/A)}{O_i} \cdot \text{Max Score for } T_i \right]$$

where T_i = area (in m^2) of a given cover type,
A = area of the habitat unit under consideration (in m^2),
O_i = optimal relative abundance of a given cover type,
N = number of cover types occurring in the habitat unit.

Maximum scores in the Michigan demonstration were developed from biologists' opinions of optimal cover type relative abundance, as shown below:

Food and Cover Requirement	Optimum Relative Abundance (%)	Maximum Score
Agriculture	15*	15*
Brush	35	35
Upland Hardwood Forest	35	35
Conifers/Shrub Swamp	15	15
Wetlands	0	0
Lakes, Rivers*	0	0
TOTAL	100*	100*

* even if the relative abundance observed in a habitat unit is greater than optimal, no additional benefit is assigned.

Interspersion

The complexity of wildlife habitat requirements has led biologists to a recognition of the importance of "edge". This term is used to express the situation that occurs where two cover types meet, with the result that the area immediately surrounding this boundary provides habitat more favorable than either contributing cover type considered alone. The reason for the superiority of edges as habitat is probably related to the fact that a boundary area makes access easier to cover types which fulfill different yet essential needs of animals, and in addition, there is often a more diverse variety of plants in such areas, both floristically and physiognomically. Measurement of edge in terms of both quantity and quality is the basis of this, and the next habitat assessment variable which are discussed.

The more the pattern of arrangement of cover types in the habitat consists of small blocks with a high ratio of edge to area, the greater the interspersion (INT) is said to be. Thus, in general, the greater the interspersion of cover types the better the habitat, because there is more ready access to different cover types, and edges composed of cover types which animals need in quick succession are more abundant.

In the model, INT is defined as the weighted arithmetic mean of the average shape factor for each significant cover type found in a habitat unit. Significant cover types are those considered in the calculation of FC.

The <u>shape factor</u> is used to normalize the edge/area ratio of each example of all the significant cover types to that of a circle (set at 1.0), which is the geometric shape with the least possible perimeter per area enclosed. Shape factor is calculated as shown:

$$\text{Shape Factor} = \frac{\text{edge}}{2\sqrt{\text{Area}\ \pi}}$$

The "edge" of a given example of a cover type is calculated by summing the nominal lengths of the sides of the resolution elements it contains that form a boundary with another cover type.

Juxtaposition

The linear distance associated with the different kinds of edge that occur between the cover types of the habitat, divided by the total amount of edge occurring in the habitat unit and then multiplied by an "edge desirability factor", forms the basis of our mathematical approximation to the juxtaposition habitat quality component. In the Michigan deer model, JUX was calculated as follows:

$$\text{JUX} = \frac{k_1(\text{AG/BR}) + k_2(\text{AG/FOR}) + k_3(\text{AG/SWP}) + k_4(\text{BR/FOR}) + k_5(\text{BR/SWP}) + k_6(\text{FOR/SWP})}{\text{Average Total Weighted Edge per Habitat Unit of Good Habitat}}$$

where edge type:		has edge desirability:
AG/BR	= Agriculture/Brush	$k_1 = 4$
AG/FOR	= Agriculture/Upland hardwood forest	$k_2 = 3$
AG/SWP	= Agriculture/Swamp or conifers	$k_3 = 4$
BR/FOR	= Brush/Upland hardwood forest	$k_4 = 2$
BR/SWP	= Brush/Swamp or conifers	$k_5 = 1$
FOR/SWP	= Upland hardwood forest and Swamp or conifers	$k_6 = 2$

Rating Procedure

For the model approach described above to have application to fulfilling the need for a method of rapidly surveying habitat quality over large areas, a cost-effective means of obtaining the input data required by the model is also necessary. Two types of remote sensing appear to be logical sources of input data for the model: categorized Landsat data, and digitized cover type information from high-altitude aerial photographs. Costs and accuracies of cover type classification vary between these two data sources, and the user will have to judge which remote sensing system offers the accuracy/cost tradeoff most favorable to a given project's objectives.

The procedure for use of the model showing the role of the remote sensing data is diagrammed in the flow chart shown in Figure 6.

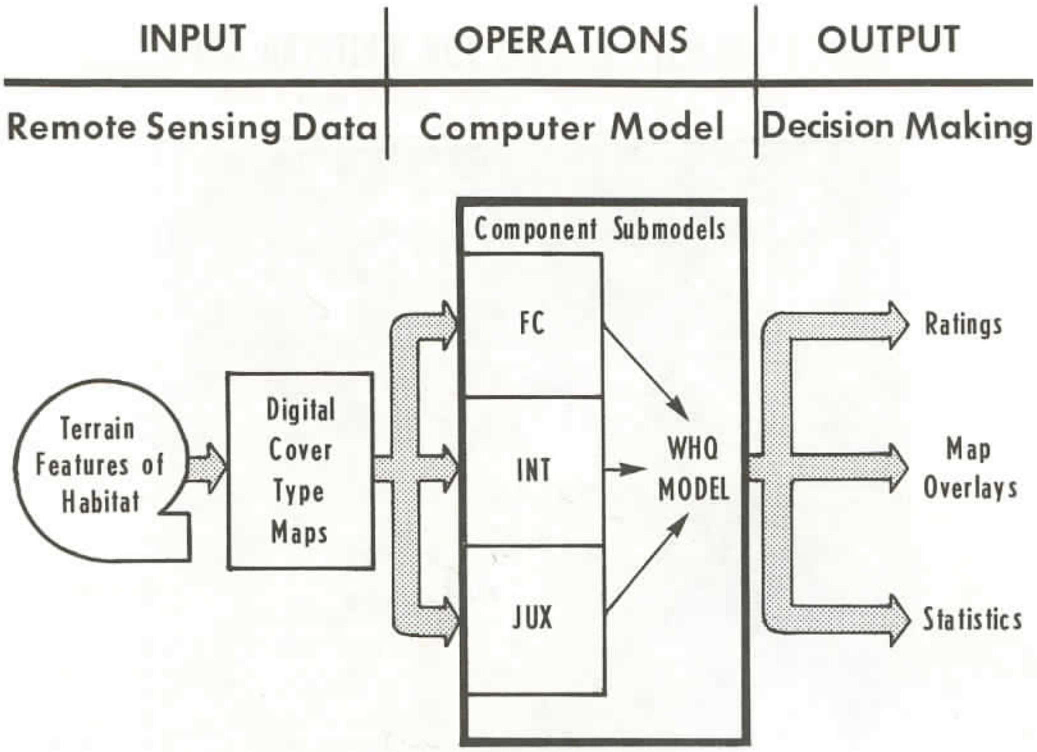

FIGURE 6. HABITAT QUALITY RATING PROCEDURE

Results

Figure 7 illustrates how the model works in practice. In this demonstration, categorized Landsat data was used as input to the Michigan deer model. The size of the indicated habitat unit is 1 sq mile, corresponding to a section.

The coefficients used in the model were determined empirically after examining examples of good and poor habitat. The final ratings were scaled from 0 to 100 for ease of comparison. The specific form of the model was:

Habitat Quality Rating = 0.83 FC(0.51 INT + 0.56 JUX)

Conclusion

This technique represents a methodology for making estimates of a wildlife habitat quality over large areas which are correlated with estimates of wildlife habitat quality made using traditional techniques. Its major advantage over conventional techniques is that it is less subject to individual bias or variations in application, making comparisons of habitat quality over time and space more meaningful. In addition, it is potentially also a quicker procedure and less costly to use.

LITERATURE CITED

Dasmann, R. F. 1964. Wildlife biology. John Wiley & Sons, Inc. New York, NY. 231 p.

Istvan, L.B., and M.T. Bonday, 1977. A 'digital' technique for manual extraction of data from aerial photography. Proceedings of 11th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, pp. 1329-1336.

Leopold, A. 1933. Game management. Charles Scribner's Sons. New York, NY. 481 p.

Roller, N.E.G. 1974. Airphoto mapping of ecosystem development on the E.S. George Reserve. Unpublished M.F. Thesis. University of Michigan. 70 p.

Sattinger, I.J., R. Dillman, and N.E.G. Roller. 1975. Analysis of recreational land and open space using ERTS-1 data. Environmental Research Institute of Michigan, Report No. 193300-60-F. 46 p.

Shick, C. 1967. Deer management on private lands. Cooperative Extension Service, Michigan State University, Publication No. 3P-5-67-ISM-CR. 8 p.

HABITAT QUALITY RATINGS FOR WHITETAIL DEER

Dexter Township
Washtenaw County, Michigan

Scale ⊢——⊣ 1 Mile

Ratings	Legend
100 Good Habitat	Orange .... Agriculture
	Yellow Green .... Brush
	Medium Green .... Upland Hardwood Forest
	Magenta .... Shrub Swamp
	Purple .... Other Wetlands
	Dark Green .... Conifers
0 Poor Habitat	Blue .... Water

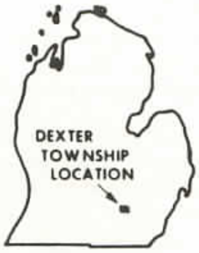

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FIGURE 7.

Remote Sensing for Waterfowl Nesting and Nesting Habitat Old Crow Flats, Yukon Territory, Canada [1]

D. Russell[2], D. Mossop[2], C. Goodfellow[3]

Abstract

Remote sensing data provided valuable insight into the understanding of waterfowl nesting and nesting habitat on Old Crow Flats, Yukon. Timing and duration of ice breakup varied from year to year during the study (1974-78) and were found to be related to waterfowl, especially diver, productivity. Nesting habitat is defined and attempts at extrapolation of these areas to the whole of Old Crow Flats are explained.

INTRODUCTION

Waterfowl investigations of the Old Crow Flats in northern Yukon Territory, Canada were conducted from 1974 - 78. The objective of the work was to determine broad management criteria for the waterfowl populations of the area.

One of the more significant facets of this work was to estimate waterfowl productivity. The field work was designed to establish ecological parameters of breeding waterfowl, including nesting strategies, nesting habitats, breeding density, brood sizes and survival to Fall. This research was conducted on a sample of Old Crow Flats (see Fig. 1). The purpose of this paper is to explain our attempts at utilizing remote sensing techniques to aid in the establishment of a broad management plan.

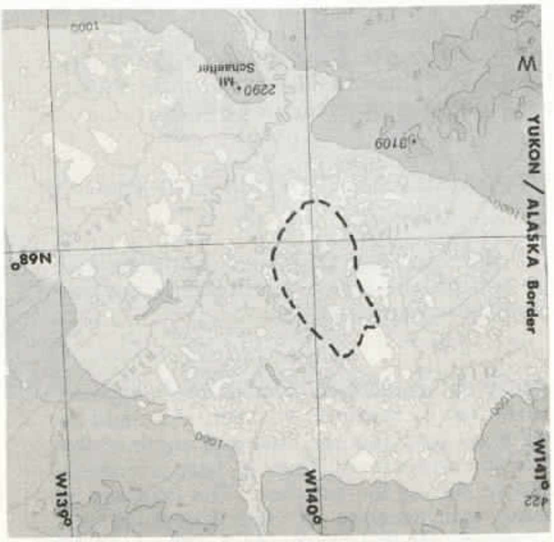

Figure 1 Old Crow Flats showing intensive study area (1: 1000 000)

OLD CROW FLATS

The study area lies in a 518,000 ha (2,000 sq. mi.) lactustrine plain ringed on all sides by mountainous terrain. This basin was formed during the Pleistocene period when melt waters of the eastern ice sheet poured across mountain passes. The existing outlets could not accommodate the vastly increased flow, and lakes were established in the lowest portions of the plateau, to be drained as the outlets were sufficiently eroded (Zoltai and Pettapiece, 1973).

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[1] Paper presented at the PECORA IV - Applications of Remote Sensing Data to Wildlife Management Conference, Sioux Falls, S. Dakota, October 10 - 12, 1978.

[2] Donald Russell, Habitat Biologist, Game Branch, Government of Yukon Territory, Whitehorse, Yukon Territory

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[3] Carolyn Goodfellow, Scientist, Canada Centre for Remote Sensing, Ottawa, Ontario

The plain lies at approximately 305 m (1,000 feet) above sea level. The substrate is a deep layer of alluvial silts into which the principal drainage, the Old Crow River, has cut a meandering valley approaching 30 m (100 feet) below the general level of the area. Over this inorganic material an organic layer of variable thickness has been formed by *Sphagnum* species and other plant remains. The substrate is permanently frozen.

The area of the plain occupied by wetlands suitable for waterfowl is 388,599 ha (1,500 sq. mi.). The area is highly productive compared to adjacent tundra and forested areas. It forms the basis for a large part of the economy of the Old Crow people who yearly trap and hunt the area.

Approximately 400 - 500 thousand waterfowl utilize the Old Crow Flats annually. Field research has revealed three major duck species breeding in the area. The most productive diving ducks are scaup (lesser and greater) and white-winged scoter, while American wigeon is by far the most important breeding dabbler species.

WATERFOWL BREEDING ECOLOGY AND REMOTE SENSING

Over the four years of field work, several important conclusions about the breeding ecology of waterfowl have been made:

a) Nesting of waterfowl on the Flats appears strongly affected by seasonal weather. As could be expected for an area 160 km (100 m.) north of the Arctic Circle, waterfowl face a very stringent time schedule during the summer. The lateness of spring thaw and advance of fall freeze-up are important environmental parameters in the productivity of waterfowl. Barry (1966) and others have found a relationship between nesting success and snow cover in spring for northern waterfowl, notably geese.

By utilizing Landsat imagery, three aspects of ice breakup were of interest: (1) detection of early ice-free lakes; (2) timing and pattern of breakup among years; and (3) relationships between timing of ice breakup and waterfowl productivities.

b) Nesting habitat of the most common waterfowl on the Flats, diving ducks, has been identified as emergent vegetation dominated by *Carex aquatalis*. These plants in association with others are responsible for the formation of sedge mats and islands. This habitat, although quite widespread throughout the area, is also discrete, occupying certain lakes while completely absent from most.

The formation and occurrence of sedge mats and islands in lakes is the subject of further study. They appear to be related to sudden changes in lake levels, which presumably are caused by erosion of ice dykes and lake borders.

Aerial photographs taken in 1951 and 1972, a 21 year interval, were compared for an indication of stability of wetland borders. Such a measure of lake level dynamics would be valuable in assessing the future trends of waterfowl productivity in the area.

c) The waterfowl counts arrived at breeding densities of various species in sedge emergents in the intensive study area. Attempts were made to extrapolate these to produce patterns of nesting density throughout the Flats as well as to produce an estimate of total productivity for the Flats.

METHODS AND MATERIALS

Imagery

No new aerial photography was flown. The following three sets of air photos were utilized.

Dates	Film	Scale
1951	B & W Panchromatic	1:64,800
1972	B & W Panchromatic	1:55,200
1972	Colour IR	1:144,000

A number of Landsat scenes were examined visually to document ice breakup on the Old Crow Flats for the years 1974 - 1978. Maps were produced showing the progression of breakup in those years for early and mid June.

Annual swan productivity (young/100 adults) was calculated from July and August ground and aerial surveys for the years 1974 - 1978.

Dabbler and diver productivities (young/transect mile) were calculated from systematic shoreline searches for the years 1975 - 1977. Searches were conducted by canoe during August each year. No data were collected in 1974 or 1978.

Aerial photos were utilized in conjunction with ground nest searches to delineate nesting habitat of divers and swans. Ground plots were established in the intensive study area to document plant species composition and abundance within the nesting habitat. Plots were located in as many successional stages as possible. The change in area of nesting habitat of sample lakes from 1951 to 1972 was calculated using a Zeiss-Jena Sketchmaster and dot grid.

To extrapolate intensive study area data to the rest of the Old Crow Flats, an unsupervised classification of land and water areas of the study area was conducted on the Image Analysis System at the Canada Centre for Remote Sensing in Ottawa, Ontario. This digital classification of the July 20, 1976 scene (20545 - 20072) used the four dimensional clustering approach described by Goldberg and Shlein (1977).

RESULTS AND DISCUSSION

Relation of Waterfowl Productivity to Ice Breakup

Figures 2 and 3 illustrate the typical progression of ice breakup on Old Crow Flats. Figures 2 and 3 were constructed from early and mid June, 1974 Landsat imagery.

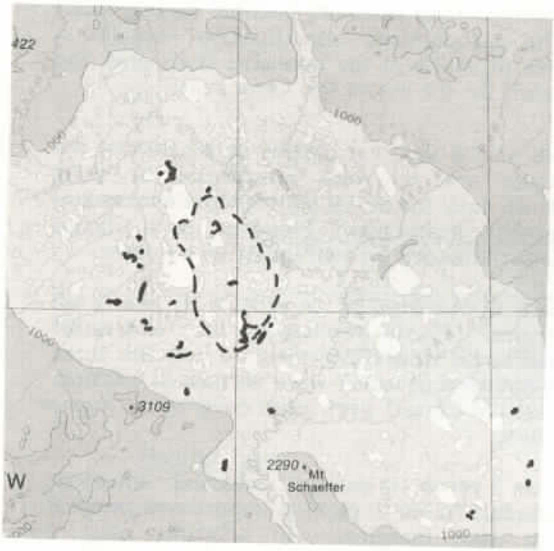

Figure 2 Ice free lakes on May 29, 1974, shown in black (1:1000 000)

Fieldwork indicated that early ice free lakes are important to spring staging of waterfowl which utilize these areas prior to the opening up of nesting habitat. For the years under study (1974-78) Landsat imagery revealed that the same lakes were consistently ice-free earliest, but the timing and duration of breakup varied from year to year. These early ice-free lakes appear to be non-random, extending in a loose chain across the south-western border of the Flats. Future fieldwork should determine variables highly correlated to early ice-free lakes (for example, lake size, depth and siltation).

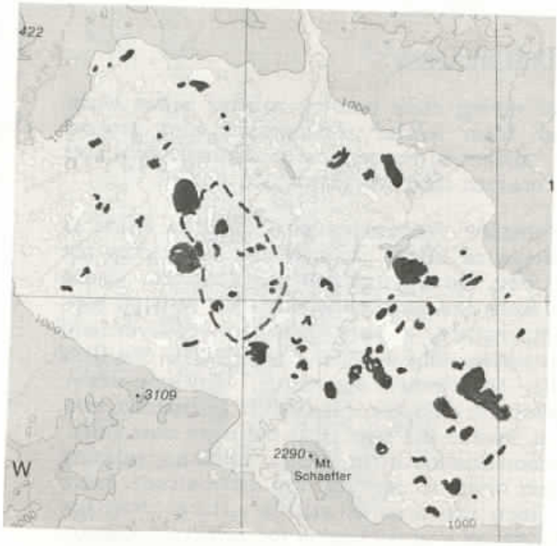

Figure 3 Ice remaining on lakes June 18, 1974 (1:1000 000)

Tables 1 and 2 relate timing of breakup to dabbler/swan and diver productivity respectively. The rationale for comparing productivity of dabblers and swans to early June melt and divers to mid June melt is related to the timing of peak nesting in the respective waterfowl groups.

Our attempt to relate waterfowl productivity to timing of breakup lead to some interesting results. Swans appear to be influenced by factors other than early breakup except in extremely late springs (for example, 1978). With enough years' data we predicted that a key breakup date could be determined beyond which swans are adversely affected by late ice.

Although dabbler productivity does appear correlated to timing of early June breakup, the influence is not strong. Dabbler's nesting habitat is generally not in close proximity to water areas. It can be hypothesized that apparent correlation may reflect duckling survival rather than nesting success.

Diver productivity is strongly correlated to mid June breakup. This correlation should be expected since divers are late nesters with no chance of re-nesting and also because nesting habitat is strongly correlated with emergent vegetation. It was unfortunate that duck productivity was not determined in 1978, a year with an unusually late breakup.

Nesting Habitat Types

Two diving duck nesting habitat types were identified from aerial photographs and ground plots; -- advanced succession in drained lakes and partially drained lake margins.

A constant phenomena on Old Crow Flats is the drainage of lakes. Ice wedges and dykes rot and give way, leaving exposed lake bottoms. These exposed sites revegetate quickly due to high surface temperature, a very deep active layer and abundant surrounding seed sources. Within the first year *Salix* sp., *Senecio congestus*, *Rorippa islandica*, *Epilobium palustre*, *Equisetum scirpoides*, and *Carex* sp. invade the site. It is believed that *Salix* species soon dominate the area. Once an isolating vegetation mat is formed the permafrost table rises. Since the area is still a natural drainage basin, water once again begins to collect. *Carex aquatilis* soon dominates and forms the almost continuous cover typical of ideal nesting habitat. The *Salix* species that dominated the drier sites die. As the water table rises, more and more emergent vegetation becomes inundated.

Partially drained lake margins produce the major nesting vegetation on Old Crow Flats. Four zonal patterns appear to typify these areas. In standing water *Carex aquatilis* forms almost pure stands with *Hippuris vulgaris* scattered throughout. At the water/land interface *Glyceria maxima* dominates, gradually intergrading with a *Carex rostrata* community on mesic sites. *Carex* and *Eriophorum* tussocks interspersed with *Salix* form extensive upland communities surrounding most lake margins.

Table 3 reveals the changes in extent of the two habitat types within the intensive study area, which were identified from a multitemporal comparison of the aerial photographs.

Figure 4 shows emergent advance between 1951 - 1972 on one of the partially drained lakes considered (Pintail Slough).

Results from the 21 year comparison of emergent vegetation advance or retreat lend support to field observations on the formation of such areas. The two drained lakes in the intensive study area both exhibited a decrease in area of emergent vegetation. If the formation of such areas is related to a rising permafrost layer then this decrease in emergent vegetation can be expected.

Field data indicates that these lakes become poor for waterfowl nesting as water levels increase to a level where the water/land interface is located in the inundated *Salix* zone.

By comparison, partially drained lakes exhibited a relatively high emergent advance over the 21 year period (2.3 - 6.3%/year). It is expected that as the sedge advance continues and cuts off drainage channels to the larger lakes (see narrow neck in Fig. 4), nesting sites would become unavailable as the water level rises to the shrub zone.

Extrapolation of intensive study area data

Computer digital classification of Landsat digital data was attempted to extrapolate from those areas of emergent vegetation in the intensive study area to the rest of the Old Crow Flats, thereby determining areas of possible nesting habitat. The unsupervised classification revealed a water area of 38.7% of the intensive study area and 1,129 sq. km for the entire Old Crow Flats.

Two of the spectral classes delineated by the unsupervised analysis were interpreted by using ground truth data and aerial photography as containing emergent vegetation. However, both classes proved unsatisfactory for extrapolation purposes.

Class 3 consisted of an outline of nearly all lake margins. Pixels overlapping land and water with reflectance values intermediate between those of water and land probably were defined as wetland. Also located in Class 3 were lakes covered in *Nuphar polysepalum*.

Class 5 correctly defined extensive emergent vegetation but failed to pick up important emergent stands at lake margins. In addition, class 5 delineated dense submergent stands as well as extensive stands of *Equisetum* emergents. Area calculations made from Class 5 on Dry Frozen Lake revealed 14.4 acres with unsupervised classification of Landsat data compared to the 43 acres determined using aerial photography (1972).

Table 1

Relationship between early June ice break and dabbler/swan productivity, Old Crow Flats, 1974-78

Year (lowest to highest ice cover - early June)	Productivity Dabbler (young/transect mile)	Swans (young/100 adults)
1977	4.5	16.3
1974	-*	16.3
1976	4.0	22.6
1975	3.4	18.8
1978	-*	2.7

* no data available

Table 2 Relationship between mid June ice breakup and diver productivity, Old Crow Flats, 1974-78

Year (lowest to highest ice cover, mid June)	Productivity Diver (young/ transect mile)
1977	7.7
1975	4.3
1976	2.5
1974	-*
1978	-*

* no data available

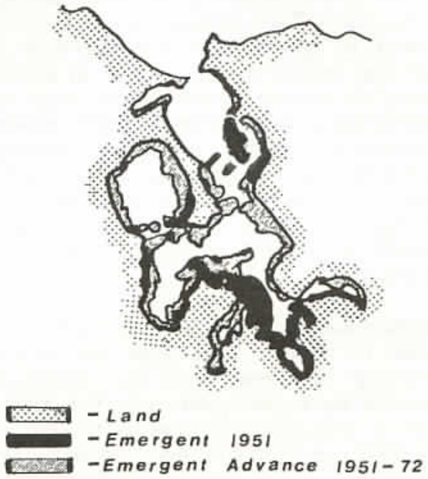

Figure 4 Emergent advance, 1951 - 1972 for Pintail Slough, Old Crow Flats.

Table 3

Advance (+) or retreat (-) of emergent vegetation in two habitat types, 1951 - 1972

Habitat type	Lake	Average % area change/year 1951 - 1972
Drained lake	Mary Kassi dry lake	-1.0
	Old dry lake	-0.1
Partially drained lakes	Pintail Slough	+6.3
	Dry frozen lake	+4.9
	Big dry lake	+2.3

Attempts at unsupervised classification of emergent mats provided less information than was initially hoped. It seems logical, however, that relatively small areas such as the emergent mats, located at the land/water interface, would be difficult to differentiate given the spatial resolution of Landsat.

Class 5 proved useful in locating unknown extensive emergent mats outside the intensive study area. Information gained from the results of the classification can be utilized as vegetation surveys extend to the rest of the study area.

CONCLUSIONS

The Yukon Game Branch can quickly realize benefits from the study. The delineation of early ice free lakes is important not only in planning field surveys but also in land use decision-making. Areas on the Old Crow Flats delineated as early ice free lakes must be given special protection in terms of land use decisions. As a rule in arctic latitudes spring migration takes place prior to general spring breakup and waterfowl are dependent upon unique and highly traditional staging areas where, for various reasons, open water occurs unusually early. The use of such areas is apparently a strategy for survival in the far north where general breakup comes too late for an adequately long breeding season.

As satellite imagery improves in resolution, it will be possible to monitor key lakes and relate timing of breakup in these lakes to waterfowl productivity. We have demonstrated that there appears to be a relationship between timing of breakup and waterfowl, at least diver, productivity. It will be extremely useful to continental waterfowl management to be able to predict annual productivity from spring satellite imagery.

More field work is required to better understand the dynamics of the key habitat types for nesting diver ducks. Permanent plots can be established in sample stands to determine the relationship between nesting density and successional stage of the two habitat types. Extrapolation of nesting habitat types to the rest of Old Crow Flats could not be accomplished satisfactorily using unsupervised classification of Landsat data. To extrapolate diver breeding habitat areas, early aerial photography must be utilized and correction factors for acreage increase or decrease in the two habitat types applied.

This study has revealed benefits of remote sensing which go beyond understanding waterfowl nesting strategy and nesting habitat on the Old Crow Flats. Management agencies are coming to realize the value and potential of modern remote sensing data as an aid to wildlife management. The analysis dealt with in this paper is not highly sophisticated and is relatively inexpensive. Such useful data has remained relatively unexploited by many wildlife management agencies.

ACKNOWLEDGEMENTS

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LITERATURE CITED

Barry, T. W. 1966. The geese of the Anderson River Delta, Northwest Territories. Ph.D. Thesis, Univ. of Alberta, Edmonton. 181 p.

Goldberg, M. and S. Shlien. 1976. Computer implementation of 4-dimensional clustering algorithm. Canada Centre for Remote Sensing, Research Report 76-2. March, 1976.

Zoltai, S.C. and W.W. Pettapiece. 1973. Studies of vegetation, landform and permafrost in the Mackenzie Valley. Terrain, vegetation and permafrost relationships in the northern part of the Mackenzie Valley and northern Yukon. Environmental Social Committee, Northern Pipelines, Task Force on Northern Oil Development, Report No. 73-4.

Analysis of Vegetation Change Following Wildfire, and its Effects Upon Wildlife Habitat[1]

Larry J. Sugarbaker[2]

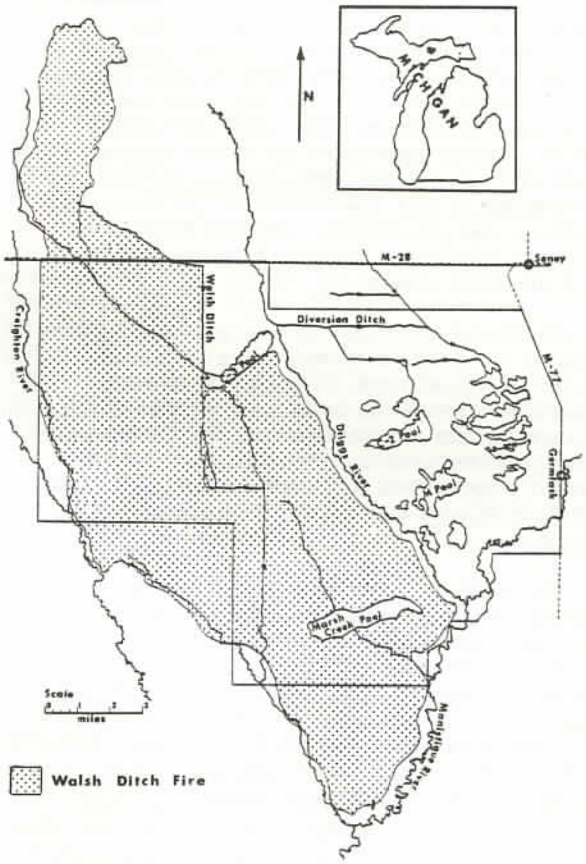
Abstract. Color-infrared and black and white aerial photography were used to construct post-fire and pre-fire vegetation maps of the Walsh Ditch Fire area on the Seney National Wildlife Refuge in upper Michigan. From the two maps, an overlay was prepared to show vegetation changes and the fire perimeter, including areas within the perimeter that were not burned.

INTRODUCTION

On 30 July 1976 a thunderstorm resulted in a lightning fire on a remote part of the Seney National Wildlife Refuge located in Michigan's upper peninsula. In accordance with refuge policy, the fire was allowed to burn as long as there was no threat to the wilderness resource, human life, or damage to property. By 11 August, it was determined that an emergency existed and fire suppression efforts were initiated. Final containment was not complete until 21 September, when an estimated 74,000 acres had been burned in the Walsh Ditch Fire. A map of the refuge and the fire boundary are presented in Figure 1.

Present day occurance of large fires in the Lakes States is rare and the remote sensor data obtained before, during, and after the Walsh Ditch Fire provided a unique opportunity to demonstrate the utility of remote sensing techniques for monitoring and evaluating ecological change following wildfire. This paper describes the techniques used in mapping and comparing vegetation change, and has ramifications for evaluating wildlife habitat and studying future successional change following wildfire.

Figure 1.-- Seney National Wildlife Refuge



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

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DESCRIPTION OF AREA

Treeless string bogs and topographically oriented strips of bog forest cover much of the area that was burned in the Walsh Ditch Fire. This patterned complex has been described in detail by Heinselman (1965). The entire region associated with these peatlands is a vast sandplain which was produced by the deposition of outwash from the recession of the last (Valders) ice sheet. A continuous peat blanket several feet thick covers much of the sandplain but is interrupted by many sand knolls which appear to be extinct sand dunes that formed sometime after the deposition of the sandplains.

The bog forests covering much of the area consist primarily of tamarack (Larix laricina(DuRoi) K. Koch) and occasional black spruce (Picea mariana (Mill.) B.S.P.). These forests are generally several hundred feet wide, often more than a mile long, oriented parallel to the slope (which is about 6-12 feet per mile), and are always found trailing downslope from the sand "islands". Intermediate to these bog forests are long narrow strips of string bog. The bogs consist of alternating low bog ridges (German Stränge) and wet sedgy hollows (Swedish flarke, English flarks) which form crossbanding that can be easily seen on air photos. The sand knolls support upland vegetation which is dominated by red and white pine (Pinus resinosa Ait. and P. strobus L.).The ground cover consists of sedges and grass sod. Bracken fern and low sweet blueberry (Vaccinium pennsylvanicum Lam.) are also common.

Downslope from the string bog and forest complex, the peatlands support a different vegetation cover type. Intermittent sand knolls are surrounded by a vast meadow which has very little resemblance to the tamarack forest and bog complex found to the north. Dominant vegetation in these meadows consists of sedges (Carex spp.) or cottongrasses (Eriophorum spp.).

The area north of the patterned forests consists of long trailing grass meadows, which are waterways, and appear too wet to support any kind of forest growth other than some willow (Salix spp.) and tag alder (Alnus rugosa (DuRoi) Spreng.). On either side of the grass meadows, a diversity of forest types exist, including tag alder lowlands, spruce-fir, aspen, and upland pine forests.

METHODS AND MATERIALS

Pre-fire and post-fire vegetative cover maps were prepared and compared to determine what changes took place as a result of the fire. The post-fire vegetation cover was mapped directly onto U.S. Geological Survey (USGS) 7.5 minute quadrangle sheets at a scale of 1:24,000. Cover type changes and the actual fire perimeter were mapped as an overlay to this map base.

The Michigan Land Cover/Use Classification System (MLUCRC, 1976), a four level expansion of the land-use classification scheme prepared by Anderson, et al.(1976) for the U.S. Geological Survey was used. Levels one and two of the Michigan system are similar to the Anderson classification system and are outlined in Table 1.

Table 1.--

Levels I & II * Michigan Land Cover/Use Classification System

1 URBAN & BUILT UP
- 11 Residential
- 12 Commercial, Services, & Institutional
- 13 Industrial
- 14 Transportation, Communication & Utilities
- [15] Map Industrial Parks under appropriate category in Commercial Services & Institutional (12) or Industrial (13)
- 16 Mixed
- 17 Extractive
- 19 Open & Other

2 AGRICULTURAL LAND
- 21 Cropland, Rotation & Permanent Pasture
- 22 Orchards, Bush-Fruits, Vineyards & Ornamental Horticulture Areas
- 23 Confined Feeding Operations
- [28] Inactive Land (These plant communities will be mapped under herbaceous rangelands (31).
- 29 Other Agricultural Land

3 RANGELAND
- 31 Herbaceous Rangeland
- 32 Shrub Rangeland

4 FOREST LAND
- 41 Broadleaved Forest (generally deciduous)
- 42 Coniferous Forest
- 43 Mixed Conifer-Broadleaved Forest

5 WATER
- 51 Streams & Waterways
- 52 Lakes
- 53 Reservoirs
- 54 Great Lakes

6 WETLANDS
- 61 Forested (wooded) Wetlands
- 62 Non-Forested (non-wooded) Wetlands

7 BARREN
- 71 Salt Flats (not applicable to Michigan)
- 72 Beaches & Riverbanks
- 73 Sand Other than Beaches
- 74 Bare Exposed Rock
- 75 Transitional Areas
- 79 Other

8 TUNDRA (not applicable to Michigan)

9 PERMANENT SNOW & ICE (not applicable to Michigan)

The smallest area that can be consistently classified and identified on a 1:24,000 map sheet is about two acres in size (MLUCRC, 1976). The presence of sand knolls as an integral part of the patterned forests and their effect on quality of wildlife habitat made their identification and mapping important for this study. Those smaller than two acres in size were identified by point symbols which indicated size class and whether or not they supported overstory vegetation.

Post-fire vegetation cover. Color-infrared (CIR) aerial photography (nominal scale, 1:15,840) obtained by the U.S. Fish and Wildlife Service (FWS) in May 1976, was the primary data source for mapping post-fire vegetative cover. In addition, CIR photography obtained in September 1976 (nominal scale, 1:68,000), and CIR photography (nominal scale, 1:15,840) from October 1977 were used as supporting information.

Vegetation type boundaries were traced onto stable base mylar from alternate photos. When fall-off at the edge of a frame or other image defects prevented a clear distinction of type boundaries, intermediate photos were used to solve these ambiguities.

Most information on the mylar sheets was transferred to quadrangle map sheets with the use of a Map-O-Graph reflecting projector. Since the Map-O-Graph has no way to correct image scale for tilt, some type boundaries were transferred to the base map with a Bausch and Lomb Zoom Transfer Scope.

Three trips were made to the study area to gather groundtruth information and field-check the map product. The initial trip provided familiarity with vegetation types occuring in the study area. As many cover types were photographed from the ground as possible, and their locations on the photographs determined. These ground photographs provided a partial key for the initial classification of cover types. A second trip was made to the refuge to check questions that had arisen during image interpretation and to field-check areas already mapped. A final trip was taken to the study area when the post-fire vegetation maps were nearly completed to field-check problem areas and check map accuracy.

Pre-fire vegetation cover was determined in approximately the same manner as post-fire cover. It was not, however, necessary to produce a finished map of the pre-fire conditions. By overlaying a manuscript copy of the pre-fire map onto the post-fire cover map, it was possible to document changes in cover types. These changes were recorded on a new overlay. USGS black and white aerial mapping photography from May 1971 was the primary source for documenting pre-fire vegetative cover, however, it was often easier to determine pre-fire vegetation boundaries from the CIR post-fire photography. Burned over forest, for example, could usually be seen as either standing or wind-blown snags, and burned shrublands produced a different texture than areas that were previously grasslands.

Vegetation change and fire boundary. As just described, vegetation change was documented by superimposing the pre-fire map over the post-fire vegetation cover map. The areas where cover type changes occurred were classified as they existed in the pre-fire condition. The fire boundary was also documented on this overlay using the CIR photography from May 1977 as the primary data source. Very little green-up had occurred in this area by May, so most of the burned area was still blackened. The September 1976 imagery proved to be unreliable for determining fire boundaries because many flare-ups occurred into October, creating additional burn areas that were not documented on that imagery.

DISCUSSION

Mapping of vegetative cover from seasonal CIR photography has been reported by different researchers (Seher and Tueller, 1973; Gammon, et al., 1976). There is very little research reported, however, for vegetation mapping of disturbed areas. Mapping of vegetation communities as they appear during the year following the Walsh Ditch Fire on the Seney National Wildlife Refuge has proved to be an effective method of documenting major cover type alterations resulting from the fire. This is realized by comparing pre-fire vegetation cover with post-fire cover and presenting the change in the form of an overlay to the post-fire map. The fire perimeter, including islands of unburned vegetation, are also documented on the mylar overlay.

During the two growing seasons following the fire, FWS researchers have conducted extensive surveys of small mammal and breeding bird populations for both burned and unburned portions of the refuge[3]. In addition, vegetation was evaluated in terms of overstory and understory for species composition and

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[3]Anderson, S.H. 1978. The evaluation of Seney National Wildlife Refuge fire on Wildlife and wildlife habitat. Unpublished progress report, U.S. Fish and Wildlife Service. 10 p.

density in each of the sample plots. By being able to delineate major vegetation communities for both burned and unburned areas, it is reasonable to expect that inferences about the impact of fire on both habitat and wildlife populations can be made. Without current vegetation maps and an accurate account of the burned areas, this would not be possible.

Delineation of vegetation boundaries for the burned areas and the classification of some vegetation types could not be accomplished solely from the use of the May 1977 imagery. During the early part of May (when this photography was obtained), little green-up has occurred in Michigan's upper peninsula. As a result of this and the burned surface, it was difficult to separate vegetation types, particularly where lowland herbaceous growth occurred. It was expected that this would happen, so imagery from the following October was obtained in order that the vegetation types that recovered after one growing season could be detected. Unfortunately, the film was underexposed and subsequent efforts to correct this problem produced a poor quality print. It was possible to separate upland deciduous vegetation from the conifers, but any attempt to delineate some wetland vegetation boundaries was unsuccessful. Seher and Tueller (1973) reported that they were able to differentiate between several wetland vegetation types by species from late summer CIR photography, so it is felt that the problems encountered here are inherent to this study.

Mapping of cover types in the unburned areas proved to be much easier than mapping burned areas. Although there is a large diversity of cover types represented on the refuge, most of the areas within a given type remained uniform in appearance for unburned areas and criteria for classifying vegetation remained constant for most types. In the burned areas, however, snags, burned shrubs, and a varying degree of vegetation recovery in given areas made it difficult to evaluate the vegetation cover on the basis of rigid mapping criteria. Consequently, more extensive ground-truthing was required for these areas and the classification procedure was much more subjective.

There are many examples of varying returns from burned area, but the following are typical of the problems encountered. In many places, fire scars on tree boles indicated that the surface fire was intense even though there was no crown fire. Many of these trees were showing obvious signs of stress, or were dead, one year after the burn. In such cases it might be argued that the heavily damaged tree stands should not be classified as coniferous forest, but should be classified according to the ground layer vegetation which is largely obscured.

When fire burned through black spruce stands all that remained were charred upright snags, most of which were standing one year after the burn. Recolonization of these areas by aspen (Populus tremuloides Michx.), jack pine, occasional black spruce, and herbaceous invaders was prompt, but residual snags prevented the detection of vegetation recovery on CIR imagery.

In burned areas where lowland shrubs were the dominant vegetation types prior to the fire, lowland grasses and forbs responded quickly during the following spring. In this case, areas that were previously shrublands, and adjacent areas which were low grasslands are now all classified as grasslands, even though the burned over shrublands give a very mottled appearance on the imagery.

It could be argued that since pre-fire maps and post-fire maps are available, vegetation changes and successional trends could be established based on the information obtained from the two maps. It is important, however, that the individuals who use the maps realize that all areas are mapped according to the dominant vegetation type present at the time the imagery was obtained. In most lowland grasslands, for example, the encroachment of alder and willow shrubs seems inevitable, but where fire passed through these areas, the invasion of shrubs is at least temporarily set back. Here, both the pre- and post-fire maps indicate that this entire area is dominated by grasses and, indeed, this is the case but the appearance of these grasslands has changed considerably. A second example occurs on the burned uplands and sand knolls. In most cases, surface fires burned through these areas leaving more than half of the overstory (usually dominated by red pine) intact. Here, both pre-fire and post-fire maps indicate that upland conifers are the dominant vegetation type, but as a result of fire, future vegetation composition will be greatly affected. Therefore, in this situation, knowing whether or not a fire occurred in a given area can affect future habitat management decisions.

The situation described above raises another question for discussion. The degree of burn for most examples up to this point (with the exception of the spruce stand example) have been in areas of relatively light burn. Areas that experienced a heavy burn (that is, areas where all available fuel was nearly consumed and mineral soil was left exposed) are in a transitional state. The Michigan Land Cover/Use Classification System has provisions for mapping such barren ground as transitional (table 1). In some of these areas, however, seed bed conditions were favorable, and regeneration (particularly aspen) was quickly established. At this point, the dominant vegetation type is aspen. Whether or not the aspen survives on this area is questionable, and it would seem more appropriate to label this area transitional also. Surely, all areas are dynamic, and the point at which we recognize something as being at least temporarily static in terms of its classification is arbitrary.

The Michigan Land Cover/Use Classification System does not have any provisions for indicating the severity of burn. Such information, if it were obtainable from the imagery or some other source could be included in the classification as a fifth diget. This would be a valuable indicator of the direction of succession and development of future vegetative cover, and as a result of this additional information, better management decisions could be made.

The effects of the Walsh Ditch Fire on wildlife habitat are inconclusive at this time, but many field observations have indicated that habitat conditions have either improved or remained stable for most wildlife species. The most immediate response to the fire has been the creation of more edge and the setback of successional development in most areas[3].

Since the initial establishment of the Seney National Wildlife Refuge was for the propagation of waterfowl, the effects of fire on waterfowl habitat are a primary concern. Water quality studies on the refuge have not shown any significant changes in water quality, and since water levels on much of the refuge are controlled by a system of dikes and gates, the water regime in the pond system was not affected by the fire[3]. On many occasions, Canada geese (Branta candensis) were observed to be grazing on the lush growth within the burn area and in one instance, a mallard (Anas platyrhynchos) was seen nesting within the confines of dead alder brush. Generally, it is felt that the fire has sufficiently set succession back in the marsh complex in order to better maintain the waterfowl habitat.

The Walsh Ditch Fire has helped maintain the sharp-tailed grouse (Pedioecetes phasianellus) habitat, particularly in the open meadows where the sand knolls supporting vegetation provide excellent cover. On one occasion, a grouse was flushed four different times from adjacent knolls where it had sought cover. Most of these sand knolls still have some overstory of red or white pine, and aspen and jack pine regeneration is sufficient to create additional cover and food sources for wildlife in the future. Whitetail deer (Odocoileus virginianus), sandhill cranes (Grus canadensis) and many other game and non-game species or their sign were sighted in the field during ground-truth studies.

SUMMARY AND CONCLUSIONS

Color infrared and USGS black and white aerial photography were used to construct post-fire and pre-fire vegetation maps of the Walsh Ditch Fire on the Seney National Wildlife Refuge. From the two maps, an overlay was prepared to show vegetation cover type changes and the fire perimeter including areas within the perimeter that were not burned.

Vegetation cover types in unburned areas remained fairly uniform in appearance and a set of mapping criteria could be established for individual cover types. In the burned areas, however, snags and burned shrubs, coupled with varying degrees of vegetation recovery during the first growing season, made it difficult to consistently evaluate cover types from the photos alone. Despite this problem, results of this study lead to the following conclusions:

1. Vegetation types and vegetation recovery can be mapped for disturbed areas from CIR seasonal photography.

2. Fire boundaries can be accurately mapped from CIR photography obtained prior to green-up following the fire.

3. Vegetation change detection is possible by comparing post-fire vegetation with pre-fire maps.

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LITERATURE CITED

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A Land-use and land cover classification system for use with remote sensor data. U.S. Geol. Survey Prof. Paper 964. 28 p.

Gammon, P.T., D. Malone, P.D. Brooks, and V. Carter. 1975. Three approaches to the classification and mapping of inland wetlands. Proc. Ninth Int. Symposium on Remote Sensing of Environment. pp. 1545-1555. University of Michigan Press. Ann Arbor.

Heinselman, M.L. 1965. String bogs and other patterned organic terrain near Seney, Upper Michigan. Ecology, Vol. 46: 185-188.

MLUCRC. 1976. Michigan land cover/use classification system. Division of Land Resources Program, Michigan Department of Natural Resources, East Lansing. 66 p.

Seher, J.S. and P.T. Tueller. 1973. Color aerial photos for marshland. Photogram. Eng. 39(5): 489-499.

Landsat Imagery for Wildlife Habitat Inventory Mapping [1]

Charles T. Traylor

W. Theodore Mealor, Jr.[2]

Abstract.--The expense of automated image processing can preclude the use of satellite data for many mapping projects. The technique used to prepare the timely and cost efficient wildlife habitat map of Mississippi is based upon traditional cartographic and photographic techniques coupled with relatively simple visual interpretation of LANDSAT imagery.

INTRODUCTION

Since the advent of LANDSAT-I, a number of methodologies for producing small scale land cover-land use maps have been devised. Although simple tracings of the earth's surface from LANDSAT film chips were first employed, more and more sophisticated means of interpreting and presenting electromagnetic data were devised as space technology increased. Automated processing, requiring expensive equipment and technically trained people, has increased the utility of remotely sensed data and improved the quality of the resulting products. Unfortunately the cost of these products may be prohibitive to some potential users, thereby negating their usefulness.

The method of preparing a wildlife habitat inventory map described in this paper combines traditional cartographic and photographic techniques with relatively simple remote sensing interpretation of LANDSAT imagery. The technique provides an efficient and cost effective method for producing small scale forest resources and wildlife habitat maps as demonstrated by the habitat inventory map of Mississippi prepared for the Mississippi State Game and Fish Commission. Using an existing LANDSAT mosaic as a base, approximately 20 man hours were devoted to preparing the finished product. The total cost for printing 500 copies of the map was about $40.00, exclusive of labor.

BACKGROUND

The Mississippi State Game and Fish Commission contracted the Cartographic Services Laboratory-Mississippi Applied Remote Sensing Laboratory, research and service units of the Department of Geography and Area Development, University of Southern Mississippi, to prepare a revised edition of their wildlife habitat map. The previous wildlife habitat map had been prepared in the 1940's from a variety of sources. The State Game and Fish Commission desired a map that was timely, reflected accurately the areal distribution of their selected land cover habitat indicators, and could be used in assessing wildlife populations and distributions. Also, the classification scheme used to depict land cover-land use had to mesh with previous categories used by the Commission (Table 1).

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

[2]Respectively Assistant Professor of Geography and Area Development and Director of the Cartographic Services Laboratory, University of Southern Mississippi, Hattiesburg, Mississippi, and Professor and Chairman, Department of Geography, Memphis State University, Memphis, Tennessee.

Table 1.--Wildlife Habitat Classification Categories

1. Delta Hardwoods
2. Bottomland Hardwoods
3. Upland Hardwoods
4. Cottonwood/Willow
5. Longleaf - Slash Pine
6. Loblolly - Shortleaf Pine
7. Agricultural and Open Land (including urban)

Time and cost factors prohibited the assemblage and interpretation of data from aerial photography or through detailed field survey. Also, the cost of automated image processing of LANDSAT data prevented it from being an acceptable alternative. However, the ability to visually interpret composited LANDSAT positive 70mm film chips coupled with a photographic-cartographic technique utilizing an already existing LANDSAT mosaic, provided an inexpensive, accurate, and easily prepared product; an alternative attractive to the Game and Fish Commission.

TECHNIQUE[3]

The interpretive techniques and final display of the land cover types were predicated upon the availability of a high quality LANDSAT mosaic of the State of Mississippi. A false-color, uncontrolled mosaic prepared by NASA-Earth Resources Laboratory provided ample total contrast for identification of forest types and for use as a photographic base for display.

Film chips of each spectral band for each frame used in preparing the mosaic of Mississippi were acquired for land cover identification. Using existing information on habitats and land cover available from a variety of resources, appropriate settings on a color additive viewer were developed to enhance tonal qualities charactertistic of each of the categories in the classification scheme. The spatial distribution of each category on each frame was traced on acetate. The individual sheets of acetate were then registered on the mosaic and transferred to one overlay. This, in effect, created a generalized map which delineated the various forest types across the state. At this point the map reflected only forest types with no agricultural or other cultural features depicted.

Separation of non-forested land, including enclaves of open areas within forests, was achieved photographically from the NASA mosaic through the use of high contrast lithographic film. One of the characteristics of high contrast lithographic film is its lack of sensitivity to red. Because the heavily wooded areas (Table 1, Categories 1-6) appeared in various hues of red, it was relatively simple to separate them from agricultural and open land that registered in pinks, grays, and whites. By controlling film exposure and development time, reproducing the LANDSAT mosaic onto the high contrast lithographic film allowed the agricultural/open land areas to be exposed but not the forest areas. On the resulting negative forest land appeared white and agricultural/open land appeared black. Even small enclaves of forest lands within open areas, particularly in the Yazoo Basin, registered white on the negative.

In a sense, the control of exposure and development time of the high contrast lithographic film is a manual technique of density slicing. Admittedly, the method used to produce the Mississippi map is subjective; a density wedge would be more accurate than trial and error associated with exposing and developing the photograph of the mosaic. However, because the mosaic was a color composite of LANDSAT film chips for each of the four spectral bands for each of 11 scenes, it was not feasible to use a wedge. In fact, because of the variations in tone and hue of the mosaic, the final negative itself was a mosaic of several exposures, each tailored for a specific area of the state.

The primary problem involved in the photographic procedure was its inability to discriminate between forest lands and those agricultural fields in full growth, for both appeared in tones of red. Identification of those agricultural areas reflected in tones similar to forested land was accomplished by compositing the original film chips on a color additive viewer. Once identified, those agricultural areas appearing white on the photographic negative were manually opaqued so they would "drop out" in the final processing steps.

The final step was color preseparation and printing. The individual forest classifications were delineated on scribecoat using the overlays produced from interpretation of the LANDSAT film chip composites. Peel coat color separations were made with windows covering the total area of each forest type,

[3]All color illustrations are omitted from the text. However, a limited number of the published maps are available and may be obtained by writing the authors.

according to the classification and color scheme of the legend. During the printing plate exposure process, the high contrast negative was used as a color drop-out mask for each one of the forested area classifications. This procedure insured that colors would be printed only where various forest habitats existed.

The resulting map shows the pattern of distribution of woodland habitats within the state of Mississippi by color in a format which has unprecedented detail considering the cost and time frame under which the map was produced. The procedure could be applied to other areas and other problems where variation in the intensity of remotely sensed data exist.

Imaging Remote Sensing Systems for Animal Censuses[1]

J.D. Heyland[2]

Abstract.--Imaging remote sensing systems for animal censuses currently available to wildlife biologists are radar, thermal infrared scans, aerial photography and satellite imagery. More importance is assigned to the latter two because of the greater promise they show for application in routine census procedures and related studies.

When I was first approached to present a paper at Pecora IV, it was late winter. There was still snow around and the possibility of summer, let alone October ever arriving seemed so remote that I readily agreed. Since then, the knowledge that I had to prepare this paper has been unrelenting. On occasion, especially during the lazy days of July, I almost managed to forget. As August rolled past, I became increasingly terror struck as I realized that Pecora was a reality. So with the recognition that my conscience spoiled my summer, I am here to talk about imaging systems for animal censuses.

I did not keep track of the number of requests I received for my first wildlife note published several years ago, but it may have amounted to 14 of the 300 reprints I ordered. However, when the proceedings of the Workshop on Remote Sensing of Wildlife became available, I decided to record the requests so as to get a feeling for the number of individuals and organizations interested in the subject. To date, I have received over 110 requests - many with additional questions attached. Personally, I find this extremely gratifying, not because I was the editor, but rather to see the degree of interest across the world. I say the world because we have received enquiries from Spain, Australia, The Netherlands, Poland, and other countries as well as from North America.

I anticipate that there will be an even better response to Pecora IV so editors be warned - print plenty of copies.

[1]Paper presented at Pecora IV Symposium: Application of Remote Sensing Data to Wildlife Management, Sioux Falls, South Dakota, October 10-12, 1978.

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INTRODUCTION

This paper is not designed to provide answers on the status and structure of any one population of animals. Rather its purpose is to furnish some information to scientists who may wish to use aerial photography and other sensors to obtain more precise data on their subject(s). I have tried to keep it uncomplicated for two reasons. The first is that many wildlife biologists have yet to use remote sensing for purposes other than habitat studies and may not be familiar with other applications. The second is that there is a lack in the literature of documented techniques and procedures to which the biologist can turn when he wants to use remote sensing methods in wildlife studies. There is a very useful rôle for remote sensing in studies of many wildlife populations and it is my intent to make some suggestions for its application.

When undertaking a program to manage a population of wild animals from which an annual allotment is harvested, it is necessary to be familiar with certain characteristics of the population. Basic to all is a knowledge of its size. Further, it is desirable to have some information concerning the structure of the population. For example; 1) into how many age classes can it be divided and what are the ratios of these classes, 2) what are the overall sex ratios and what are they within the age classes, 3) what is the annual recruitment and 4) what is the annual mortality from natural causes and from hunting. If the population is migratory, information pertaining to where and when the animals will be found may be required.

Some animal censuses are aural or involve other indirect methods, but many are visual. Visual surveys may be made from ground level especially if information on relatively small groups of animals is required. However, censuses of big game and waterfowl are often airborne. The majority of these are made at altitudes of less than 200 metres. At such heights, and at forward speeds of 170 kph, the data gathering capabilities of a human observer are limited to either intense inspections of small areas or general observations of large areas. Under these conditions it is difficult if not impossible for an observer to scrutinize and note accurately all aspects of the ecology of an area. Many decisions for management practices require more accurate data than those which can be obtained solely from low level aerial surveys and the quickly made decisions related to them.

There are two types of factors which influence airborne visual counts of animals; 1) internal factors within the observer, and 2) external factors relating to the animals and the environment (Graham and Bell, 1969). Nausea or drowsiness which may result from too warm a cockpit and/or the movement of the aircraft, differences in the ability of various observers to detect the target species, vibration, cold and other physical discomforts are examples of the former. Aircraft construction, e.g., curved windowns may distort vision or wings and struts may interfere with the view. Aggregations of animals may be too large for even "good" estimates. These examples are in the latter category. Low-flying aeroplanes usually cause animals to flee and therefore the observer seldom sees them in normal undisturbed groupings. All of these factors, and others, mitigate against efficient visual censuses.

Many papers reporting on animal population studies which have involved airborne censuses describe techniques by which the author restricted his view to a desired transect width. I believe that most biologists would admit that an observer cannot maintain, visually, constant transect widths during a census. It is even improbable that the same observer is capable of placing his head in exactly the same position each time he looks out the aircraft's window. That is, he can never be sure that the amount of terrain he sees between the strip markers is identical to that which he observed previously. The situation is worse if a shorter or taller person observes through the same window. Some of these problems may be reduced if the observer lines up "strip markers" on the window and the strut. However, roll, pitch and bank of the aeroplane all introduce errors in strip width. Obliquely oriented visual surveys almost always ignore the strip of terrain directly beneath the aircraft.

A more basic consideration in airborne visual estimates of animals is that observers cannot count accurately. Personal experience indicates that when aggregations of animals or birds exceed 50 to 75, observers usually underestimate numbers by 50 to 100 percent. Further evidence of underestimating is provided by R. Browne, Canadian Wildlife Service (pers. comm.), Sinclair (1972 and 1973), Norton-Griffiths (1973 and 1974), Pennycuick and Western (1972), and Goddard (1967 and 1969).

IMAGING SYSTEMS

It seems obvious that if biologists wish to obtain information on wildlife species they should seek to obtain the most accurate and complete sets of data possible. Given that in many cases the unaided human eye/brain combination will not provide such data the biologist must turn to some type of imaging and recording system. By so doing he will freeze the scene in time and hence be able to examine and interpret the image in a systematic and unhurried fashion. In addition, the biologist will be able to return time and again to the same scene to glean additional information.

Four imaging systems are currently available to the biologist: Radar, Thermal Infrared Scans, Aerial Photography and Satellites.

Radar

Radar stands for Radio Detection and Ranging. It is a tool which is able to detect a target, usually airborne, and to determine its direction and/or altitude, and its range (i.e. the distance between the radar and the target), and in some cases its approximate size or characteristics. The parameters measured by a specific radar depend on its type and purpose. Typical radars have a transmitter (TX) that generates short bursts of radio energy, a waveguide through which the radio waves travel from the transmitter to the feedhorn and an antenna that "focuses" the radio waves that leave the feedhorn in a beam. If the beam is aimed towards a target the radar waves will hit the target and be reflected in all directions. A very small fraction of those reflected waves will travel back the very same way they came and will reach the antenna. The antenna focuses the returned radar waves (the returned signal or echo) onto the feedhorn, from where they travel through the waveguide to the receiver (RX). The so-called TX/RX switch ensures that pulses produced by the transmitter are beamed into the sky while incoming echoes are directed to the receiver. The receiver amplifies the returned signal, which is then displayed as a bright dot or line on a cathode ray tube (CRT). The calibrated CRT shows the range of the target which is determined from; (a) the time it takes a radar pulse to travel from the radar to the target and back again, and (b) the known speed of radio waves (Blokpoel 1975). Other parameters measurable by the type of radar in use may be displayed on the CRT, or may be routed to a plotter, tape recorder or computer.

Airborne objects that can reflect radar energy (i.e. radar targets) are aircraft, meteorological phenomena (especially clouds and rain), birds, bats and insects. Whether or not a particular radar can detect any or all of those objects depends on the characteristics of the radar, the range and height of the object, and the weather conditions.

Radar has been used extensively to study migratory and local movements of birds. Eastwood (1967) provides a review of such work up to the mid-1960's, Myers (1964, 1969) provides comprehensive bibliographies, and Richardson (1972, and this volume), Gauthreaux (1974, 1977) and Bruderer and Steidinger (1972) summarize methodological aspects.

Advantages of radar are; (1) ability to detect airborne objects over long distances and to measure their positions, directions and speeds of movement, etc., (2) ability to function in darkness and in conditions of reduced visibility, (3) ability to detect objects at high altitudes, and (4) amenability for automatic recording and 24 hour per day use.

The main shortcomings of radar studies of movements of birds are; (1) the species rarely can be determined solely from the radar presentation, and (2) the number of birds represented by each echo cannot normally be determined.

Ray and Wartzok (1975) have successfully used L-band imaging radar in the sidelooking format (SLAR or Side Looking Airborne Radar) to determine surface characteristics of the ice upon which Pacific walrus (Odobenus rosmarus divergens) haul out in the Bering Sea.

Thermal Infrared Scans

Thermal infrared radiation emitted by homeotherms is an important avenue of heat loss which may also be utilized for remote detection of individual animals using a thermal infrared line scanner (Lavigne, Øritsland and Falconer, 1977). Thermal infrared imagery has been tested with limited success on a number of animals including white-tailed deer (Odocoileus virginianus) (Croon, McCullough, Olson and Queal, 1968; McCullough, Olson and Queal, 1968 and Graves, Bellis and Knuth, 1972), polar bears (Ursus maritimus) (Brooks 1970), harp seals (Pagophilus groenlandicus) (Lavigne and Ronald 1975), bison (Bison bison), elk (Cervus canadensis), moose (Alces alces) and white tail and mule deer (O. hemionus) (Wride and Baker 1977), boar (Sus scrofa) and European Cervidae (Lenco 1976). The reason for this limited success, as Ray and Wartzok (1975) pointed out is that a majority of animals have evolved rather effective methods of minimizing the temperature differential between their surfaces and the environment, resulting in very little thermal contrast with their backgrounds. Lavigne et. al. (1977) also noted that it is important to recognize that the radiative surface temperature of any homeotherm will vary depending on the ambient environmental conditions. For example, the intensity of solar radiation, windspeed, ambient air temperature, the animal's speed and for many species whether the animal has summer or winter pelage will all influence the rate of heat loss and therefore the radiative surface temperature.

Some species may have high radiative temperatures relative to the ambient air eg. the polar bear (Øritsland, Lentfer and Ronald, 1974) or the hairless Pacific walrus. Ray and Wartzok (1975) found infrared imagery in the 10-12 micrometer band to be particularly useful in their studies of Pacific walrus. The thermal contrast between the hairless walrus and the ice upon which it hauls out may range from 20 to 35°C. This is sufficient to permit thermal detection of the animals which at times is more acute than are visual sightings. Although the spatial resolution of the scanner which they used was only 1 milliradian (3 feet ground resolution at 3000 feet altitude) it was sufficient to detect animals though not to separate them when they were bunched up. Counts of groups were made from vertical photographs exposed simultaneously with the IR scan.

On the other hand, the temperature difference may be minimal. For instance the radiation temperature of adult harp seals lying on sea ice may drop to less than 0.2°C above air temperature when it is raining (Lavigne et al, 1977). Under such conditions detecting an animal with a thermal scanner would be unlikely.

In conclusion, it is apparent that thermal scans are of limited use in wildlife studies particularly in routine activities such as censuses. The most promising use of a thermal scanner may be for detecting and monitoring certain pinipeds such as harp and grey seals on ice. However, even in seal studies the thermal scanner must be considered as a back-up instrument.

Aerial Photography

LeRoy C. Stegeman presented a paper to the Fourth North American Wildlife Conference in 1939 in which he urged use of "... three dimensional photography in wildlife studies". He wrote: "Photography fo-tog-ra-fi, which means the art of writing with light, is a young art". It is far from young now and has made such strides since Daguerre perfected the Daguerrotype in 1839 that unless you are a full time user it is impossible to stay current with the daily technical and artistic developments.

In spite of Stegeman's urging and the obliquely direct references to the utility of photographs in wildlife studies of others such as Bell (1937) and Hunter (1945), wildlife biologists seemed to have largely ignored the camera for censusing until after World War II.

In 1948, Daniel L. Leedy compiled a list of actual and potential uses for photography in wildlife work. He illustrated several uses for oblique photos in counts and other aspects of animal population studies. He pointed out that it was not until World War I that significant studies were made in the field of aerial photography. However, at that time the major combatants recognized the utility of aerial photos and strove to perfect the technique. I have no doubt that if we were to examine photos taken over the trenches in France horses and mules would show up between the guns.

Once again, and in spite of Leedy's enthusiasm the technique seems not to have caught on excepting in a very few cases. In those cases, the results were spectacular and should have amply illustrated the superiority of photo-censuses over visually gathered data. Reports such as those published by Spinner (1946, 1949), Kelez (1947), Chattin (1952) and Eicher (1953) made it abundantly clear that in many situations individual animals could be counted on aerial photographs. In the main, however, aerial photographs were used for illustrating articles and for interpreting habitat.

Aerial photographs can be taken either obliquely or vertically. Leedy (1960) discussed oblique photography as applied to studies of wildlife populations. Heyland (1973) pointed out a number of problems associated with this type of photograph, but added that they are excellent for illustrative purposes or could be used for censusing animals on vertical faces such as sea bird colonies or mountain dwelling mammals such as mountain goats. I would add that for sex and age separation of some mammals such as caribou a slightly oblique angle may be an advantage as long as it is not so exagerated as to conceal animals behind each other.

Vertical photographs eliminate or drastically reduce the impact of most of the biases inherent in visual censuses and oblique photographs. A number of recent studies of a wide variety of species have demonstrated the superiority of this type of photography. In addition to those mentioned above, the following have published the results of their work: Grzimek and Grzimek (1960) and Bartholemew and Pennycuick (1973), flamingoes (Pheoenicopterus ruben), the latter also counted pelicans (Pelicanus onocrotalus and P. rufescens), Bauer (1963), penguins (Aptenodytes patagonica and Eudyotes chrysolophus), Sergeant (1965) and Mansfield (1970) and Vaughan (1970), seals, and Brassard et Potvin (1973), caribou (Rangifer tarandas), Croze (1972) age structure in elephant populations (Loxodonta africana), Norton-Griffiths (1973), for counting wildebeest (Connochaetes taurinus albojubatus), Driscoll and Watson (1974), pocket gophers (Thomomys talpoides) and Leonard and Fish (1974) for sandhill cranes (Grus canadensis canadensis), Heyland (1972 and 1973) counted waterfowl. Heyland (1974) in addition to censusing beluga (Delphinapterus leucas) by means of photographs used the imagery to study other aspects of their biology. A few workers have also used vertical photos to study domestic animals. These include Perkins (1971), Dudzinski and Arnold (1967), Colwell (1964) and Crofton (1959).

Regardless of the type of photography to be used, or indeed for the needs of any imaging system, a number of aspects of the biology of the target species must be considered. Know the animal(s) which are to be studied. Before it is possible to recognize a species on aerial photographs one must first be cognizant of the animal in all possible aspects. It is necessary to be able to distinguish it by morphology, its photo signature (the rendition it receives on the film), its behaviour, habitat preferences, other species with which it associates, any seasonal changes in its appearance and other aspects of its biology.

The morphological appearance and photo signature of species on film lend themselves to the creation of keys. For example, fat not thin, rounded versus pointed, thick or thin in the shoulders, white versus grey, dark or light are simple but effective descriptions for distinguishing one species from another or perhaps one sex from another. An excellent example was developed by Norton-Griffiths (1973) in his study of migratory wildebeest in the Serengeti National Park. He described the photo signature of three species on vertical photographs at approximate scales of 1:9, 974 and 1:9, 933 as follows:

Wildebeest: "... they appear as little white blobs (the silvery grey patch on their backsides) surrounded by a dark border."

Zebra: "... which appear as tiny white sausages."

Thomson's gazelle: "... which appear as tiny white dots with no black border."

He goes on: "Other species have different shapes to wildebeest and do not have the light patch. Wildebeest calves are easily distinguished from gazelle".

Habitat selection is an important element and is directly related to a species behaviour. As an example, diving ducks on prairie sloughs are more often found out on the open water because of their characteristic feeding behaviour whereas puddle ducks are found close inshore where they can more easily feed off the bottom.

Species associations are equally important. There are only two ungulates in the Arctic Islands, caribou and musk-oxen (Ovibovus canadensis). Neither can be confused with the other on a photograph. Musk-oxen can be differentiated from boulders because of shape, tone and the fact that boulders do not move between successive photographs. Musk-oxen are characteristically found either as isolated individuals or in relatively close aggregations of up to sixteen or eighteen animals. Caribou may be found singly or in loose groups from two to many hundreds. They are not nearly as dense in tonal rendition as are musk-oxen, and are much thinner both in morphology and in the shadow they cast. In addition caribou have antlers and musk-oxen do not.

Accurate photo interpretation depends on an integration of many small bits of information. Thus, it is not possible to identify any of the above as a single key element. Rather all, plus other characteristics, must be considered together to obtain correctly interpreted imagery.

Any camera/film combination can be used to photograph wildlife. However, the more critical the lens, the sharper will be the photograph and, therefore, the more useful the imagery. The choice of camera format depends on the needs of the individual and the size of the budget. Thirty-five millimeter or 70 mm cameras may serve for "snap" shot inventories, sampling by transect or even total coverage of small areas. However, large format film offers certain advantages. Contact prints are sufficient for most studies. Thus, delays caused by waiting for enlargements of small films are avoided. Considerably fewer 23 cm x 23 cm exposures are required when covering an area than would be necessary for smaller films. For example, during the winter of 1972, the Quebec Biological Research Service censused a herd of caribou which occupied 5.44 square miles (14.1 km^2). Forty-three 23 cm x 23 cm contact prints of 60 percent forward overlap were required to provide stereoscopic coverage. It was calculated that 1169, 70 mm photos would have been required for the same coverage and this with no forward overlap between frames (Brassard and Potvin, 1973).

Although large format film may be desirable in many cases, it must be pointed out that much excellent work is being done using 35 mm and 70 mm systems. Notable in this area is the Ontario Centre for Remote Sensing and the University of Minnesota's Institute of Agriculture, Forestry, and Home Economics Remote Sensing Laboratory.

The ultra violet portion of the spectrum has received some attention recently. Polar bears and new-born white coated harp seals are examples of cryptically coloured animals. Fortunately and for reasons not understood, the pelage of both of these animals is highly absorbent of ultra violet radiation. Drs. David Lavigne and Nils Øritsland took photographic advantage of this phenomena. By fitting an ordinary 70 mm camera with a quartz U.V. admitting lens they were able to turn both of these animals black while the ice and snow substrate under each, being highly U.V. reflecting, remained white. This "narrow-band" photography has had important implications in populations studies of the western Atlantic harp seal population for now it is possible to determine more accurately annual reproduction levels using the technique (Lavigne and Øritsland 1974 a and b).

Stegeman (1939) called for the use of "three dimensional photography in wildlife studies". This was one call which biologists heard and heeded for there are few of us who have not looked through a stereoscope at one time or another. Obtaining stereoscopic photo coverage of dynamic subjects such as moving animals is not possible with the conventional procedure of in-line sequential exposures because if the subject moves between exposures it is no longer in stereo. Therefore, in general, stereoscopy is of little use in animal censuses. At the same time, however, this lack of stereo can be used to confirm an animal's presence in the scene because while the background is in stereo, the out-of-stereo object will appear to float.

Recently, Mr. Parker G. Williams, President of Integrated Resources Photography Ltd., Vancouver, B.C. developed a method of obtaining stereo coverage of dynamic subjects, i.e. moving objects (Williams 1978). Williams is able to do so by placing a vertically looking 70 mm camera on each wing tip of a Cessna 180 aeroplane and arranging to expose the cameras simultaneously. This is a variation on the concept of the stereometric camera which is about a century old and which was first used in the air by Eugene Avery in the late 1950's (Avery 1958).

Because the base, the distance between the wing tips, is fixed good effective stereo is confined to very large scale photography. Nevertheless the geometry of the imagery is of sufficient quality to permit measurements of objects. The advantage is that, as Williams perfects the instrumentation, it will be possible to accurately measure the heights of animals even though they may be moving at the time of the exposure. This could be useful in age and sex structuring in populations of big game.

Satellite Imagery

The newest remote sensing tool available to the wildlife biologist is satellite imagery. Imagery from two satellites is currently and readily available to civil authorities throughout the world. These are the Multispectral Scanned (MSS) images from the Landsat series and Very High Resolution Radiometer (VHRR) imagery from the NOAA weather satellites. The former cover an area approximately 169 km x 169 km and the latter some 1,609 km^2. Landsat III, the most recent of these experimental resource satellites, carries two panchromatic Return Beam Vidicon (RBV) cameras each with a ground resolution of 40 m - twice that of the MSS. The RBV cameras image the same scene as the MSS but in four separate and overlapping photographs.

Given the ground resolution of Landsat MSS and NOAA, it is obvious that no animal, no matter how big will ever be visible on any of this imagery. It is possible, although unlikely, that aggregations of highly concentrated animals might be visible on RBV imagery. Thus animals cannot be studied directly on imagery from either of these satellites. However, considerable progress is being made in using the pictures for indirect study of some populations of waterfowl. Heyland (1975), Reeves, Cooch and Munro (1976) and Kerbes and Moore (1975) have described studies of snow cover on the nesting grounds of Arctic-nesting geese. The methods suggested by these authors have met with mixed success and have indicated the need for further study in this area. I am pleased to see that Henry Reeves has continued his studies and is presenting his data at the symposium.

I have always maintained that with careful studies it would be possible to classify wildlife habitat using satellite imagery. This has been rewarded by a number of satellite/habitat papers in the recent literature. I note with pleasure that Dick Kerbes, Gordon Venable and Dave Gilmer are presenting papers in this area. An interesting side aspect of these is that they contain data pertaining to habitat in three latitudes in North America from the arid south to the central Arctic coast.

We are far from being out of the earth observation satellite business. A fourth Landsat vehicle Landsat-D is planned. When it is launched in 1981 it will carry a Thematic Mapper (TM) with a 30 m resolution in six spectral bands and 120 m in the seventh. The bands included are three in the visual range, three in the near infrared and the last (7) in the thermal infrared.

The experimental satellite Seasat-A was successfully launched on June 26, 1978. It is designed to help predict weather, study ice movement, guide ships and help locate fish. It orbits the earth every 100.7 minutes at an altitude of 800 km.

The main difference between Seasat-A and previous earth observation satellites is the use of active and passive microwave sensors to achieve an all-weather capability. However, in the case of sea surface temperature this all-weather capability is obtained only at the cost of a rather coarse resolution (100 km).

Seasat carries a visible and infrared radiometer, a scanning microwave multi-channel radiometer, a short pulse altimeter, a scatterometer and synthetic aperature radar (SAR). The data from all sensors, except SAR, will be continuously recorded on board and read out to ground receiving stations. The most interesting sensor on Seasat-A is the SAR, because it has not been used on previous satellites and because it will be capable of high resolution (25 m) all-weather "pictures" from a swath 100 km wide to one side of the satellite's track.

In 1983, the French Centre National d'Etudes Spatiales (CNES) is expected to launch the Satellite Probatoire pour l'Observation de la Terre (SPOT) from the Kourou Spatial Centre, in Guiana. This project consists of a multi-mission platform carrying payloads adapted to particular missions; visible, infrared or microwave sensors. The platform can be placed in sun-synchronous orbits in a 600 km to 1,200 km range with descending modes between 08:00 and 10:00 local time.

The SPOT-1 mission, by definition of the experts, is dedicated to a range of applications similar to Landsat-D, e.g. forest management, crop statistics, geology, cartography, hydrology, land use, oceanography etc. What the "experts" leave off the top of the list is, of course, wildlife biology.

The payload will consist of two identical High Resolution Visible (HRV) scanners, the HRV data recording and playback subsystem, the HRV data transmission subsystem and the data collection platform subsystem. The HRV unit is a "push-broom" scanner with no moving parts. The scanner will have two modes of operation; three-band multispectral or panchromatic. Each spectral band of the HRV will have four one-dimensional arrays consisting of 1728 imaging Charge Coupled Devices (CCD) per array. A line of scanned data is acquired by sampling 6000 elements in the four arrays which are situated in the focal plane of the optical unit. Successive lines are obtained as the vehicle moves along its orbit. The swath width of scanned terrain will be 60 km with an instantaneous resolution of 20 m in the multispectral mode and 10 m in the panchromatic mode. It is anticipated that there will be orbit to orbit overlap such that stereoscopy will be possible.

A fourth satellite has reached the description stage. Although the proposed vehicle has not been named, NASA has assigned the task the title stereosat Applications Explorer Mission (AEM). The general objective of the suggested AEM programme is to acquire stereoscopic imagery covering the world's land masses. The most immediate use of the data is in exploration geology, however the data should satisfy a strong need in a more diverse set of disciplines including basic geology, environmental studies, engineering studies and cartography.

The technical objectives of the proposed mission are to demonstrate the usefulness of acquiring and using stereoscopic data on a global scale and to demonstrate the practical application of the "pushbroom" line-scan imaging technique. To satisfy these objectives, the proposed satellite would have the following technical specifications; resolution 15-20 m, swath width 30 km, coverage land mass to plus/minus 80 lat. and coverage of at least three full cycles/year.

These four vehicles are not being designed specifically with the wildlife biologist in mind. However, we all agree that to date Landsat imagery has been a most useful tool. There is no doubt in my mind that Landsat-D will receive very close attention and will sense data which will be immediately applicable by wildlife scientists. The other satellites, Seasat, SPOT and AEM are as yet unknown quantities. If Seasat lives up to its expectations there appears to be every reason for marine biologists, at least, to look forward to it providing a tremendous amount of valuable data.

The mental images which SPOT and the AEM present are very exciting. Imagine being able to interpret your favourite wildlife habitat in stereo from imagery sensed from space! These satellites may be many years away from reality but when they are launched terrain scientists and wildlife biologists will have mapping tools of considerable strength.

I have, I am afraid let my biases for remote sensing technology show rather clearly by down-playing thermal sensing and radar in favour of photography and satellites. This was intentional for two reasons. The first is that you will be hearing shortly from John Richardson on radar and Mark Wride will present a paper on thermal scanning in the poster session. The second reason is that except for special situations radar and IR thermal scans are not of universal application to the wildlife biologist.

I believe that emphasis should be placed on perfecting photographic and satellite data acquisition and interpretation techniques. Photographs or electronically generated images are perhaps the greatest data collection and storage systems available to man. Carefully guarded and maintained they will store a scene frozen in time for an unknown amount of time. Acquiring and storing imaged data is usually not a problem - interpretation is. It is up to the scientist to extract from the photograph the information which is germaine to his field of endeavour. The information which he obtains will be accurate and objective and not subject to the biases which are inherent in conclusions drawn by fleeting glances of the scene passing below. Armed with such data, the biologist is better able to face the task for husbanding the resource for which he is responsible because the decisions he will make will be based more on quantifiable facts and less on guess work.

LITERATURE CITED

Avery, T.E. 1958. Helicopter stereo-photography of forest plots. Photogramm. Engng. 24.

Bartholomew, G.A. and C.J. Pennycuick. 1973. The flamingo and pelican populations of the Rift Valley lakes in 1968-69. E. Afr. Wildl. J. , 11:189-198.

Bauer, A. 1963. Utilisation de la photographie verticale ā l'etude ornithologique des iles Australe: Dēnombrement des manchotieres de l'ile aux Cochons (Archipel de Crozet) et de l'ile de Kerguelen. TAFF. No. 25.

Bell, R.H.V., J.J.R. Grimsdell, L.P. Van Lavieran and J.A. Sayer. 1973. Census of Kafue lechwe by aerial stratified sampling. E. Afr. Wildl. Jr., 11 (1):55-74

Bell, W.B. 1937. Methods in Wildlife Census. Journal Amer. Statistical Assn. 32: 537-542.

Blockpoel, H. 1975. Radar studies of airborne bird movements. Workshop on Remote Sensing of Wildlife, Quebec, 18-20 November. Ed. J.D. Heyland.

Brassard, J. M. et F. Potvin. 1973. Etude biométrique d'un troupeau de caribous ā partir de photographies aériennes verticales. MS. Biological Res. Service. Que. Dept. of Tourism, Fish and Game.

Brooks, J.W. 1970. Infra-red scanning of polar bear In Bears and Their Management. IUCN Pub. No. 23, Calgary, 6-9 November.

Bruderer, B. and P. Steidinger. 1972. Methods of quantitative and qualitative analysis of bird migration with a tracking radar. Proc. of a Symposium on Animal Orientation and Navigation. NASA SP-262, Washington, D.C.

Chattin, J. 1952. Appraisals of California waterfowl concentrations by aerial photography. Trans. of the 17th North Amer. Wildl. Conf.

Colwell, R.N. 1964. Uses of aerial photography for livestock inventories. In Proc. Ann. Meeting, Agr. Res. Inst. Res. Counc.

Crofton, H.D. 1958. Nematode parasite populations in sheep on Lowland farms. VI. Sheep behaviour and nematode infections. Parasitology, 48(3 & 4):251-260.

Croon, G.W., D.R. McCullough, C.E. Olson, and J.M. Queal. 1968. Infrared scanning techniques for big game censusing. J. Wildl. Mgt. 32(4).

Croze, H. 1972. A modified photogrammetric technique for assessing age-structures of elephant populations and its uses in Kidepo National Park. E. Afr. Wildl. J., 10(2):91-115.

Driscoll, R.S. and T.C. Watson. 1974. Aerial photography for pocket gopher populations. Proc. Sym. on Remote Sensing and Photo Interp., Int. Soc. Photo. Commission VII.

Dudzinski, M.L. and G.L. Arnold. 1967. Aerial photography and statistical analysis for studying behaviour patterns of grazing animals. J. of Range Mgmt., 20(2):77-83.

Eastwood, E. 1967. Radar Ornithology. Methuen, London, 278 p.

Eicher, G.J., Jr. 1953. Aerial methods of assessing red salmon populations in western Alaska. J. Wildl. Mgmt., 17(4):521-527.

Gauthreaux, S.A., Jr. 1974. The detection, quantification and monitoring of bird movements aloft with airport surveillance radar (ASR). Proc. Conf. on the Biol. Aspects of the Bird/Aircraft Collision Program. (pp. 289-307) Clemson University, S.C.

Goddard, J. 1967. The validity of censusing black rhinoceros populations from the air. E. Afr. Wildl. J., 5:18-23.

Goddard, J. 1969. Aerial census of black rhinoceros using stratified sampling. E. Afr. Wildl. J., 7:105-114.

Graham, A. and R. Bell. 1969. Factors influencing the countability of animals. Proc. of the Workshop on the Use of Light Aircraft in Wildl. Mgmt. in East Africa. East African Agr. and For. Jour., Vol. XXXIV - Special Issue.

Graves, H.B., E.D. Bellis and W.M. Knuth. 1972. Censusing white-tailed deer by airborne thermal infra-red imagery. J. Wildl. Mgmt. 36:875-884.

Grzimek, M. and B. Grzimek. 1960. Flamingoes censused in East Africa by aerial photography. J. Wildl. Mgmt., 24(2):215-217.

Heyland, J.D. 1972. Vertical aerial photography as an aid in wildlife population studies. Proc. First Cdn. Sym. on Remote Sensing.

Heyland, J.D. 1973. Increase the accuracy of your airborne censuses by means of vertical aerial photographs. Trans. 27th Northeast Fish and Wildl. Conf.

Heyland, J.D. 1974. Aspects of the biology of beluga (Delphinapterus leucas Pallas) interpreted from vertical aerial photographs. Proc. Second Cdn. Sym. on Remote Sensing.

Heyland, J.D. 1975. Monitoring nesting success of greater snow geese by means of satellite imagery. Third of Canadian Symposium on Remote Sensing.

Hunter, G.N. 1945. Methods of determining trends in big game numbers and range conditions. Trans. Tenth N. Amer. Wildl. Conf., American Wildlife Institute.

Kelez, G.B. 1947. Measurement of salmon spawning by means of aerial photography. Pacific Fisherman, February.

Kerbes, R.H. and H.D. Moore. 1975. Use of current satellite imagery to predict the nesting success of lesser snow geese. Workshop on Remote Sensing of Wildlife, Quebec 18-20 November. Ed. J.D. Heyland.

Lavigne, D.M. and N.A. Øritsland. 1974. Ultraviolet photography: a new application for remote sensing of animals. C.J. Zool, 52(7).

Lavigne, D.M. and N.A. Øritsland. 1974. Black polar bears. Nature, 251(5472).

Lavigne, D.M., N.A. Øritsland, and A. Falconer. 1977. Remote sensing and ecosystem management. Skrifter Nr. 166, Norsk Polarinstitutt, Oslo.

Lavigne, D.M. and K. Ronald. 1975. Improved remote sensing techniques for evaluating seal populations. ICES C.M. 1975/N:12.

Leonard, R.M. and E. Fish. 1974. An aerial photographic technique for censusing lesser sandhill cranes. Wildl. Soc. Bull., 2(4):191-195.

Leedy, D.L. 1948. Aerial photographs, their interpretation and suggested uses in wildlife management. J. Wildl. Mgmt. 12(2).

Leedy, D.L. 1960. Photo interpretation in wildlife management. In Manual of Photographic Interpretation, Am. Soc. of Photogrammetry. Ed. Robert N. Colwell, pp. 868.

Lenco, M. 1976. Essai de dénombrement du gros gibier en forêt de plaine par télédétection aérienne à basse altitude en infra-rouge thermique. Min. de la Culture et de l'environnement. Unpub. MS 8 pp. 37 + photos.

McCullough, G.W., C.E. Olson, and L.M. Queal. 1968. Progress in large animal census by thermal mapping. In Remote Sensing in Ecology. U. of Georgia Press. Ed. P.O. Johnson.

Mansfield, A.W. 1970. Population dynamics and exploitation of some arctic seals. In Antarctic Ecology, Vol. 1. Ed. M.W. Holage, Academic Press, New York.

Myres, M.T. 1964. Technical details of radar equipment detecting birds, and a bibliography of papers reporting the observation of birds with radar. Nat. Res. Council Can., Ass. Comm. Bird Hazards to Aircraft, Ottawa, Field Note 9, 20 p.

Myres, M.T. 1969. The detection of birds, and study of bird movements, with radar. In Proc. World Conf. Bird Hazards to Aircraft, Kingston, Ontario, 2-5 Sept. 1969. p. 501-519.

Norton-Griffiths, M. 1973. Counting the Serengeti migratory wildebeest using two-stage sampling. E. Afr. Wildl. J., 11:135-149.

Norton-Griffiths, M. 1974. Reducing counting bias in aerial census by photography. E. Afr. Wildl. J., 12:245-248.

Øritsland, N.A., J.W. Lentfer, and K. Ronald. 1974. Radiative surface temperatures of the polar bear, J. Mammal. 55(2).

Pennycuick, C.J. and D. Western. 1972. An investigation of some sources of bias in aerial transect sampling of large mammal populations. E. Afr. Wildl. J., 10:145-191.

Perkins, D.F. 1971. Counting sheep, cattle and ponies on Dartmoor by aerial photography. The application of aerial photography to the work of the Nature Conservancy. Ed. R. Goodier.

Ray, G.C. and D. Wartzok. 1975. Synergistic remote sensing of walrus and walrus habitat. Workshop on Remote Sensing of Wildlife. Quebec. Ed. J.D. Heyland.

Reeves, H.M., Fr. Graham Cooch and R.E. Munro. 1976. Monitoring Arctic habitat and goose production by satellite imagery. J. Wildl. Mgmt., 40(3).

Richardson, W.J. 1972. Temporal variations in the abilities of individual radards in detecting birds. Nat. Res. Council of Canada, Assoc. Comm. on Bird Hazards to Aircraft, Field Note 61.

Sergeant, D.E. 1965. Exploitation and conservation of harp and hood seals. The Polar Record., 12(80):541-551.

Sinclair, A.R.E. 1972. Long term monitoring of mammal populations in the Serengeti: census of non-migratory ungulates, 1971. E. Afr. Wildl. J., 10:287-297.

Sinclair, A.R.E. 1973. Population increases of buffalo and wildebeest inthe Serengeti. E. Afr. Wildl. J., 11:93-107.

Spinner, G.P. 1946. Improved method for estimating numbers of waterfowl. J. Wildl. Mgmt. 10(4):365.

Spinner, G.P. 1949. Observations on greater snow geese in the Deleware Bay Area. Auk 66(2).

Stegeman, L.C. 1939. The use of three dimensional, photography in wildlife studies. Trans. Fourth N. American Wildl. Conf.

Vaughan, R.W. 1971. Aerial photography in seal research. The application of aerial photography to the work of the Nature Conservancy. Ed. R. Goodier.

Williams, P.G. 1978. Wingtip stereo photography. Symposium on Remote Sensing for Vegetation Damage Assessment, Seattle Washington.

Wride, M.C. and K. Baker. 1977. Thermal imagery for census of ungulates. Proc. 11th Int. Symp. of Remote Sensing of Envir., Univer. of Michigan Extension Ser.

Radar Techniques for Wildlife Studies[1]

W. John Richardson[2]

Abstract.--This paper reviews (1) the capabilities and limitations of various types of radars for detecting and studying airborne animals (birds, bats, insects), (2) factors affecting detection range, (3) the 'state of the art' of target identification, and (4) promising radar techniques for future wildlife studies.

§1. INTRODUCTION

Radars transmit radio energy into the airspace, detect any echoes that are returned, and display information about those echoes. The radio emissions are usually short, widely-spaced pulses, so distance to an echo-producing target can be determined from the time taken for the echo to return. Emissions are beamed in a particular direction, so the direction of the target is also known.

Radars are usually designed to detect aircraft, missiles, mortar shells, ships, buoys, terrain, or severe weather. However, airborne birds, bats and even insects are sometimes detectable. Measurable parameters can include (depending on radar and target type) numbers aloft, concentration areas, altitudes, flight directions and speeds, approximate target sizes, and wingbeat frequencies. With moderate- or high-power radars, at least some of these parameters are measurable at least several km away, in daylight or darkness, and sometimes above or even in clouds. Data can often be recorded photographically, thus facilitating continuous monitoring. For these reasons, radars have become the principal tools in studies of 'bird migration in progress'. Applications include estimating numbers migrating over an area (e.g., Alerstam 1977) and studies of migration timing re weather (Richardson 1978), routes (e.g., Bellrose 1964), orientation (e.g., Emlen & Demong 1978), flight physiology (e.g., Emlen 1974; Schnell 1974) and local 'roosting' movements (e.g., Eastwood *et al.* 1962; Williams *et al.* 1973). Radars are also widely used in bird hazard to aircraft studies (Blokpoel 1976).

Unfortunately, radars also have severe limitations in wildlife studies. Targets are usually difficult to identify, and adjacent targets (e.g., individual birds within flocks) are not resolved. Results are often not quantitative, detection probability often depends on altitude, and fast-moving flocks are often overrepresented (Richardson 1972a, 1978). Care must be taken to recognize the various limitations, and to avoid or compensate for them whenever possible.

Operational radars first appeared during World War II, and birds and insects sometimes were detected even by these comparatively low-powered instruments. However, biologists did not use radars to any significant extent until the late 1950's (for birds), mid-1960's (insects) or late 1960's (bats). While radars can detect certain objects on the ground (see §5), to date biologists have used radars only to detect airborne animals--primarily birds. Myres (1970) gives a comprehensive (to 1969) list of papers reporting detection of birds, bats and insects, and Eastwood (1967) gives a detailed summary of 'radar ornithology' up to the mid-1960's. Schaefer (1976) and Ireland *et al.* (1976) are recent detailed accounts of insect and bat detection by radar.

§2. TYPES OF RADARS

Almost any type of radar can be useful in certain wildlife studies but capabilities vary widely. Powerful radars give a broad but often only qualitative view; smaller radars reveal more detail about individuals, but only in a local area. Tracking radars provide more detail than surveillance radars, but require continuous attention and more data processing. Some problems can only be addressed by using two disparate radars simultaneously. General accounts of radar technology include Barton (1964), Nathanson (1969) and Skolnik (1970). Information about most specific radar

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models can be found in one or more of Anon. (1965), Battan (1973:276*ff*), Barton (1975), *Jane's Weapon Systems*, various issues of *Aviation Week & Space Technology*, and the catalogue of Radio-Research Instrument Co. (3 Quincy St., Norwalk, Conn.). All types of radars in Table 1 have been used in ornithological studies, and some in bat and insect studies.

The well-known 'Plan Position Indicator' or PPI display (Fig. 1) is used with radars whose beams rotate horizontally (Table 1A,B). Number, extent and positions of echoes are directly evident on the PPI, and flight directions and speeds become evident over time as the echoes move. Time exposures (Fig. 2) and time-lapse techniques (Phelp & Downie 1962; Solman 1969; Williams & Mix 1973; Yacobi & Baturov 1974) are used to record data for subsequent analysis. The chief limitations of

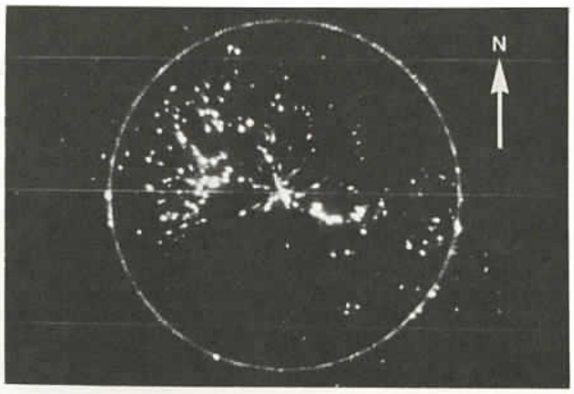


Figure 1.--Southeastward bird migration visible on PPI of ASR-5 airport surveillance radar near Halifax, N.S. Each echo is a bird or flock. Circle denotes radius of 5 n.mi.(9¼ km).

Table 1.--Characteristics and applications (emphasizing bird studies) of various radar types. ++ = very suitable, + = suitable, ± = some capability (often difficult), - = unsuitable.

Radar type	Typical characteristics				Beam width[4]		Parameters measurable[5]									
	Band[1]	kW Peak Power	Range[2]	Pulse Duration[3]	Horizont.	Vertical	Chronology	Routes	# Flocks	# Birds	Bearing	Distance	Height	Course/Speed	Grouping	Signature
A. FAN-BEAM SEARCH																
Ship navigation	X-S	25	S	SM	2°	20°	+	±	+	+	++	++	-	++	±	-
Airport surveil.	S	400	SM	M	1½	20	++	±	++	±	++	++	-	++	-	-
Air route; military	S,L	5,000	ML	ML	1	10	++	++	++	-	++	+	-[6]	+	-	-
B. PENCIL-BEAM SEARCH																
Weather surveil.	C,S	500	ML	ML	2	2	++	++	±	+	++	++	±	++	-	-
Mod. Ship/Airborne[7]	X	25	S	SM	2	2	+	±	-	+	++	++	+	+	±	±
Tracking (search mode)[8]	X-	40-	SM	SM	1-2	1-2	±	±	±	±	++	++	+	+	±	-
	S	5,000	ML	M	½-1	½-1	±	+	±	±	++	++	+	+	-	-
C. HEIGHT FINDERS																
Precision approach	X,C	150	S	SM	5	1	±	-	±	±	±	++	++	-	±	-
Surveillance	C,S	4,000	ML	M	3	1	±	±	±	-	±	+	+	-	-	±
D. VERTICAL BEAM	X	25	S[9]	SM	2	2	+	-	-	+	-	-	++	-	±	±
E. TRACKING[8]	X-	40-	SM	SM	1-2	1-2	-	-	-	-	++	++	++	++	+	++
	S	5,000	ML	M	½-1	½-1	-	±	-	-	++	++	++	++	+	++

[1]See §3 for band (wavelength) designations.
[2]Usable range for biological targets; S=short (<5 km), M=Medium (5-30 km), L=Long (>30 km).
[3]Short (<½ μsec), Medium (½-2 μsec) or Long (>2 μsec); corresponding range resolutions are <75 m, 75-300 m and >300 m.
[4]Corresponding resolutions (in km) ≈ Range (km) x sine (Beamwidth).
[5]Parameters 1-4 concern multiple targets; 5-10 concern individual targets.
[6]Roughly measurable on multiple-beam (3 dimensional) radars.
[7]Ship navigation or aircraft weather radar with dish antenna (see Graber & Hassler 1962; Schaefer 1976).
[8]Upper and lower lines give characteristics of low and high power trackers, respectively.
[9]Range is measured vertically in this case.

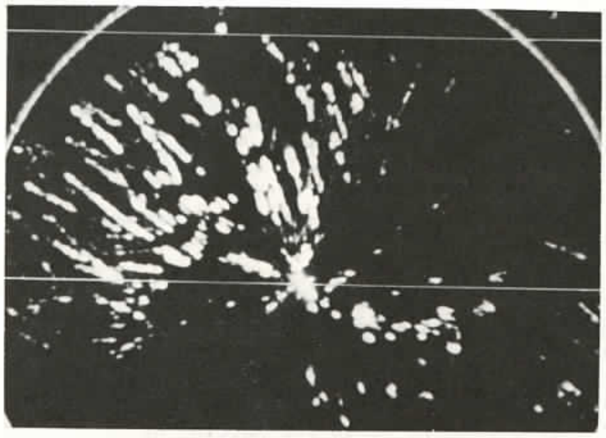


Figure 2.--Time exposure (1.75 min) of PPI of Halifax ASR-5 radar. Each streak is the path of a bird or flock going ∿SE.

fan-beam search radars are (1) lack of height data, (2) poor resolution and inability to detect low-flying targets at long range, (3) suppression of some weak echoes by special circuitry--see §3, and (4) lack of detail about single targets. Pencil-beam search radars provide height data, but do not scan the entire airspace. Weather radars are especially useful because they are calibrated to permit measurement of echo intensity (Gauthreaux 1970, 1974).

The 'Range Height Indicator' or RHI display (Fig. 3) can be used with pencil-beam and specialized height-finding radars when the beam nods up and down. Height-finding is the main application, but some other parameters can be measured (Table 1B,C). When targets are numerous, resolution on long-range height finders is often inadequate for quantitative studies (Fig. 3). Precision approach radars have much better resolution and accuracy, but may not detect high-altitude biological targets (e.g., Sutter 1957; Hunt & Blokpoel 1973).

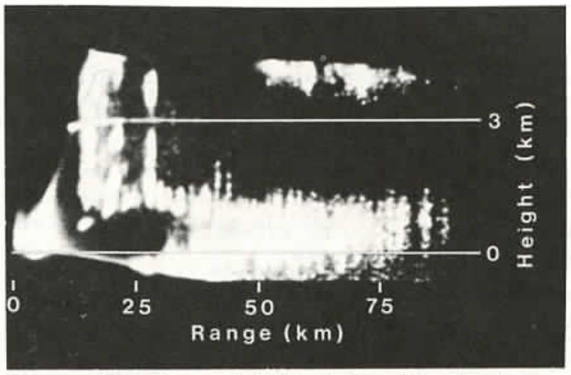


Figure 3.--Range Height Indicator showing dense layer of unresolvable bird echoes at low altitude and cloud ∿4 km aloft. Within 30 km birds are hidden by terrain echoes.

A 'Time vs Height' record can be obtained from a radar having a fixed vertically-pointed beam. From this, numbers aloft at various heights and times can be determined (Table 1D).

Tracking radars have been used, since the late 1960's, to obtain more detailed information about single bird, bat or insect targets (often single individuals). The beam of a tracking radar, once pointed at an object, automatically follows it across the sky. Echo strength and position (in 3 dimensions) are recorded with every pulse--several hundred times/sec. Wingbeat frequency and 'flap-glide' pattern can often be determined from the 'amplitude signature' (Fig. 4). Some tracking radars can also record the Doppler shift of the echo. Tracking radars can also be used in a search, height-finding or vertical beam mode. For techniques, see Bruderer & Steidinger (1972), Williams & Williams (1972); for examples of precision applications, see Larkin *et al.* (1975), Able (1977), Emlen & Demong (1978). A brief discussion of Doppler radars is included as an Appendix.

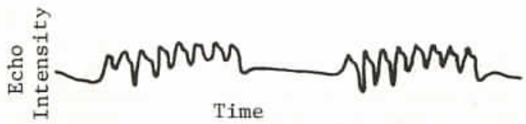


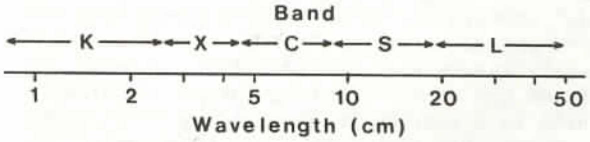
FIGURE 4.--Amplitude signature of a White-throated Sparrow tracked by FPS-16 C-band monopulse tracking radar (from Williams & Williams 1972). Two 'flapping' periods (each with 8 wingbeats) separated by 'glide' periods are shown. Record length is 1½ sec.

§3. RANGE CAPABILITY

Radars can detect small animals at surprisingly long distances. One reason is that an inverse square spreading rule applies to both outgoing and returning energy. Hence, a target with 0.0001 times the cross-sectional area of another (e.g., bird vs aircraft) can be detected 0.1 times as far away. Also, water (the main component of animal tissue) reflects a high proportion of the incident radar energy--about 60% as much as would a comparably-sized metal object. Furthermore, the average echo intensity from a group of targets too close to be resolved is the sum of their individual echo intensities. Thus, a flock of waterfowl can produce 'point' echo comparable to that from a small aeroplane. Maximum detection ranges of the 3 radar types listed in Table 1A would be about ½, 5 and 35 km for a single Starling, and 5, 50 and 150 km for a large flock of geese.

On a long-range low resolution radar (3 μs pulses; 1° horizontal beam width), targets at all heights above a 450 x 700 m area would be unresolved at a range of 40 km. Every such volume of airspace will contain at least 10 small birds when even a modest broad-front nocturnal migration is in progress, and 50+ birds during a dense broad-front migration. Echoes from such migrations often saturate radar displays at ranges of 0-45 km.

Most radars produce energy with a specific wavelength within the range 1-50 cm. This range is traditionally divided into several bands:



The intensity of echo from large targets is proportional to target cross section. However, when target dimensions(d) are small re wavelength (λ), echo intensity $\propto d^6/\lambda^4$. Thus, rain drops produce far more echo than the smaller droplets in clouds. Clouds and rain both produce far more echo at K or X band than at S or L band. Radars designed to detect weather systems operate at short or moderate wavelengths; those to detect aircraft often operate at longer wavelengths to minimize weather echo. Similarly, insects produce strong echoes only at short wavelengths, whereas birds (and presumably bats) produce strong returns at all but the longest radar wavelengths (Glover *et al.* 1966; Konrad *et al.* 1968). In practice, insect echoes can be a significant source of confusion in ornithological studies with X-band radars (e.g., Bruderer 1971; Blokpoel & Burton 1975), but are rarely detectable at normal working ranges on S- and especially L-band radars.

Average echo strength from an aircraft, bird or insect (and presumably bat) is larger when the broadside rather than the head or tail aspect faces the radar (Edwards & Houghton 1959; Bruderer & Joss 1969; Houghton 1969; Nathanson 1969; Schaefer 1976). Thus, targets are often detected at greater range if moving tangentially than if moving radially, and unidirectional, broad-front bird or insect flights often saturate a roughly elliptical rather than circular area of the PPI (e.g., Richardson 1976:Plate 5; Schaefer 1976:162*ff*). However, many radars, especially those designed for aircraft detection, have Moving Target Indicator (MTI) circuits, which suppress echoes from targets that have little or no radial velocity. MTI is useful for detecting birds in the presence of echo from terrain, but with MTI only the birds moving at least partly towards or away from the radar are detectable (Fig. 2). Even they are partly suppressed, especially if a headwind reduces their ground speed. MTI and other radar circuits are often necessary, but can seriously reduce detection range and the usefulness of radars as quantitative instruments (Richardson 1972a).

§4. IDENTIFICATION

Uncertainty about target identity is one of the main limitations of radar. Visual identification is only occasionally possible, since one of the main uses of radar is to detect targets that cannot be seen. Echo characteristics and behaviour usually form the only available basis for partial or complete identification.

Useful visual information can, on occasion, be obtained in at least four ways: (1) An observer in an aircraft or ground vehicle can be directed by radio to the location of a radar target (Hofmann 1956). However, this method is expensive and difficult, especially at night (but see Weitnauer 1956) or if the radar has no height-finding ability. (2) A telescope mounted on the antenna of a tracking radar can be used to identify nearby targets in daylight (e.g., Harper 1958; Gehring 1967; Houghton 1969; Ireland & Williams 1974). (3) A sighting of a bird or flock can occasionally be associated at a later time with a specific echo visible on a radar photograph, but only if few targets are present or if the target is very intense or distinctive, such as a dispersal from a bird or bat roost, or a waterfowl flock (Sutter 1957; Eastwood *et al.* 1962; Gehring 1963; Grimes 1973; Williams *et al.* 1973; Blokpoel 1974). (4) If general visual observations show that one species predominates, that species is probably the one responsible for corresponding activity detectable simultaneously by radar; however, the radar might also be detecting high-altitude, invisible targets.

Echo characteristics and behaviour provide many clues about target identity. Inanimate targets are usually easily recognized, especially on time-lapse PPI films:

- terrain produces intense, extensive, stationary echoes
- vehicles produce point echoes that move along consistent routes
- waves give non-persistent, scintillating echoes
- ships give intense, slow-moving echoes
- aircraft echoes move rapidly; often disappear at known airports
- precipitation and cloud echoes are usually

extensive; often characteristic in shape; move slowly in a uniform direction

In contrast, birds, bats and insects produce point echoes, often weak, that move slowly in variable directions; when many are aloft, the point echoes merge into an extensive mass of echo at close range, but are resolved around the edges of the mass.

Bat echoes have been little studied, but seem generally similar to bird echoes. Bats fly almost exclusively at night, often too low to be detected by radar. When they leave large roosts, 'blossoming' echoes can appear on the PPI; such echoes recur nightly, can often be identified visually, and can provide useful data about bat activity (Grimes 1973; Williams *et al.* 1973; Ireland *et al.* 1976). In much of North America, observations of silhouettes against the moon show bats to be much less numerous than nocturnal bird migrants, and thus an insignificant source of contamination during ornithological studies. With tracking radars, bats may be recognizable by their erratic paths and amplitude signatures (Bruderer 1969), but more study is needed.

Insects are detected primarily by short-wavelength radars (§3). In comparison with birds, echo intensities and airspeeds tend to be lower, and wingbeat rates (sometimes evident from amplitude signature if a tracking radar is used) tend to be higher. However, large insects and small birds can be difficult to distinguish, especially when only echo intensity (not track, speed or signature) is recordable (e.g., Blokpoel and Burton 1975). Schaefer (1976) discusses use of signatures to distinguish major groups of insects.

Birds can often be identified to major group from the behaviour of their echoes. Daily local movements of blackbirds, Starlings, gulls or waterfowl to and from roosts are very characteristic and amenable to visual verification. Migration departures from such roosts are also occasionally evident (e.g., Harper 1959; Richardson & Haight 1970). Migrating hawks are often recognizable by their tendency to fly at mid-day and to form lines of echoes (Gehring 1963; Houghton 1970; Richardson 1975). Sometimes a species or group is known to migrate in an unusual direction at a specific season, and corresponding echoes appear on radar (e.g., Richardson in press). Nocturnal, broad-front migrations of passerines are recognizable by the rapid appearance of immense numbers of weak, slow-moving echoes about ½ hr after sunset.

The detailed characteristics of individual echoes recordable on tracking radars provide further clues to identity. Airspeed, echo intensity, wingbeat rate, and the temporal pattern of flapping and gliding are all potentially useful. However, for most of these variables there is both overlap among species and intra-specific variation (Bruderer *et al.* 1972; Emlen 1974; Vaughn 1974; Pennycuick 1975). Seemingly appropriate multivariate classification methods have not yet been applied to the identification problem. Another complication is that echo intensities and signatures become much more difficult or impossible to interpret when the target consists of more than one bird (Houghton 1969; Houghton & Blackwell 1972; Flock 1974).

In summary, reliable identification to species level is now rarely possible from echo behaviour or characteristics alone. Improvements are possible by making more use of the data contained in echo signatures, but physical differences among many species are so slight that their echoes will remain indistinguishable in the foreseeable future. Fortunately, species-level identification is not essential in some types of studies, since related species often behave similarly.

§5. FUTURE OPPORTUNITIES

Foreseeable opportunities for expanded use of radars in wildlife studies are of two kinds: (1) use of standard methods and presently available radar equipment in circumstances where they are not now used, and (2) development of new methods and applications.

Several hundred medium- and high-power search radars (air traffic control, military, weather) suitable for ornithological studies are presently operating in North America. Locations of most can be found by reference to the FAA Air Traffic Service Fact Book, Macdonald (1971:22), Scholin (1977) and aeronautical maps, or by contacting the operating agencies (FAA, NOAA and USAF in the U.S.A.; MoT, AES and CAF in Canada). It is often possible to obtain biological data from such radars while they are being used for their normal purpose, or when they are not being used. Local and migratory movements of birds have been studied at only a small minority of these sites. These radars are suitable for studies of the patterns, routes and timing of bird movements. Such radars have also been used to study bat movements, but in most areas it is doubtful whether bats are sufficiently common or concentrated for search radar to be a useful technique.

Because bird migration is inherently a large-scale phenomenon, some aspects can only be understood if simultaneous observations are made over an area even larger than that covered by a long-range radar (Lowery & Newman 1966). Simultaneous studies at several radar sites are possible (Bellrose 1964; Richardson & Gunn 1971) but logistically difficult. Flock & Bellrose (1970) showed that several widely-separated radars could be monitored successfully at an FAA Air Route Traffic Control Centre, and Beason (1978) used this capability to monitor six radars simultaneously over 4 migration seasons. However, radar data are now digitized before transmission to civil and military control centres. Although some bird echoes are digitized and transmitted (Richardson 1971, 1972b), a variable but often large fraction are suppressed by special radar circuitry or the digitizer. Thus, radar data from remote sites are now highly biased and unsuitable for quantitative studies (Richardson 1972a), and a valuable source of broad-scale data no longer exists.

The continuing development of procedures that suppress non-aircraft echoes from aircraft surveillance radars (Klass 1973; Brown & Nucci 1975; East 1975; Hartley-Smith 1975; Taylor & Brunins 1975) makes it increasingly difficult to obtain unprocessed and relatively unbiased radar signals even at the individual radar sites. However, advances in search radar design are not all detrimental for purposes of studying wildlife. Pulse compression techniques can be applied to improve range resolution without decreasing maximum range. Doppler discrimination techniques can be used to enhance detection of small moving objects. Moving target detectors can now be built to consider azimuthal as well as radial motion (Anon. 1975). These features are not available on most existing radars, but can be expected to become more widely used.

Small search radars generally have the advantages of high resolution, portability, absence of circuits that suppress biological targets, and sufficiently modest cost and maintenance requirements to permit full-time use in biological studies. Such radars have been used infrequently to date (Graber 1968; Schaefer 1976; Williams *et al.* 1976), but would be valuable for many applications in which high resolution and quantification are critical. Their portability can partially compensate for their short range.

Use of radars in studies of terrestrial (as opposed to airborne) animals has rarely been mentioned. Gulls and other moderate or large sized birds resting on runways and other smooth surfaces can be detected by airport surface detection (ASDE) radars (W.F. Inglefield, in Busnel & Giban 1965:135; Schaefer 1969; Gauthreaux 1976). ASDE radars are used at some major airports to assist in controlling ground traffic, and might be useful in revealing bird hazards to aircraft, especially in poor visibility conditions. Personnel-detection radars might be useful for detecting large mammals, especially at night, but such radars are not yet generally available and it is not clear what advantages they would have over other sensors. Side-looking airborne radars (SLAR) are potentially valuable for studies of animal habitat, especially when resolution is enhanced by synthetic aperture techniques (de Loor 1976), but to my knowledge SLAR has not proven useful for direct detection of animals.

To date few biologists have used tracking radars despite their unparalleled capabilities in studies of the flight behaviour and orientation of airborne animals. In the cases of insects and bats, the only tracking radar work has been methodological rather than biological. Accessibility is a major limitation, since most tracking radars are operated by the military at locations where missiles are launched. However, a few civil tracking radars are operated by NASA and for weather research. Military surplus trackers have been used to advantage (e.g., Schaefer 1968; Griffin 1973; Larkin *et al.* 1975; Able 1977), but these often suffer from maintenance difficulties and have minimal provisions for recording data. Also, modern monopulse trackers provide more precise positional and signature data than older 'conical scan' trackers (Barton 1964; Skolnik 1970).

Beams of recent 'phased array' radars are steered electronically rather than by physical movement of the antenna (Kahrilas 1976). This allows great flexibility in scanning pattern, and allows instantaneous repositioning of the beam. On some radars the latter feature, in conjunction with computer control, permits interleaved tracking of two or more targets. This capability could facilitate studies of the spacing of airborne animals (*cf.* Eastwood & Rider 1966; Bruderer 1971; Balcomb 1977) and their reactions to aircraft (*cf.* Larkin *et al.* 1975). Phased-array radars have apparently not yet been used in biological studies.

In both biological and non-biological applications of radar, a main challenge is to find ways of recording and interpreting the large amount of potentially useful information contained in the echoes. Important advances are possible here. In search radar studies, numbers aloft are usually recorded by subjective examination of the PPI display or, less often, by laborious manual counting of echoes. Electronic counting methods have been developed (Clausen 1973; Hunt 1975-77) but in North America have been little used. Also, calibrated attenuation methods can be used to record the echo amplitude information that is normally suppressed by the PPI (Gauthreaux 1970, 1974; Hunt 1973). Extraction of information about flight directions from PPI photographs could be greatly facilitated by electronic aids (e.g., X-Y digitizers) that are now readily available.

Some radars have provisions to digitize echo position and amplitude for on-line or off-line computer processing. Such capabilities have rarely been used in biological studies, although several workers have made analogue tape recordings of radar signatures for subsequent digitization and computer analysis. Recent advances in electronics permit direct transfer of selected data from the receiver of any type of radar to a computer, at modest cost, even on radars not originally designed for such data acquisition (Larkin & Eisenberg 1978). Linkage of radars with computers can provide several advantages in wildlife studies: (1) More data can be made available with less need for time-consuming manual steps like photo interpretation. (2) Less distortion of data (e.g., echo amplitude) occurs, since analogue circuits and recorders with limited dynamic range or frequency response can be avoided. (3) Analysis of amplitude and Doppler signatures as clues to identity or flight behaviour is facilitated, since computation-intensive autocorrelation and spectrum analysis techniques are valuable in interpreting radar signatures. (4) Computer control of radar scanning or tracking pattern becomes a possibility on radars dedicated to wildlife studies. When item (4) becomes a reality, complex observation programs (e.g., Bruderer 1971) should be possible even when the radar is unattended.

§6. LITERATURE CITED

Able, K.P. 1977. The flight behaviour of individual passerine nocturnal migrants: a tracking radar study. Anim. Behav. 25: 924-935.

Alerstam, T. 1977. [How many Wood Pigeons *Columba palumbus* leave south Sweden in autumn?] Vår Fågelv. 36: 14-20. (Swedish, Eng. summary).

Anonymous. 1965. US radar catalogue. Interavia 20: 59-62.

-----. 1975. New target detector sifts out clutter. Av. Wk. & Space Tech. (8 Sept.): 49-51.

Balcomb, R. 1977. The grouping of nocturnal passerine migrants. Auk 94: 479-488.

Barton, D.K. 1964. Radar system analysis. Prentice-Hall, Englewood Cliffs, N.J.

-----. 1975. Real-world radar technology. pp. 1-22 *In*: IEEE 1975 Int. Radar Conf. IEEE, N.Y.

Battan, L.J. 1973. Radar observation of the atmosphere. Univ. Chicago Press, Chicago.

Beason, R.C. 1978. The influences of weather and topography on water bird migration in the southwestern United States. Oecologia 32: 153-169.

Bellrose, F.C. 1964. Radar studies of waterfowl migration. Trans. N.Am. Wildl. Nat. Resour. Conf. 29: 128-143.

Blokpoel, H. 1974. Migration of Lesser Snow and Blue Geese in spring across southern Manitoba. Part 1. Can. Wildl. Serv. Rep. Ser. 28, 29 p.

-----. 1976. Bird hazards to aircraft. Clarke, Irwin & Co., Toronto.

Blokpoel, H. & J. Burton. 1975. Weather and height of nocturnal migration in eastcentral Alberta: a radar study. Bird-Banding 46: 311-328.

Brown, B.M. & G. Nucci. 1975. Evolution of primary radars for air traffic control. Interavia 30: 1287-1290.

Bruderer, B. 1969. Zur Registrierung und Interpretation von Echosignaturen an einem 3-cm-Zielverfolgungsradar. Orn. Beob. 66: 70-88.

-----. 1971. Radarbeobachtungen über den Frühlingszug im Schweizerischen Mittelland. Orn. Beob. 68: 89-158.

-----, B. Jacquat & U. Brückner. 1972. Zur Bestimmung von Flügelschlagfrequenzen tag- und nachtziehender Vogelarten mit Radar. Orn. Beob. 69: 189-206.

----- & J. Joss. 1969. Methoden und Probleme der Bestimmung von Radarquerschnitten frei fliegender Vögel. Rev. Suisse Zool. 76: 1106-1118.

----- & P. Steidinger. 1972. Methods of quantitative and qualitative analysis of bird migration with a tracking radar. pp. 151-167 *In:* NASA SP-262, Washington.

Busnel, R.-G. & J. Giban (ed.). 1965. Le problème des oiseaux sur les aérodromes. Inst. Nat. Rech. Agron., Paris.

Clausen, P. 1973. Results and description of electronic counting of birds. 8th Mtg. Bird Strike Comm. Europe, Paris. Mimeo.

de Loor, G.P. 1976. Radar methods. pp. 147-186 *In:* Remote censusing for environmental sciences. Springer-Verlag, Berlin.

East, T.W.R. 1975. A family of solid state air traffic control radars. pp. 318-323 *In:* IEEE 1975 Int. Radar Conf. IEEE, N.Y.

Eastwood, E. 1967. Radar ornithology. Methuen, London.

-----, G.A. Isted & G.C. Rider. 1962. Radar ring angels and the roosting behaviour of Starlings. Proc. Roy. Soc. B 156: 242-267.

----- & G.C. Rider. 1966. Grouping of nocturnal migrants. Nature 211: 1143-1146.

Edwards, J. & E.W. Houghton. 1959. Radar echoing area polar diagrams of birds. Nature 184: 1059.

Emlen, S.T. 1974. Problems in identifying bird species by radar signature analyses: intra-specific variability. pp. 509-524 *In:* Proc. Conf. Biol. Aspects Bird/Aircraft Collision Probl. Clemson Univ., S.C.

----- & N.J. Demong. 1978. Orientation strategies used by free-flying bird migrants: a radar tracking study. *In:* Proc. Symp. Anim. Migr., Orient. Homing. Springer Verlag, Berlin.

Flock, W.L. 1974. The identification of birds by radar. pp. 429-442 *In:* Proc. Conf. Biol. Aspects Bird/Aircraft Collision Probl. Clemson Univ., S.C.

----- & F.C. Bellrose. 1970. A radar study of bird migration in the central United States. pp. 273-283 *In:* Proc. World Conf. Bird Hazards to Aircraft. Nat. Res. Counc. Can., Ottawa.

----- & J.L. Green. 1974. The detection and identification of birds in flight, using coherent and noncoherent radars. Proc. IEEE 62: 745-753.

Gauthreaux, S.A., Jr. 1970. Weather radar quantification of bird migration. BioScience 20: 17-20.

-----. 1974. The observation of birds with weather and airport surveillance radars. U.S. Air Force Weapons Lab. AFWL-TR-74-57, 50 p.

-----. 1976. The role of radar in the avoidance of bird/aircraft collisions. pp. 179-190 *In:* Proc. Bird Hazards to Aircraft Training Seminar and Workshop. Clemson Univ., S.C.

Gehring, W. 1963. Radar- und Feldbeobachtungen über den Verlauf des Vogelzuges im Schweizerischen Mittelland: Der Tagzug im Herbst (1957-1961). Orn. Beob. 60: 35-68.

-----. 1967. Analyse der Radarechos von Vögeln und Insekten. Orn. Beob. 64: 145-151.

Glover, K.M., K.R. Hardy, T.G. Konrad, W.N. Sullivan & A.S. Michaels. 1966. Radar observations of insects in free flight. Science 154: 967-972.

Graber, R.R. 1968. Nocturnal migration in Illinois--different points of view. Wilson Bull. 80: 36-71.

----- & S.S. Hassler. 1962. The effectiveness of aircraft-type (APS) radar in detecting birds. Wilson Bull. 74: 367-380.

Green, J.L. & B.B. Balsley. 1974. Identification of flying birds using a Doppler radar. pp. 491-508 *In:* Proc. Conf. Biol. Aspects Bird/Aircraft Collision Probl. Clemson Univ., S.C.

Griffin, D.R. 1973. Oriented bird migration in or between opaque cloud layers. Proc. Am. Philos. Soc. 117: 117-141.

Grimes, L.G. 1973. The potential bird and bat hazards to aircraft in the vicinity of the international airport at Accra, Ghana. Ghana J. Sci. 13: 10-19.

Harper, W.G. 1958. Detection of bird migration by centimetric radar - a cause of radar 'angels'. Proc. Roy. Soc. B 149: 484-502.

-----. 1959. Roosting movements of birds and migration departures from roosts as seen by radar. Ibis 101: 201-208.

Hartley-Smith, A. 1975. The design and performance of a modern surveillance radar system. pp. 306-311 *In:* IEEE 1975 Int. Radar Conf. IEEE, N.Y.

Hofmann, H. 1956. Kiebitze auf dem Radarschirm. Orn. Beob. 53: 79-81.

Houghton, E.W. 1969. Radar track of two crows. Roy. Radar Estab. Memo. 2483, 25 p.

-----. 1970. Spring migration at Gibraltar. Roy. Radar Estab. Memo. 2593, 33 p.

----- & F. Blackwell. 1972. Use of bird activity modulation waveforms in radar identification. Bird Strike Comm. Europe, Paris 1972, 31 p.

Hunt, F.R. 1973. Bird density and the Plan Position Indicator. ACBHA[3] Field Note 63, 14 p.

-----. 1975. Automatic radar equipment to determine bird strike probability. Part I. night-time passerine migration. ACBHA[3] Field Note 69, 24 p.

-----. 1976. The probability of bird-aircraft collisions based on radar data. ACBHA[3] Field Note 74, 19 p.

-----. 1977. Automatic radar equipment to determine bird strike probability. Part II. Migrating water-fowl flocks. ACBHA[3] Field Note 75, 18 p.

----- & H. Blokpoel. 1973. A bird height finding radar for air traffic control. A progress report. ERB-873, Radio Elect. Eng. Div., Nat. Res. Counc. Can., Ottawa. 15 p.

Ireland, L.C. & T.C. Williams. 1974. Radar observations of bird migration over Bermuda. pp. 383-408 *In:* Proc. Conf. Biol. Aspects Bird/Aircraft Collision Probl. Clemson Univ., S.C.

-----, V.A. Harris, S.S. Ireland, T.C. Williams & J.M. Williams. 1976. Radar investigations of the bat hazard to high performance aircraft at Randolph AFB, Texas. U.S. Air Force Weapons Lab. AFWL-TR-75-146, 61 p.

Kahrilas, J.J. 1976. Electronic scanning radar systems (ESRS) design handbook. Artech House. 372 p.

Klass, P.J. 1973. FAA to evaluate new air route radar. Av. Wk. & Space Tech. (15 Sept): 51-53.

Konrad, T.G., J.J. Hicks & E.B. Dobson. 1968. Radar characteristics of birds in flight. Science 159: 274-280.

[3]Associate Committee on Bird Hazards to Aircraft, Nat. Res. Counc. Can., Ottawa.

Larkin, R.P., J.R. Torre-Bueno, D.R. Griffin & C. Walcott. 1975. Reactions of migrating birds to lights and aircraft. Proc. Nat. Acad. Sci. 72: 1994-1996.
----- & L. Eisenberg. 1978. A method for automatically detecting birds on radar. Bird-Banding 49: 172-181.
Lowery, G.H., Jr. & R.J. Newman. 1966. A continent wide view of bird migration on four nights in October. Auk 83: 547-586.
Macdonald, D.S. 1971. White paper on defence. Information Canada, Ottawa. 50 p.
Myres, M.T. 1970. The detection of birds and insects, and the study of bird movements, with radar. pp. 501-519 *In:* Proc. World Conf. Bird Hazards to Aircraft, Nat. Res. Counc. Can., Ottawa.
Nathanson, F.E. 1969. Radar design principles. McGraw-Hill, N.Y. 626 p.
Pennycuick, C.J. 1975. Mechanics of flight. pp. 1-75 *In:* Avian biology, Vol. 5. Academic Press, N.Y.
Phelp, N.R. & G. Downie. 1962. Radar recording. Brit. Kinematogr. 40: 4-14.
Richardson, W.J. 1971. Spring migration and weather in eastern Canada: a radar study. Am. Birds 25: 684-690.
-----. 1972a. Temporal variations in the ability of individual radars in detecting birds. ACBHA[3] Field Note 61, 68 p.
-----. 1972b. Autumn migration and weather in eastern Canada: a radar study. Am. Birds 26: 10-17.
-----. 1975. Autumn hawk migration in Ontario studied with radar. pp. 47-58 *In:* Proc. N. Am. Hawk Migr. Conf., Syracuse, N.Y., 1974.
-----. 1976. Autumn migration over Puerto Rico and the western Atlantic: a radar study. Ibis 118: 309-332.
-----. 1978. Timing and amount of bird migration in relation to weather: a review. Oikos 30: 224-272.
-----. in press. Southeastward shorebird migration over Nova Scotia and New Brunswick in autumn: a radar study. Can. J. Zool. 57.
----- & W.W.H. Gunn. 1971. Radar observations of bird movements in east-central Alberta. Can. Wildl. Serv. Rep. Ser. 14: 35-68.
----- & M.E. Haight. 1970. Migration departures from Starling roosts. Can. J. Zool. 48: 31-39.
Schaefer, G.W. 1968. Bird recognition by radar. A study in quantitative radar ornithology. pp. 53-86 *In:* Problems of Birds as Pests. Academic Press, London.
-----. 1969. An airport bird detection radar for reducing bird hazards to aircraft. Loughborough Univ. of Technol., U.K. 32 p.
-----. 1976. Radar observations of insect flight. pp. 157-197 *In:* Insect Flight. Blackwell, Oxford.
Schnell, G.D. 1965. Recording the flight-speed of birds by Doppler radar. Liv. Bird 4: 79-87.
Scholin, A.R. 1977. USAF in Alaska. Air Force Mag. 60(4): 39-44.
Skolnik, M.I. 1970. Radar handbook. McGraw-Hill, N.Y.
Solman, V.E.F. 1969. Photography in bird control for air safety. J. Biol. Photog. Assoc. 37: 150-155.
Sutter, E. 1957. Radar als Hilfsmittel der Vogelzugforschung. Orn. Beob. 54: 70-96.
Taylor, J.W., Jr. & G. Brunins. 1975. Long-range surveillance radars for automatic control systems. pp. 312-317 *In:* IEEE 1975 Int. Radar Conf. IEEE, N.Y.
Vaughn, C.R. 1974. Intraspecific wingbeat rate variability and species identification using tracking radar. pp. 443-476 *In:* Proc. Conf. Biol. Aspects Bird/Aircraft Collision Probl. Clemson Univ., S.C.
Weitnauer, E. 1956. Zur Frage des Nächtigens beim Mauersegler. Orn. Beob. 53: 74-79.
Williams, T.C., L.C. Ireland & J.M. Williams. 1973. High altitude flights of the Free-tailed Bat, *Tadarida brasiliensis*, observed with radar. J. Mamm. 54: 807-821.
-----, T.J. Klonowski & P. Berkeley. 1976. Angle of Canada Goose V flight formation measured by radar. Auk 93: 554-559.
----- & H. Mix. 1973. An inexpensive apparatus for recording data from radar Plan Position Indicator displays. Bird-Banding 44: 124-125.
----- & J.M. Williams. 1972. Tracking radar techniques for studying migratory birds. NASA CR-62082, Wallops Station, Va. 10 p.
Yacobi, V.E. & A.A. Baturov. 1974. [Photoregistration of the radio locator screen for studying bird migrations.] Zool. Zh. 53: 1397-1401 (Russ., Eng. summary).

APPENDIX--DOPPLER RADARS

Radars able to detect the Doppler shift of echoes provide a direct measure of radial speed and enhanced ability to detect weak moving echoes in the presence of stronger terrain echoes. Small continuous-wave (CW) Doppler radars have been used to record flight speeds, wingbeat rates and Doppler signatures of birds (Schnell 1965; Flock & Green 1974). However, the simpler CW radars are limited in application by inability to measure range. Pulsed-Doppler radars can reveal range as well as bearing, speed and both Doppler and amplitude signatures (Green & Balsley 1974). They are potentially valuable in wildlife studies because they can measure so many echo characteristics.

Utilization of Color-Infrared Aerial Photography to Characterize Prairie Potholes[1]

Robert G. Best[2]

Abstract.--An application of remote sensing to obtain quantitative wetland resource data has been demonstrated. The classification of wetlands on color-infrared imagery is illustrated. Two procedures for the classification of hydrophytes are discussed. Automated density slicing technique had an overall classification accuracy of 77.9% and a positional mapping accuracy of 67.3%. Statistical models to predict volume of standing water and maximum storage potential of wetland basins are presented.

INTRODUCTION

In a normal year the prairie pothole region, of southcentral Canada and the northern plains states, produces a significant proportion of the annual waterfowl production (Smith et al., 1964). The area is characterized by a high density of wetland basins formed in glacial deposits. Wetlands in the area are viewed as a barrier to agricultural production and consequently many have been destroyed by draining or filling and leveling. Techniques are required to quantify and characterize the quality of remaining wetlands in order to determine and minimize the impact of future losses.

Interpretations of color-infrared aerial photography can be an operational alternative to costly, time consuming ground surveys. The relatively high infrared reflectance of hydrophytes and the very low infrared reflectance of water and water-logged soils facilitates the interpretation of the presence of hydrophytes and water regime parameters which are required to identify seasonally flooded basins, as well as more permanent wetlands. The classification of wetlands on color-infrared imagery is illustrated. Interpretations were transferred to clear acetate overlays and area measurements made on the Spatial Data (Data Color 703) unit of the Remote Sensing Institute's Signal Analysis and Dissemination Equipment (SADE). Inventory data were encoded into a computerized storage and retrieval system capable of producing tabular summaries and spatial displays.

The occurrence and distribution of hydrophytes are determined by the water depth and duration of inundation. The presence of specific hydrophytes can be used to indicate the water regime and extent of wetlands. A technique for photographic multispectral partitioning of color-infrared imagery is presented as it applies to the classification of hydrophytes.

The destruction of wetlands has many adverse effects in addition to the loss of wildlife habitat. Wetlands act as storage reservoirs for runoff preventing flooding and recharging ground water supplies. Haan and Johnson (1967) found a statistical relationship between wetland basin morphology and volume in northcentral Iowa as part of a study to develop a hydrologic model for small watersheds. The volume of water in a wetland and the maximum storage potential of the wetland basin can be statistically estimated from morphometric measurements made on aerial photography. Example models for wetlands in the Devil's Lake Basin of North Dakota are presented.

This presentation will summarize and illustrate several applications of color-infrared aerial photography for characterizing prairie potholes. These applications include inventory and classification of wetlands, classification of hydrophytes and estimation of volume.

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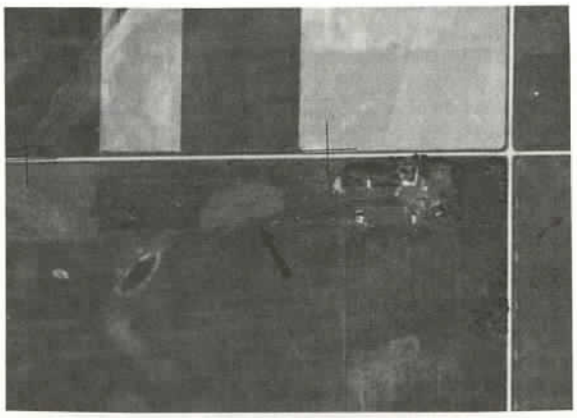
Wetland Inventory and Classification

The term "wetlands" has been defined in numerous ways. Wetlands are defined in this report as depressions which contain shallow and sometimes temporary or intermittent waters long enough to promote the growth of hydrophytes.

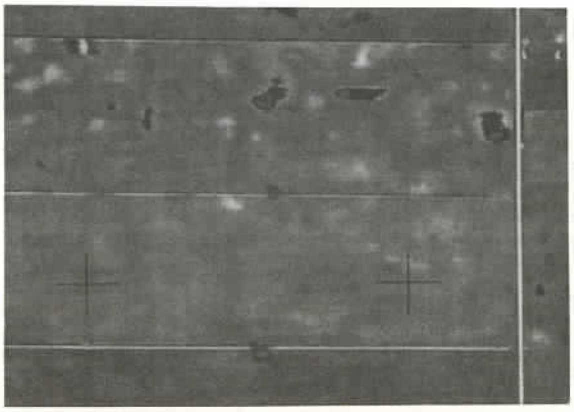
Interpretation procedures were developed for use with high altitude (60,000 ft AGL) color-infrared imagery collected by a NASA RB-57 aircraft. The original scale of the imagery was approximately 1:120,000. Black and white enlargement prints were exposed from the color-infrared transparencies. Each print was scaled during printing to correct scale differences in the original imagery and to prepare an interpretation product of suitable scale. Forty enlargement prints were randomly selected to determine the scale and variability. The mean scale was 1:12,590 with a coefficient of variability of 1.0%. The variation in scale was not considered a significant source of error in the area measurement.

Wetlands were classified according to water regime and usefulness to waterfowl as described by Martin et al. (1953) and illustrated by Shaw and Fredine (1956). In the classification system prairie potholes are classified as one of four types in the inland fresh wetland category.

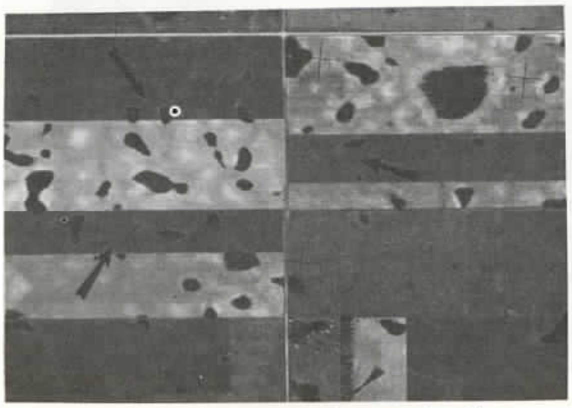
Seasonally flooded basins or flats (Type 1) are the most abundant in the region, both in number and acreage. These basins contain water for short periods, generally in the spring following snowmelt or periods of heavy rainfall. These wetlands are used by waterfowl during the spring migration. Smartweeds (Polygonum sp.) and wild barley (Hordeum jubatum) are characteristic of the Type 1 wetlands in the region, but vegetation may vary depending on the duration of inundation and the season. Most basins are cultivated and planted to agricultural crops. Wetlands in non-cultivated lands were easily identified on the color-infrared imagery collected during early spring. The wetland vegetation had greater infrared reflectance than did surrounding vegetation (fig. 1a). Basins in fallow fields were delineated by dark tones and smooth texture indicating water or waterlogged soils on the color-infrared imagery (fig. 1b). The basin normally included the waterlogged soils as well as the standing water. This is important because standing water may last for only several days while the waterlogged soils persist for longer periods. Type 1 wetlands in growing fields of small grain were the most difficult to delineate because only the portion



a.--Type 1 wetland in non-cultivated land.



b.--Type 1 wetland in bare soil.



c.--Type 1 wetland in growing grain fields.

Figure 1.--Type 1 wetlands on color-infrared imagery.

of Type 1 basins that contained water could be interpreted on the imagery due to the masking effect of the growing grain (fig. 1c). Optimum conditions for data collection occur early in the spring when basins are full of water and the soil surface is bare. It may also be possible to delineate the basins on imagery collected after the small grain is harvested because in many cases wetland vegetation, primarily smartweed, will grow in the basin during these dryer periods of the year.

Inland shallow fresh marshes (Type 3) are the second most common type in the region. In Type 3 wetlands, the soil is usually waterlogged during the growing season and is often covered by 15 cm or less of water. They are common as seep areas on irrigated lands. Wetlands of this type are used extensively as nesting, feeding, and early brood-rearing habitat by waterfowl. Tillage of Type 3 wetlands occurs only after prolonged dry periods. Vegetation includes giant bureed (Sparganium sp), spike rushes (Eleocharis sp), bulrushes (Scirpus sp), and various other aquatic plants. The depth of the water does not generally limit the growth of marsh vegetation in the central portion of the wetland and often closed stands of emergent vegetation occur. Type 3 wetlands can be interpreted on color-infrared imagery by the presence of water in early spring with an abundance of marsh vegetation throughout the basin (fig. 2). Type 3 wetlands and inland deep fresh marshes (Type 4) often have some degree of overlap and in some instances are difficult to differentiate.

Figure 2.--Type 3 wetland on color-infrared imagery.

The Type 4 wetlands usually have 15 cm to 1 m or more of water during the growing season. Deep fresh marshes (Type 4) in combination with Type 3 wetlands constitute the principal production areas for waterfowl. Emergent vegetation is similar to that of a Type 3 wetland with a shift in dominance to Scirpus sp. and Typha sp. in the Type 4 with floating-leafed aquatics common in areas where water depths limit emergent vegetation growth. During periods of normal precipitation, Type 4 wetlands can be distinguished from Type 3 wetlands because they usually have a greater percentage of open water occurring in the central portion of the basin (fig. 3).

Figure 3.--Type 4 wetlands on color-infrared imagery.

If high water levels are persistent, emergent vegetation may be excluded from the entire central portion of the basin. Peripheral bands of vegetation, common to shallower types, (i.e. Hordeum jubatum) are often present around deep marshes in shallow portions of the basin. When delineating the extent of the basin, this "band" should be included. The vegetation on the periphery is evident on the color-infrared imagery because of the higher infrared reflectance of the wetland vegetation in early spring.

Shallow prairie lakes and reservoirs are classified as Type 5 wetlands. The water is usually less than 3 m deep and fringed by emergent vegetation. Rooted aquatic plants are common in water depths less than 2 m. Type 5 wetlands provide brood habitat in mid and late summer when less permanent wetlands are dry. These wetlands are also important during fall migration of waterfowl. Type 5 wetlands are identified by their relatively large size and smooth dark tones indicating open water (fig. 4).

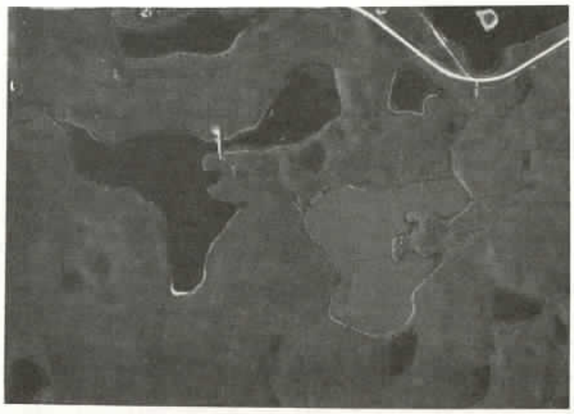


Figure 4.--Type 5 wetlands on color-infrared imagery.

Interpretations were transferred to clear acetate overlays and area measurements made on the Spatial Data unit of RSI's SADE (fig. 5). Included in the Spatial Data unit are a closed circuit television camera, a constant illumination light box and an electronic digital planimeter which measures relative areas of one or more of 32 density levels when used in conjunction with the color display monitor. The total area of each of four wetland types was measured as a percentage of the 64.8 hectare (160 acre) unit cell. To determine the accuracy of the electronic digital planimeter, 40 quarter sections were randomly selected and the wetland areas were measured with a compensating polar planimeter. The mean difference between the wetland acres per quarter section as measured on Spatial Data and that measured with the planimeter was 0.032±.028 hectares at the 95 percent confidence level.

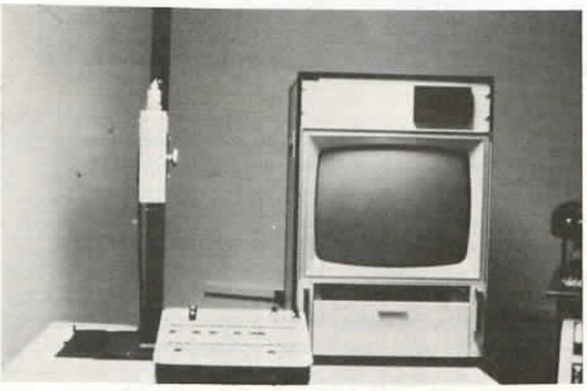


Figure 5.--Spatial Data unit used for area measurement in wetland inventory.

Inventory data, including the number and area of each type for each unit cell, were encoded into a computerized storage and retrieval system. The system is flexible and accepts collateral data including spatial distribution by legal description, ownership, irrigation classes and other pertinent data which might be used to stratify the wetland inventory data. The system is capable of producing tabular summaries and spatial displays of the data.

Classification of Hydrophytes

An area within a large Type 4 wetland in Kingsbury County, South Dakota was selected to develop and test interpretation techniques. The area was selected because relatively large pure dense stands of common hydrophyte were present.

Nine classes representing six different aquatic macrophytes, one of upland grasses, one open water and a non-typical spoil pile class were interpreted and delineated on enlargement prints. The interpretations were verified and adjusted by ground verification.

A second technique which employs photographic separation of the original color film and a color encoded density analysis was developed and evaluated. Black and white separations using red (wratten 25), green (wratten 74) and blue (wratten 98) filters were made in an attempt to partition the effects of infrared, red, and green reflectance on the original film. Separations were made on panchromatic film which is equally sensitive to all 3 wavelengths and processed to $\gamma = 1$ to maintain the relative reflectance effects of the original film. Pin registered combinations of positive and negative separations were used to produce a ratioing effect (Lockwood, 1975).

Each separation and ratio "sandwichs" were "sliced" in 4 equal density increments and color encoded on a CRT monitor of Spatial Data model 703. Enlargement prints were made from 35 mm slides taken of the monitor. The classification of hydrophytes was made by identifying the relative density of each class in each image separation. Interpretations were rectified to remove monitor distortion by registering to enlargement prints on a zoom transfer scope.

Density sliced interpretations and the ground verified photo interpretation of vegetation classifications were encoded into a computerized spatially-oriented data base in order to calculate the accuracy of the density sliced interpretation. A grid of known cell size (1 cell = .017 hectares) was superimposed on the interpretations. Digitization of the interpretation data involves coding on a row-by-row basis those cells where the dominance of one class changes to another. Output products include computer plotted maps at any useful scale, areal tabulations and statistical comparisons.

Confusion matrices, statistical accuracy and mapping accuracy were calculated using methodology developed by Kalensky and Scherk (1975). Each cell in the data was treated as an individual pixel.

Volume Estimation

A random sample of 29 potholes was selected in the Devil's Lake Basin, North Dakota. Depth profiles were ground surveyed and volume at the time of data collection and maximum storage potential (volume at overflow) were calculated by summing the volume of each stratum as defined by Reid (1961):

$$V = 1/3\ (A_1 + A_2 + \sqrt{A_1\ A_2})\ h$$

Where: A_1 = area of upper surface of a contour stratum

A_2 = area of lower surface of a contour stratum

h = depth of the stratum

Three volume measurements were used as the dependent variables in a regression analysis with morphometric measurements (area, length, breadth, length of shoreline and shoreline development index) made on enlargements of aerial photography as the independent variables.

RESULTS AND DISCUSSION

The procedures for inventory and classification that have been described were implemented in two operational inventories. The techniques were first employed to determine the impact of a large scale irrigation development on the wetland habitat in the 125,550 hectare Oahe unit in eastcentral South Dakota (Best and Moore, 1977). Field checking and low-altitude aerial reconnaissance of a selected sample found no misclassification of habitat type and no significant differences in the delineation of basin extent for the 50 wetlands checked. Table 1 is an example of a computer generated tabular summary of the inventory data stratified by irrigation class and predetermined areas within the Oahe unit. Several other tabular summaries were produced using different stratifications including a listing of inventory data for each quarter section within the area.

Table 1.--Example of computer generated tabular summary of wetland inventory data from Oahe Irrigation Unit.

	IRRIGATION DISTRICT ACRES	TYPE I&II NUMBER	TYPE I&II ACRES	TYPE III,IV&V NUMBER	TYPE III,IV&V ACRES	ARTIFICIAL WETLANDS NUMBER	ARTIFICIAL WETLANDS ACRES	TOTAL WETLAND NUMBER	TOTAL WETLAND ACRES	STREAMS ACRES	NATURAL DRAINS ACRES
BROWN COUNTY											
1,2,&3	61280.	1275.	1099.2	1.	123.7	58.	28.5	1334.	1191.4	315.9	104.8
5	6630.	178.	145.6	0.	8.7	9.	6.5	187.	160.8	33.8	2.4
6	13020.	219.	388.7	5.	497.4	10.	3.0	234.	889.1	230.2	30.7
UNKNOWN	12450.	511.	455.5	1.	10.2	12.	1.2	524.	466.9	70.0	19.1
EAST LAKE PLAIN SPINK COUNTY											
1,2,&3	85770.	828.	843.6	0.	60.0	60.	15.7	888.	919.3	264.2	188.3
5	16800.	286.	247.5	1.	7.0	18.	4.4	305.	258.9	9.4	17.6
6	11240.	89.	148.7	0.	0.0	20.	5.2	109.	153.9	168.8	37.5
UNKNOWN	1400.	36.	26.6	0.	0.0	1.	0.2	37.	26.8	0.0	0.0
WEST LAKE PLAIN SPINK COUNTY											
1,2,&3	74330.	930.	1018.7	8.	760.0	81.	34.5	1019.	1813.2	311.3	122.5
5	6080.	123.	167.0	0.	0.0	8.	2.4	131.	169.4	4.0	6.2
6	18570.	409.	935.2	4.	476.5	50.	12.2	463.	1423.9	117.6	59.7
UNKNOWN	2960.	70.	55.6	0.	0.0	4.	1.1	74.	56.7	20.1	0.0
TOTALS	310790.	4954.	4969.8	21.	2443.5	330.	116.9	5305.	7930.2	1565.3	588.8

Further processing of the data produced spatial displays of raw data or data summaries. Printer overstrike displays can be obtained or data can be computer plotted to match any scale. Data can be displayed in color via the color display monitor of the SADE system (fig. 6).

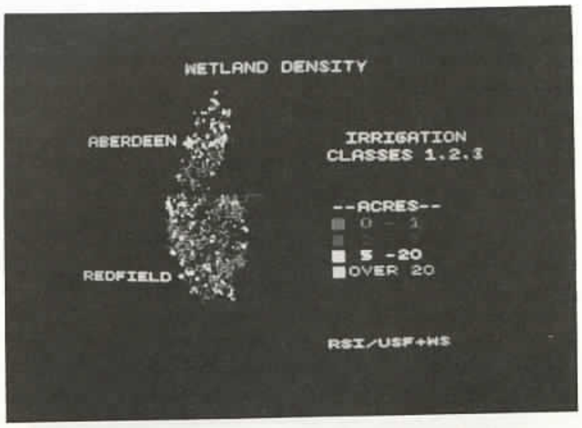


Figure 6.--Color encoded display of wetland inventory data for Oahe Irrigation Unit.

The South Dakota Department of Wildlife, Parks and Forestry tested the procedures in their county by county inventory of wetlands in South Dakota (Brocroft et al., 1978). The wetland inventory data were stratified by township ownership and land use. Computer symbol prints were used to display the density of wetlands in no./section and acres/section by townships in the Faulk County inventory. The authors recommended continued use of the technique where high altitude color-infrared imagery was available.

Vegetation classes can be visually interpreted by tonal and textural differences on enlargement prints of low altitude color-infrared aerial photography. Two classes, Typha sp. and Scirpus sp. are genus' in which species could not be separated. Only two species of hydrophytes, Scholochloa festucacea and Phragmites communis could be consistently interpreted when they occurred in pure dense stands. A shallow marsh class consisting of a mixed stand Scirpus sp., Eleocharis sp., Sparganum sp., Polygonum sp. and grasses could be interpreted by unique textural difference. The wet meadow zone, a mixed stand of grasses and sedges which delimits the extent of the basin, could be interpreted by uniform tones and its peripheral position. Considerable interpretation experience and knowledge of aquatic plant communities is required to make an accurate visual interpretation of the above classes.

The photographic separation and automated density slicing technique was developed to eliminate the need for experienced photo interpreters. The best discrimination of hydrophyte classes occurred in the infrared separation. Ratios of separations provided no additional information. This may be attributed to the fact that the near infrared sensitive film layer is deliberately made approximately 1½ stops less with respect to daylight illumination than the red and green sensitive film layer. Table 2 is a confusion matrix comparing the density sliced interpretation to the photo interpretation and ground verification which is considered accurate. The overall classification accuracy was 77.9% and a positional mapping accuracy was 67.3% (table 2).

Table 2.--Confusion matrix presenting classification and mapping accuracy of density sliced interpretation of hydrophyte classes.

CLASS	UPL	WM	PHR	TY	SC	SM	SF	SP	OW	TOTAL	Omissions No.	Omissions %	M_I%
Upland (UPL)	251	18	0	0	0	0	0	0	0	269	18	6.7	88.7
Wet Meadow (WM)	14	353	0	25	20	6	0	0	0	418	65	15.5	77.1
Phragmites (PHR)	0	0	2	0	0	0	0	0	0	2	0	0	100
Typha Sp. (TY)	0	1	0	212	86	2	9	1	1	312	100	32.0	54.5
Scirpus Sp. (SC)	0	1	0	51	508	0	9	17	2	588	80	13.6	68.2
Shallow Marsh (SM)	0	0	0	0	0	37	6	2	0	45	8	17.8	62.7
Scolochloa festucacea (SF)	0	0	0	49	31	6	160	7	1	254	94	37.0	57.1
Spoil Piles (SP)	0	0	0	1	11	0	1	15	3	31	16	51.6	25.4
Open Water (OW)	0	0	0	0	9	0	1	1	90	101	11	10.9	89.8
TOTAL	265	373	2	338	665	51	186	43	97	2020			
Commissions No.	14	20	0	77	157	14	26	28	7				
Commissions %	5.3	5.4	0	22.8	23.6	37.8	14.0	65.1	7.2				
Overall Classification Accuracy K	77.9%												
Overall Mapping Accuracy M	67.3%												

The overall mapping accuracy (M) is weighted to reflect differences in the sample size of each category. The mapping accuracy (MI) of each class is presented in the far right column of the table. The sample size for Phragmites sp. is too small to be compared to the relative accuracy of the other classes. The low accuracy for delineating spoil piles can be expected because the vegetation present is not representative of a wetland ecosystem. Table 3 is a confusion matrix in which classes of hydrophytes with similar characteristics have been combined. Upland, wet meadow and open water classes remain the same. The Schlochloa festucacea was combined with the shallow marsh class. The Phragmites sp., Typha sp., and Scirpus sp. classes were grouped into the deep marsh class and the spoil piles are termed other. The overall classification accuracy and positional mapping accuracy have increased to 88.0% and 79.8%, respectively. This indicated that some of the errors were misclassification of hydrophytes with similar characteristics. The primary source of positional error can be attributed to the nonlinearity of the CRT monitor and errors in rectification.

Table 3.--Confusion matrix presenting classification and mapping accuracy with similar classes combined.

CLASS	UPL	WM	SM	DM	OW	Other	TOTAL	Omissions No.	Omissions %	M_I%
Upland (UPL)	251	18	0	0	0	0	269	18	6.7	88.7
Wet Meadow (WM)	14	353	6	45	0	0	418	65	15.5	77.1
Shallow Marsh (SM)	0	0	209	80	1	9	299	90	30.1	63.9
Deep Marsh (DM)	0	2	20	859	3	18	902	43	4.8	82.0
Open Water (OW)	0	0	1	9	90	1	101	11	10.9	89.8
Other	0	0	1	12	3	15	31	16	51.6	25.4
TOTAL	265	373	237	1005	97	43	2020			
Commissions No.	14	20	28	146	7	28				
Commissions %	5.3	5.4	13.4	14.5	7.2	65.1				
Overall Classification Accuracy K	88.0%									
Overall Mapping Accuracy M	79.8%									

Wetland area was the only variable that was significant in the prediction of basin volumes. Linear regression of a logarithmic transformation of the data demonstrated a highly significant (99% confidence interval) relationship between waterfilled area and volume (fig. 7).

Models were developed to predict volume at the time of overflight (spring volume) and maximum storage potential (volume at overflow).

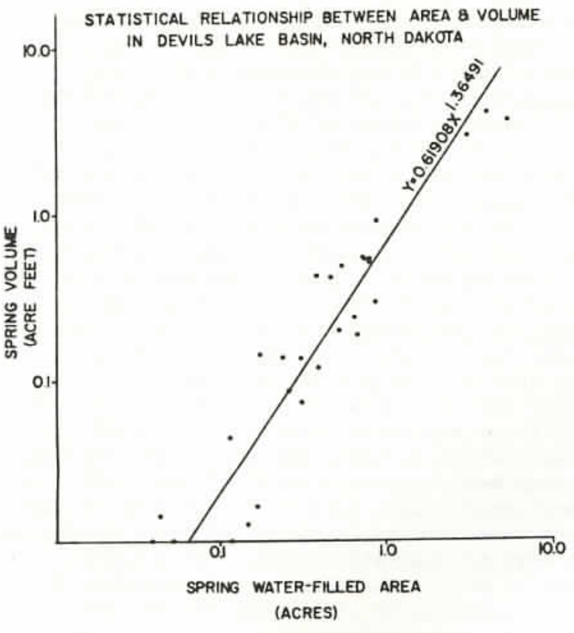


Figure 7.--Graph illustrating statistical relationship between area and volume of wetland basin in the Devil's Lake Basin.

Correlation coefficients were 0.94 and 0.78, respectively (see table 4). These results, although based on a limited number of observations, indicated that reliable models could be developed, with appropriate sampling, to apply to all prairie potholes.

Table 4.--Statistical models for predicting spring volume and maximum storage potential of wetlands in Devil's Lake Basin, North Dakota

Dependent Variable	n	$Y=aX^b$ 1/	r	r^2
Spring Volume	29	$Y=0.619X^{1.365}$	0.94**	0.88
Maximum Storage Potential	29	$Y=3.231X^{1.278}$	0.78**	0.61

1/ Independent variable (X) was area of standing water on spring imagery collected May and June 1975.

**Significant at 0.01 level.

SUMMARY AND CONCLUSIONS

The application of remote sensing to obtain quantitative wetland resource data was demonstrated. Traditionally, wetland inventories have used low-altitude black and white panchromatic photos and have been generally limited to areas the size of a county. These data are often collected during summer months for purposes other than wetland inventories which makes it difficult to interpret temporary wetlands which no longer contain standing water. The color-infrared film depicts a greater variety of tones representing variations in vegetation species and soil moisture and allows greater accuracy of interpretation. In addition, high quality color-infrared data collected in the spring when many temporary wetlands contain water improves the interpreter's capability to recognize and map the small and temporary wetlands.

Type 1 wetlands in non-cultivated land can be identified because the characteristic wetland vegetation has higher infrared reflectance than does surrounding vegetation. In fallow fields where no wetland vegetation was present, Type 1 basins can be delineated by the dark tones and smooth texture of standing water and the surrounding waterlogged soil. Only that portion of the wetland basin which contained water at the time of data collection can be delineated if Type 1 wetlands occurred in fields of growing small grain. The high infrared reflectance of the growing grain masked the waterlogged soils and wetland vegetation used to delineate basins. The number of basins which occur in grain fields can be determined but acreage will be underestimated. Data collected after recent precipitation and before the spring grains begin to grow would make interpretation easier. Type 3 wetlands could be interpreted by the presence of water in early spring and by an abundance of marsh vegetation throughout the basin. Type 4 wetlands appear similarly but can be distinguished from the Type 3 because they usually have a greater percentage of open water in the central portion of the basin. The few Type 5 wetlands in the region were distinguished from both the Type 3 and Type 4 because of their large size and the absence of emergent vegetation except on the extreme periphery.

Conventional determination of area with either a compensating polar planimeter or a series of grids, as well as manual cataloging of these data, consumes considerable labor and provides delays in completing of inventories over large regions.

Hydrophytes can be classified on CIR imagery using either manual interpretation or photographic separation and automated density slicing techniques. The need for interpretation experience and knowledge of hydrophytes that is required for manual interpretation is eliminated in the automatic density slicing technique which provides sufficient accuracy for use. However, the photo-interpreter has the advantage of making interpretations based on texture, patterns, and position in addition to tone.

These results and similar studies indicate that reliable volume prediction models can be developed from remotely sensed morphometric wetland data for the shallow wetland basins in the prairie pothole region. Traditional approaches for assessing surface storage volumes require ground surveys of depth profiles or topographic mapping and are thus time and cost prohibitive for large regional assessments. In operational use, these preliminary prediction models must be refined to reflect potential differences in spatial distribution, landscape features, and wetland characteristics. These parameters as well as an increase in the number of observations will increase the reliability and the scope of inferences of the resulting models.

LITERATURE CITED

Best, R.G. and D.G. Moore. 1977. Inventory of wetland habitat using remote sensing for the proposed Oahe Irrigation Unit in eastern South Dakota. Remote Sensing Institute. Brookings, SD. SDSU-RSI-77-03.

Brocroft, M.D., L.F. Fredrickson and R.B. Best. 1978. Wetlands inventory of Faulk County with use of remote sensing techniques. Pullman-Robertson Project W-75-R-20 Study No. L15.1 South Dakota Dept. of Game, Fish and Parks, Pierre, South Dakota. 65 pp.

Haan, C.T. and H.P. Johnson. 1967. Geometrical properties of depressions in northcentral Iowa. Iowa State Journal of Science 4(2). 149-160.

Kalensky, Z. and L.R. Scherk. 1975. Accuracy of forest mapping from Landsat computer compatible tapes in Proceedings of the 10th International Symposium on Remote Sensing of the Environment. ERIM Ann Arbor, Michigan. pp. 1159-1167.

Lockwood, H.E. 1975. Photographic image and processing. The Fifth Biennial Workshop on Color Aerial Photography in Plant Sciences and Related Fields. American Society of Photogrammetry, Falls Church, Virginia. pp. 29-44.

Martin, A.C., N. Hotchkiss, F.M. Uhler, and W.S. Bourn. 1953. Classification of wetlands of the United States. U.S. Fish and Wild. Serv. Spec. Sci. Rep. Wildl. 20. 14 pp.

Reid, G.K. 1961. Ecology of Inland Waters and Estuaries. D. Van Nostrand Co., New York, Cincinnati, Toronto, London and Melbourne. 375 p.

Shaw, S.P. and C.G. Fredine. 1956. Wetlands of the United States. U.S. Fish Wildl. Serv. Cir. 39. 67 pp.

Smith, A.G., J.H. Stoudt, and J.B. Gollop. 1964. Prairie potholes and marshes. Pages 39-50 in J.P. Linduska, ed. Waterfowl Tomorrow. U.S. Gov't Print. Office, Washington, D.C.

Comparative Efficiencies of Telementry and Visual Techniques for Studying Ungulates, Grouse, and Raptors on Energy Development Lands in Southeastern Montana[1]

Dean E. Biggins[2] and Edward J. Pitcher[3]

Abstract.--Efficiency of visual and telemetric techniques was compared in studies of mule deer (Odocoileus hemionus), pronghorn antelope (Antilocapra americana), sage grouse (Centrocercus urophasianus), sharp-tailed grouse (Pedioecetes phasianellus), and golden eagles (Aquila chrysaetos). Estimates of sage grouse distribution were similar using both techniques. The two methods produced significantly different estimates of diurnal habitat use by mule deer. Nocturnal habitat use by mule deer was impossible to assess objectively by visual techniques and was significantly different than diurnal use for instrumented deer. Telemetric observations were more expensive than visual for all species except golden eagles. A permanent antenna system was the most efficient radiotracking technique.

INTRODUCTION

Wildlife studies in the Great Plains have proliferated as a result of the rapid expansion of energy development. State and federal resource agencies have initiated several impact studies, and present regulatory statutes require that industry collect environmental baseline data. In 1976, the Fish and Wildlife Service (FWS) engaged in a series of studies on the impacts of coal development on selected species of wildlife. Since the inception of these studies, a total of more than 100 mule deer, white-tailed deer (Odocoileus virginianus), pronghorn antelope, golden eagles, and sharp-tailed grouse has been instrumented and monitored. Four different radiotracking systems were used to monitor these species. In 1975, Peter Kiewit Sons' Co. (PKS) began gathering environmental baseline data using visual techniques, and in 1976 initiated a 3-year radiotelemetry study on sage grouse. These studies were conducted on a 2000-km^2 study area centered around Decker, Montana, and extending into Wyoming.

Simultaneous collection of data using visual and telemetric techniques allowed cost and accuracy comparisons of the two methods. Efficiency evaluations of these techniques should assist the researcher in choosing between visual and telemetric methods and should also help in the selection of radiotracking techniques for telemetric studies.

Appreciation is extended to the following individuals for providing the type of assistance noted: Michael Lockhart, FWS, raptor information; Steven Amstrup, FWS, antelope and sharp-tailed grouse; Thomas Dahmer and Terrence McEneaney, FWS, field data collection; Robert Phillips, FWS, project administration and manuscript review; John Oldemeyer, FWS, statistical assistance; Mike Jackson and Brent Stettler, PKS, data collection; Sam Scott, PKS, expense records; and John Berry, PKS, data collection and graphics.

METHODS

Visual Data Collection

Peter Kiewit Sons' Co. flew an aerial grid monthly to survey mule deer and antelope

[1] Paper presented at PECORA IV Symposium on Application of Remote Sensing Data to Wildlife Management, Sioux Falls, South Dakota, October 10-12, 1978.

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distribution and habitat use. Transects were spaced at 1.6-km intervals. A visual observation for deer and antelope was defined as a sighting of any individual animal, marked or unmarked.

Established road routes and incidental sightings were used to sample sage grouse distribution and abundance. Sage grouse observations consisted of single birds and flocks. Random search, with and without bird dogs, was used to locate nesting grouse. Visual observations of sharp-tailed grouse were made incidental to sage grouse studies.

The Fish and Wildlife Service used a mark-reobservation technique in an attempt to study home range and territoriality of nesting golden eagles. Observations were obtained from deliberate search and incidental sightings of marked eagles.

Telemetric Data Collection

Four tracking methods were used in the telemetric studies: (1) triangulation with a system of nine dual beam 11-element Yagi antennas on 12-m power poles; (2) triangulation from a mobile unit with dual beam 4-element Yagi antennas; (3) handtracking with a 3-element Yagi antenna, sometimes by triangulation with compass azimuths; and (4) aerial tracking with a pair of wing-mounted 3-element Yagi antennas.

Normal tracking schedules for all species involved one to three telemetric observations weekly. A telemetric observation was a locational fix during a designated time period, with or without visual verification.

Cost Comparisons

For ease of comparison, all cost calculations were reduced to cost per observation or cost per nest site located. Costs were calculated from field expense only and do not represent total cost of research. Included were all field labor (at $8.00/hour), specialized field equipment, contractual services, and aircraft time. Not included were administrative expenses, office space and equipment, analysis labor, computer time, or vehicular expense. All field expenses of trapping, marking, and tracking were included for telemetric studies and for the golden eagle mark-reobservation study. Aircraft time and/or labor were the only field expenses for visual techniques. Unless otherwise noted, costs were based on a study duration of 3 years. Costs were derived from the actual field studies in progress but were adjusted for each species to a common time frame, number of animals instrumented, and number of observations.

The relationship between total cost and number of observations was linear for all studies which did not involve capture and marking. However, for telemetric studies, specialized equipment and trapping expenses must be amortized over the entire study, taking into consideration the number of observations obtained and the life expectancies of transmitters and/or animals. Thus, the following assumptions apply to cost calculations for the taxa indicated:

Ungulates

1. Instrument 40 animals in 3 years.
2. An annual attrition rate of about 33 percent from all causes (e.g., death of animal, radio failure).
3. Total number of observations for 3 years = 5589.

Grouse

1. Instrument 12 grouse per year.
2. Attrition is 100 percent (instrumented grouse mortality = 90 percent annually).
3. Total number of observations for 3 years = 1800.

Eagles

1. Instrument five birds per year.
2. Attrition is 100 percent (transmitter life expectancy).
3. Total number of observations for 3 years = 7800.

Cost of visual data was compared to cost of telemetric data for mule deer, antelope, golden eagles, and grouse. Cost comparisons were also made between aerial and handtracking for antelope, between permanent system triangulation and handtracking for grouse, and between all three techniques for mule deer.

Accuracy Comparisons

Factors such as darkness and vegetational cover affect animal visibility causing difficulty in interpretation of visual data. A sample of telemetric data for mule deer, collected from September through November 1976, was examined for differences between day and night habitat use. Also compared was relative diurnal habitat use from telemetric and visual (flight grid) data collected between April 1975 and September 1977. Differences in use of habitat types were checked for significance with the Chi-square test of independence. Sage grouse distribution was examined using telemetric and vehicular route data.

Radiotracking system accuracy was tested by positioning 15 transmitters at mapped points within the 40-km^2 area covered by the permanent tracking system and taking azimuth readings on them using the permanent, mobile, and handtracking methods. The same beacon[4] transmitter used in normal deer tracking was used to "zero" both mobile and permanent systems. For tracking with the handheld antenna, azimuths were read from a handheld compass. For all readings, the difference between the true azimuth and observed azimuth was recorded.

The t-test of paired comparisons was applied to the set of differences for each tracking method to test for bias (i.e., whether each mean difference was significantly different from zero)(Li 1964). Within-method variation is an important factor in judging comparative efficiency of the methods, regardless of presence or absence of bias. The Bartlett test was used to determine if variances from one method to another were significantly different (Neter and Wasserman 1974). Data were also segregated into three distance classes for each method (< 499 m, 500-999 m, and 1000-6000 m) and line-of-sight vs. nonline-of-sight. The Bartlett test was again used to compare variances. Confidence interval estimates for future observations (azimuth readings) were calculated by the formula

$$\bar{x} \pm t_{.05} \sqrt{s^2 \left(\frac{n+1}{n}\right)}$$

(Steel and Torrie 1960).

RESULTS AND DISCUSSION

Cost Comparisons

Costs of obtaining observations were less with visual techniques than with radiotelemetry except for golden eagles (Table 1). Low reobservation rates on marked eagles made this visual method extremely expensive for studying home range and movements.

Cost of locating sage and sharp-tailed grouse nests with telemetry was about $400.00 per nest. Sage grouse nests were almost twice as expensive to find without telemetric aid. This, as well as lack of visual data on sharp-tailed grouse, emphasizes the desirability of incorporating telemetric methods for low visibility animals.

Table 1.--Comparative cost per observation with telemetric systems and visual techniques.

SPECIES	COST / OBSERVATION			
	TELEMETRY			VISUAL
	Permanent	Aerial	Hand	
MULE DEER	$6.03	$9.05	$7.21	$2.48
ANTELOPE	—	9.42	7.58	1.76
GOLDEN EAGLES	—	—	8.90	124.92*
SHARP-TAILED & SAGE GROUSE	14.18	—	24.53	2.18

*Reobservation of marked eagles only

Cost comparisons among the major taxa (i.e., ungulates, grouse, raptors) should be avoided because objectives, time frames, and intensities of observation differed for each.

Accuracy Advantage of Telemetry

Vegetation has profound effects on the visibility of some species. In our study, a comparison of flight grid data with telemetric data on mule deer yielded the significantly different (P < .01) habitat use relationships shown in Fig. 1. As expected, those habitats with a timber canopy showed higher relative use with telemetry and lower use with the visual data; the reverse was true with open habitats.

With many species, daylight activities and habitat use differ from nighttime activities (Fig. 2). Without nocturnal tracking, use of some habitats by mule deer would be missed completely. Remote sensing of some type is the best means of obtaining this information.

Disadvantages of Telemetry

Two levels of sampling usually occur with telemetric studies. The first sampling level is the number of individuals instrumented. The second sampling level is the set of observations on the instrumented individuals. This second level sample is frequently given rigorous statistical treatment while adequacy of the first level sample is either

[4]A transmitter placed on a high point within the study area to which the true azimuth is known from each antenna station.

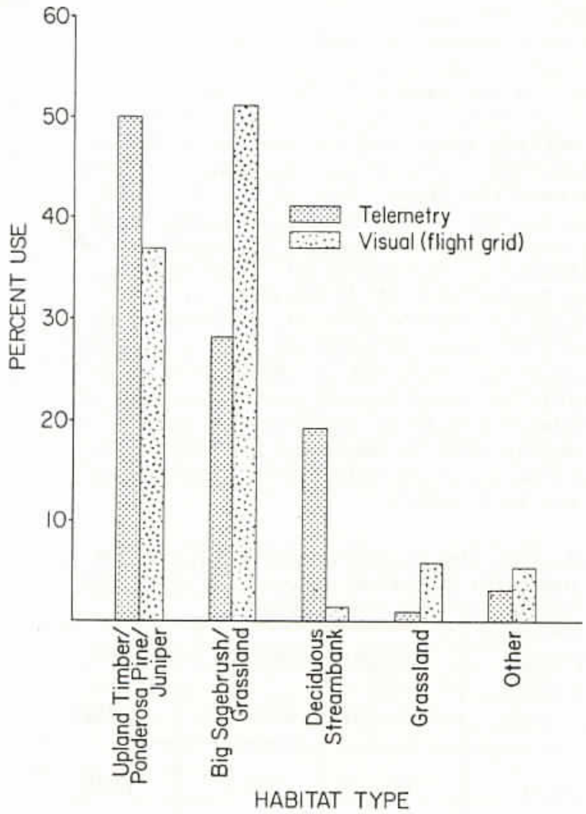

Figure 1.--Daylight use of habitats by mule deer, comparing results of telemetry and visual (flight grid) techniques.

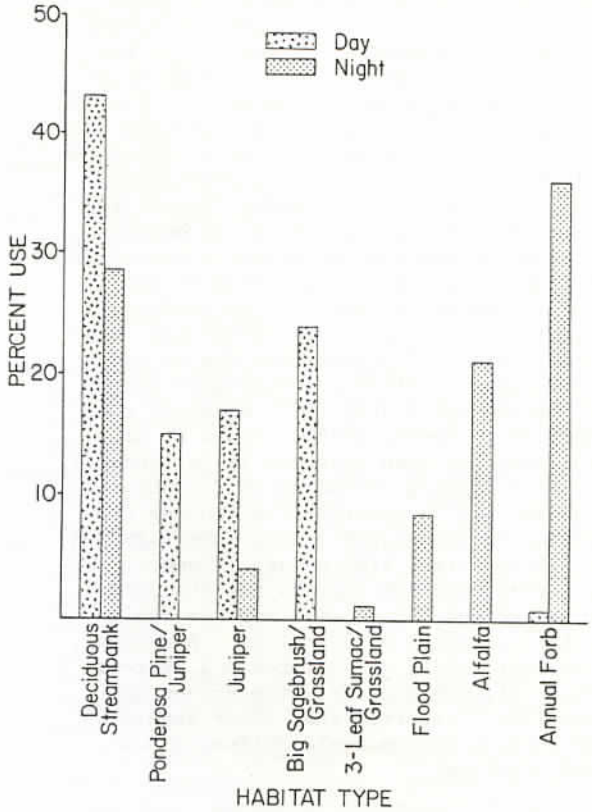

Figure 2.--Comparative day/night habitat use by instrumented mule deer, September through November, 1976.

subjectively evaluated or completely overlooked. Only one level of sampling is necessary with visual techniques.

Attachment of instrumentation to grouse seems to affect mortality rate. The longest known survival of 55 instrumented grouse was 9 months, with most loss due to predation. The assumption of 100 percent annual mortality of instrumented grouse should be made for telemetric studies. For small or sensitive populations, such destructive sampling is unacceptable, forcing use of visual techniques. Strutting ground counts may provide a useful index to population size. In our study, intensive sage grouse observation along vehicular routes provided distribution data similar to that obtained via telemetry.

Objectives should be scrutinized before a technique is selected. For example, it may not be necessary to delve into intensive telemetric studies to adequately assess annual changes in animal abundance, distributional patterns, or age and sex ratios. Telemetry may not be feasible even when desirable. State wildlife agencies are often reluctant to allow private consultants and energy firms to capture and mark game animals.

Cost and Accuracy of Radiotracking Techniques

Under the conditions specified, cost comparisons showed a fixed tracking system to be the least expensive method, followed by hand and aerial tracking (Table 1). A mobile unit using antennae intermediate in size and sophistication is a viable compromise between handtracking and a fixed system in both cost and accuracy.

The fixed system was not only the least expensive but also the most accurate at all but the closest distance class (Table 2). The three methods produced significantly different variances ($P < .05$) for all distance classes. Several highly aberrant azimuth readings were obtained at working distances (transmitter to receiver) of less than 500 m, even when considerable care was used. Cause was unknown, but we tentatively concluded that very close working distances should be avoided. The combination of very small sample sizes (only five observations for each and developing a correction factor for each antenna location.

Two alternatives to triangulation with the above systems are aerial tracking and handtracking followed by sight. Any method that relies on sight to verify the animal's position is highly accurate in the sense that the animal's position is positively known, but also subject to a number of biases. For example, handtracking followed by visual contact may alarm the animal. This has at least two important consequences: (1) alarm significantly changes the movement patterns of many species, thereby biasing future "fixes;" and (2) at times the observer unknowingly has influenced the animal's behavior before visual contact is made, thus biasing the corresponding data. Effects on both movements and habitat data are likely.

Aerial tracking has the advantages of speed and accessibility of even the largest, most remote, and rugged study areas. This method is not equally suitable for all species. Though deer and elk seem relatively undisturbed by aircraft, antelope are often alarmed at long distances. Aerial tracking is relatively inaccurate where visual contact is not made. Denton (1973) reported a mean approximation area size of 10.621 acres (4.3 ha) in a western Montana elk study using aerial tracking, with 88 percent of the approximation areas actually including the elk or test transmitter. Assuming about 90 degree intersection and with both receiving stations about 1000 m from the subject, our fixed and mobile systems produced mean error polygons of about 0.10 ha and 0.22 ha respectively.

CONCLUSION

Research objectives and cost are important considerations in choosing methodology. With a well-designed sampling plan, visual surveys provide low cost year-to-year indices of change for many parameters. In detailed studies of habitat relationships and movements, radiotelemetry is preferred because of its potential freedom from bias. Our radiotelemetry observations were more expensive than visual observations but less than mark-reobservation type sightings. Nest sites were located less expensively with telemetry than with random search.

Telemetry provides the capability of following individual animals through extended time periods, producing data that cannot be obtained by any other means. Nevertheless, caution must be exercised in extrapolating results obtained from small numbers of instrumented animals to populations.

For telemetric studies, the permanent tracking system should be considered because of its accuracy, relative freedom from bias, and lower cost per observation. Conditions that enhance this choice are a small study area, resident animals, road accessibility, relatively gentle terrain, and longer study duration.

LITERATURE CITED

Anderson, F., and P. P. de Moor. 1971. A system for radio-tracking monkeys in dense bush and forest. J. Wildl. Manage. 35(4): 636-643.

Denton, J. W. 1973. A radio telemetry system for elk: its use and efficiency. M.S. Thesis. Univ. of Montana, Missoula. 77pp.

Heezen, K. L., and J. R. Tester. 1967. Evaluation of radio-tracking by triangulation with special reference to deer movements. J. Wildl. Manage. 31(1):124-141.

Li, J. C. R. 1964. Statistical inference I. Edwards Bros., Inc., Ann Arbor, Michigan. 658pp.

Neter, J., and W. Wasserman. 1974. Applied linear statistical models. Richard D. Irwin, Inc., Homewood, Illinois. 842pp.

Slade, N. A., J. J. Cebula, and R. J. Robel. 1965. Accuracy and reliability of biotelemetric instruments used in animal movement studies in prairie grassland of Kansas. Trans. Kans. Acad. of Sci. 68(1): 173-179.

Steel, R. G. D., and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill, N.Y. 481pp.

Verts, B. J. 1963. Equipment and techniques for radio-tracking striped skunks. J. Wildl. Manage. 27(3):325-339.

Locating and Identifying Blackbird-Starling Roosts by Multispectral Remote Sensing

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Abstract.--Remote sensing techniques were used to determine if a 3 million blackbird-starling roost in a mixed conifer-hardwood area near Chapel Hill, Tennessee, could be identified from a flight altitude of 460 m. Thermal imagery of several areas of heavy conifer cover showed high effective radiation temperatures that were indicative of dense concentrations of roosting birds. Nevertheless, it was necessary to use land use imagery to determine that areas outside the roost with similar temperatures were not in roost habitat.

INTRODUCTION

In recent years it has become rather well known that concentrations of blackbirds (Icteridae) and starlings (*Sturnus vulgaris*) can be an economic, health or nuisance problem, or a hazard to aircraft. These problem birds are migratory, so it is the responsibility of the U.S. Fish and Wildlife Service to manage them. For proper management, it is necessary to know the populations and distribution of blackbirds and starlings in the United States. The best time to census the birds is in the winter when they congregate in large roosts in the southern part of the United States and along the east and west coasts.

Since 1963 the U.S. Fish and Wildlife Service has conducted a national cooperative blackbird-starling winter roost survey about every 5 years. The last survey was accomplished the winter of 1974-75 when an estimated 538 million blackbirds and starlings were found in 723 roosts (Meanley and Royall 1977). An enormous amount of time was spent in organizing these surveys and instructing the army of collaborators who were supposed to search for roosts in their areas. Once a roost was located, the collaborator, who was often inexperienced in counting large numbers of birds, attempted to estimate the roost population by counting birds as they entered the roost in the evening or left in the morning. Variation among individuals affected both the accuracy of the population estimates and the extent that an area was surveyed. Past surveys also have extended over a 1- to 2-month period, during which time birds may shift roosts.

Because of the limitations of present survey methods, a cooperative project between the U.S. Fish and Wildlife Service and the National Aeronautics and Space Administration (NASA) was undertaken to determine the feasibility of using existing NASA remote-sensing techniques for locating and identifying blackbird-starling roosts. This paper reports the results of that project.

STUDY AREA AND METHODS

The roost selected for the test was located near Chapel Hill, Tennessee, where birds were roosting in about 19 contiguous hectares of a larger mixed conifer-hardwood area. The roost area was delineated by walking through the area and looking for droppings and feathers. The dominant tree species in the roost was the eastern redcedar (*Juniperus virginiana*). None of the deciduous trees had leaves. The surrounding area was

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cultivated land interspersed with pastures and coniferous and/or deciduous trees.

Two estimates of the roosting population were made by three persons positioned around the roost as birds left the morning of 8 February and again as they entered the roost the evening of 9 February 1977. The estimated roosting population was 3 million birds. The species composition was approximately 10 percent starlings, 65 percent common grackles (Quiscalus quiscula), and 25 percent other blackbirds (brown-headed cowbirds, Molothrus ater; red-winged blackbirds, Agelaius phoeniceus; and rusty blackbirds, Euphagus carolinus).

On 8 February, flights were made over the roost with a NASA C-47 aircraft equipped with an 11-band multispectral scanner. A detailed description of the scanner was reported by Bowman and Jack (1977). The scan width at flight altitude was about 1090 m and the ground resolution element (pixel) was about 0.35 m^2. The remotely detected data were digitized and stored on magnetic tape during the flight, and later analyzed with a ground-based minicomputer system.

The roost was overflown at 1545 hours at an altitude of about 460 m above ground level to obtain multispectral scanner data generated by 10 visible and near infrared bands. The wavelengths of these bands ranged from 0.38 to 1.06 micrometers. This information was used to provide a statistical land use classification of the area. Surface air temperature during the flight was 43° F. Thermal infrared data, those in the eleventh band (8-12 micrometers), were obtained on a flight at 2140 hours at an altitude of about 460 m above ground level to determine if the roost could be delineated by measuring the thermal radiation emitted by the roosting birds. Surface air temperature during this flight was 27° F. There was no snow cover, and no precipitation fell on 8 February.

Ground truth of the vegetative types in the vicinity of the roost was obtained by a ground crew using the land classification system of Anderson et al. (1972). This information was used to train the computer to recognize and identify specific land use categories. The area was then statistically classified, which produced a Level I land use classification (Anderson et al., 1972). One departure from the Level I classification was that forested areas were further separated into Level II classifications. In the resulting nonthermal imagery the various land use classifications were color-coded.

Thermal imagery was also color-coded to divide radiation temperatures between 10.2 and 22.5° F into 22 levels. Temperatures below 10.2° F were assigned one color, as were temperatures above 22.5° F. The 24 temperature levels represented differences of 0.5 - 0.6° F, the minimum resolvable temperature difference for the thermal channel of the scanner.

RESULTS AND DISCUSSION

Normal color photographs and land use classification imagery both showed the roost site to be characterized by a uniform, dense stand of conifers traversed by a narrow band of deciduous trees. This excellent sensory agreement is meaningful in that over most of the roost site only the tree canopy can be seen from the air. The fact that the ground beneath the trees was obscured was important because it meant that the scanner viewed the tree canopy (where birds roosted).

The thermal imagery showed that the effective radiation temperatures of deciduous trees in the roost were from 10.7° F to 12.9° F. The effective radiation temperature of coniferous trees varied from about 15.0° F to 16.7° F. Since the stand of coniferous trees was uniform and dense, the entire area would be expected to have essentially the same effective radiation temperature. However, within the dense conifer stands there was one large area (about 1.1 hectare) and some small areas with effective radiation temperatures 6 to 7° higher, in general, than temperatures recorded for the rest of the uniform stand of conifers within the roost. Visual ground checks were made throughout the roost both before and after the flights and no physical features were noted that would account for these high temperatures.

The thermal imagery also showed that there were areas outside the roost with temperatures higher than those inside the roost. A comparison of the thermal imagery with the land use imagery showed that these high temperature areas were not roosting habitat but agricultural areas and water.

This means that the only conifer stand with unexpectedly high temperatures was inside the roost area. Since it was suspected that trees with large concentrations of roosting birds would have a higher temperature than surrounding trees, we conclude that the areas in the roost associated with the high effective radiation temperatures, especially the 1.1 hectare area, contained dense concentrations of birds.

Since only the densest concentrations of birds were discernible on imagery from this low altitude test, it is doubtful that the present technique could be used (even if the required resolution were available) at the extremely high altitude necessary to make the technique cost beneficial for scanning large areas for roosts. The technique would be cost prohibitive at this time because of the computer time necessary to compare thermal data with land use data to detect suspected roosts.

We believe that this test has demonstrated that large concentrations of birds can be detected in tree roosts, but with present technology it would be impractical to pursue its use as a technique for locating roosts. Perhaps in the future it will be feasible and practical to locate roosts with remote-sensing equipment carried in high-altitude aircraft or satellites. Then the winter roost area of blackbirds and starlings could be scanned within a few days and all large roosts detected. People experienced in counting large numbers of birds could then be sent to the roost sites and all roosts could be counted in a short period of time. This would allow us to accomplish our goal of using experienced people to visit all major winter roosts in a short period of time to obtain an estimate of the population of blackbirds and starlings in the United States.

LITERATURE CITED

Anderson, J. R., E. E. Hardy and J. T. Roach. 1972. A land-use classification system for use with remote-sensor data. U.S. Geol. Surv. Circ. 671. 16 pp.

Bowman, R. L. and J. R. Jack. 1977. Application of remote thermal scanning to the NASA energy conservation program. Natl. Aeron. and Space Admin. Tech. Memo. X-73570. 23 pp.

Meanley, B. and W. C. Royall, Jr. 1977. Nationwide estimates of blackbirds and starlings. Proc. Bird Control Seminar, Bowling Green, Ohio, Nov. 9-11, 1976. 7:39-40.

Use of Landsat for Evaluation of Waterfowl Habitat in the Prairie Pothole Region [1]

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Abstract.--Habitat conditions including the distribution and abundance of ponds and lakes and the availability of upland nesting cover to a large degree determine the productivity of waterfowl breeding in the prairie pothole region. Landsat provides the potential for accurately and rapidly assessing these habitat parameters on a regional basis. In this study Landsat multispectral scanner (MSS) data collected between 1972 and 1976 were analyzed to evaluate habitat conditions at study sites in North Dakota. These data provided estimates of wetland numbers that reflected seasonal and annual trends. However, many ponds important to breeding ducks were smaller than the resolution capability of Landsat sensors. Improvement in Landsat estimates were achieved by correction factors derived from a satellite/aircraft double sample. Land-use analysis was accomplished with a pattern recognition processing technique in which seven terrain categories were identified. Classification accuracy was greatly improved by the use of multitemporal analysis.

INTRODUCTION

The prairie pothole region of North America (fig. 1) includes an area of more than 700 thousand km^2 in south central Canada and north central United States. This region makes up only 10 percent of the total duck breeding area of the continent, yet it produces about 50 percent of the young in an average year (Smith et al. 1964). The abundance of water in the pothole region varies from one year to the next. Availability of water, to a great extent, determines duck productivity and the size of the fall flight (Crissey 1969, Geis et al. 1969). Other environmental factors such as wetland and upland vegetation cover also influence waterfowl productivity. In-

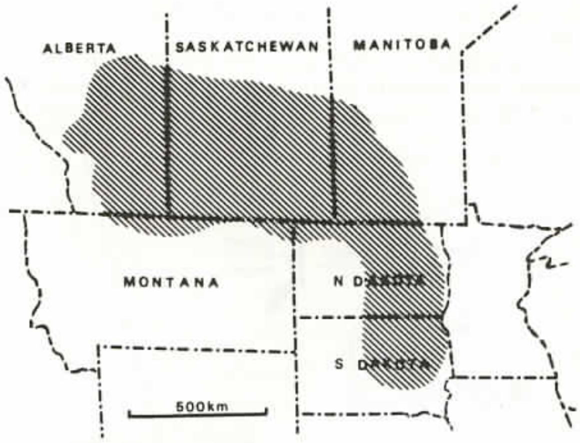

Figure 1.--Prairie pothole region.

[1]Paper presented at the Pecora IV Symposium on Application of Remote Sensing Data to Wildlife Management, Sioux Falls, South Dakota, Oct. 10-12, 1978. This research was supported by the National Aeronautics and Space Administration and the U. S. Fish and Wildlife Service.

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formation on habitat quality is potentially available from satellite and aircraft remote sensing data.

A study to investigate the use of remote sensing methods for monitoring waterfowl habitat in south central North Dakota was initiated in 1968 as a cooperative effort between the Fish and Wildlife Service (FWS) and the Environmental Research Institute of Michigan (ERIM). This initial effort was described by Nelson et al. (1970). Sequential studies using data derived from Landsat were begun in 1972 and continued through 1976 (Work and Gilmer 1976, Rebel and Work 1977, Colwell et al. 1978). The intent of our paper is to summarize the findings of the above investigations concerning the application of satellite data and automatic processing techniques for the appraisal of waterfowl habitat in the prairie pothole region of North America.

STUDY AREA

Remote sensors, particularly those aboard satellites, are capable of wide area coverage. In this study, we decided on an area of 6200 km^2 as our primary study site. Small test sites were located within this unit. The 6200 km^2 area provided an opportunity to investigate some of the problems inherent to large-area surveys such as the generation of large volumes of data representing regional ecological diversity. However, the overall size was not such that it caused serious logistical problems.

The 6200 km^2 site was within the FWS Waterfowl Survey Stratum 46, a 36,876 km^2 area which was used in 1975 as the basis of a regional survey using remote sensing (Colwell et al. 1978).

The primary study site is located in Stutsman and Kidder Counties in east central North Dakota (fig. 2). This is an area equivalent to approximately 18 percent of a frame of Landsat imagery (34,250 km^2), and it includes the town of Jamestown and two National Wildlife Refuges (i. e. Chase Lake and Arrowwood). A field station of the Northern Prairie Wildlife Research Center is situated near the village of Woodworth.

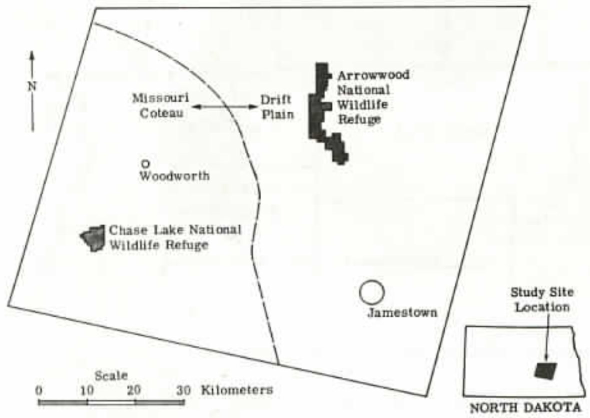

Figure 2.--Waterfowl habitat study area in east central North Dakota.

The study site is contained within the heavily glaciated prairie pothole region and includes parts of two distinct biotic subregions known as the Missouri Coteau and the Drift Plain. The Missouri Coteau is characterized mostly by knob-and-kettle topography where natural basin wetlands are generally larger, deeper and tend to be more permanent than those found on the Drift Plain (Stewart 1975). Gently rolling ground moraines are most typical of the Drift Plain which has been subjected to extensive wetland drainage.

PROCEDURES

This paper emphasizes the processing and analysis of data obtained using multispectral scanners carried aboard the Landsat 1 and Landsat 2.

Since our interest was to develop techniques appropriate for synoptic, wide-area surveys, we chose to undertake automatic data processing as the logical approach for handling large amounts of data. In this study, we have separately utilized two automatic processing techniques: pattern recognition and level or density thresholding.

In concept, the pattern recognition process is based on a requirement that each scene class exhibit a characteristic spectral signature which, in spite of some statistical dispersion, is generally unique. A discriminant function, usually a maximum likelihood criterion, can be used to classify a set of multispectral scanner data into the various scene classes. This process requires numerous mathematical calculations; a general purpose digital computer is used to accomplish these repetitive calculations. A more thorough review of pattern recognition techniques as applied to remote sensing was given by Steiner and Salerno (1975). We used pattern recognition techniques to create vegetation and land-use maps.

Level thresholding refers to techniques whereby a particular scene class may be delineated from its background on the basis of a signature occurring at a distinctive interval in a single spectral band. In this study, the thresholding technique was applied to the identification of open surface water features. The procedure was easily implemented and was effective because, at certain infrared wavelengths, the radiation from a water body was relatively uniform and lower than for other terrain features. Of the Landsat spectral bands available to us, band 7 (0.8 to 1.1 μm) was the most suitable for delineating water. Further details of this technique were described by Work and Thomson (1974) and Work and Gilmer (1976).

MAPPING OF SURFACE WATER AREAS

Level thresholding of a single near-infrared waveband of data was selected as the most practical and easily implemented means to map open water areas using MSS data for the conditions encountered in our study area. Implementation of the thresholding technique was accomplished by observing radiance values from selected water features within a scene, and comparing these values with those of other terrain features also known to exhibit relatively low radiance characteristics. In eastern North Dakota, dark soils consistently approached the low radiance characteristics of water in the near-infrared wavebands (Work and Gilmer 1976). Therefore, our basic task was to train the computer to differentiate between water and dark soils.

Thematic water mapping with the thresholding technique was the primary procedure used to analyze Landsat data collected each spring (usually May) and summer (usually July) from 1972 to 1976 (only summer data were collected in 1972). Our intent was to investigate both seasonal and annual changes in surface water conditions. Figure 3 is an example of a

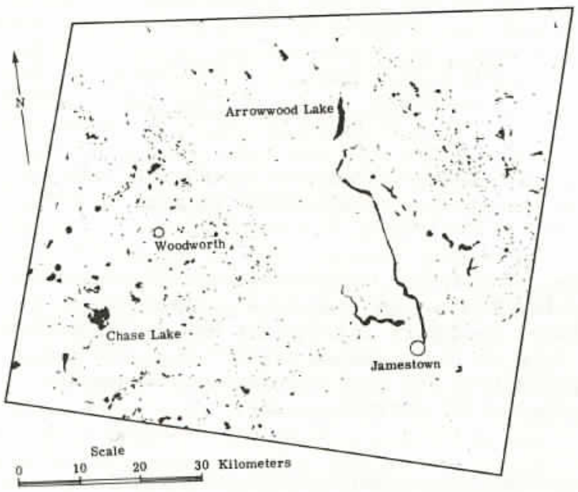

Figure 3.--Computer generated thematic water map from a Landsat observation on 15 July 1975.

thematic water map produced from an analysis of Landsat MSS data collected on 15 July 1975. The scene shows open water areas larger than about 0.4 ha. Abundant water is present at this time, particularly in the Coteau subregion (southwest portion of the map). Abnormally abundant rainfall created considerable standing water in fields and pastures during the summer of 1975.

Maps generated with a general purpose digital computer were unwieldly to handle and analyze if the scene was larger than approximately 5 percent of a Landsat frame. Therefore, these data products were not efficient for wide-area surveys. Data had greater value if they were presented in terms of tabulations and statistical tables. Capability for tabulation and statistical summaries was part of the computer software developed to analyze the Landsat data.

A program was designed to tabulate the location (Universal Transverse Mercator and latitude/longitude coordinates), perimeter, and surface water area of each pond and lake detected by Landsat for any area designated within the study site. For example, the program listed 3995 detectable water bodies representing a total shoreline perimeter of 3409 km and a total surface water area of 214 km^2 for the area illustrated in figure 3.

The repetitive nature of Landsat data permits comparisons between seasons and years. In order to demonstrate this feature and to more rigorously apply the capabilities of our computer program, we derived separate pond counts for Landsat data collected each spring and summer from 1972-76. Figure 4 illustrates the changes observed by Landsat in pond numbers

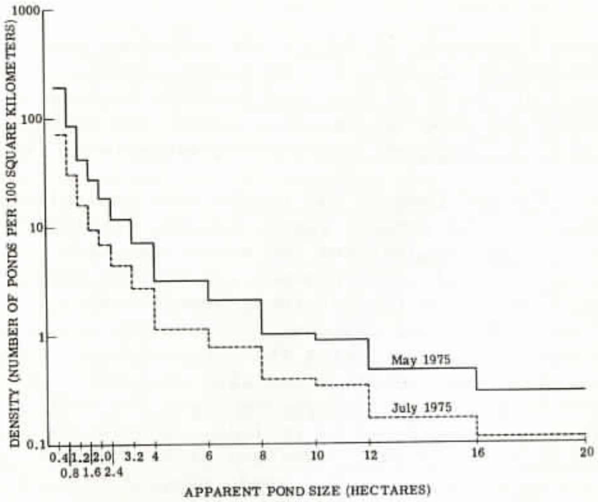

Figure 4.--Changes in Landsat indicated size distribution of ponds in FWS Stratum 46 as observed between May and July of 1975 (Colwell et al. 1978).

for the spring to summer period of 1975 determined for FWS Stratum 46. Wetland densities in the prairie pothole region are typically higher during the spring than in summer.

To evaluate the effectiveness of Landsat pond counts we compared these data to other independent sources of pond counts. These were counts made by FWS personnel along aerial transects within FWS Stratum 46 during breeding ground surveys conducted during May and July of each year. A comparison of July data (fig. 5) illustrates that Landsat counts were always

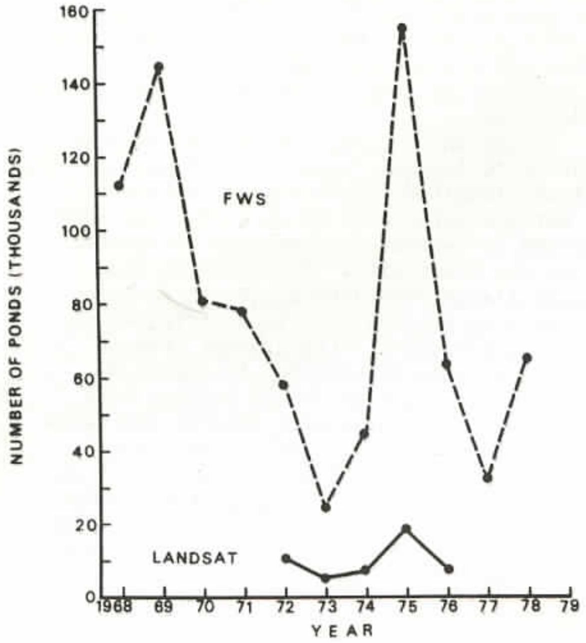

Figure 5.--Number of July ponds estimated for Stratum 46 as derived from aerial survey data of the U. S. Fish and Wildlife Service (FWS) and from Landsat data (Rebel and Work 1977, E. Ferguson personal communication).

less than FWS counts, but trends were generally parallel. The primary reason for the discrepancy between Landsat and FWS counts was that the majority of prairie ponds (70 to 80%) were less than 0.4 ha (Millar 1969, Drewien and Springer 1969) and consequently were not detected by Landsat using the thresholding analysis. The average proportion of water areas detected was 19.7 percent over the nine spring and summer survey periods. Generally, open water areas must have been at least 0.4 ha to be recognized. For ponds ranging in size from 0.4 to 1.6 ha, recognition was probable if the pond was wholly included in one digital sample. If a pond was fractionally distributed among several samples, detection may not have occurred. Our results indicated that open water areas larger than 1.6 ha were consistently detected, although not necessarily in their full size.

In an effort to improve estimates of surface water numbers, we experimented with a double sample analysis in 1975 which used both low altitude aircraft data and Landsat data. The intention was to develop correction factors based upon a Landsat/aircraft double sample (1%) which could be used to adjust the Landsat data. Visual counts of wetlands were made from imagery acquired from NASA aircraft operated at approximately 1500 m above the terrain. The comparison was done using a linear regression analysis, after which standard statistical procedures (Cochran 1963) were used to adjust the pond and lake count to a realistic estimate of water body occurrence. Figure 6 illustrates the analysis for May

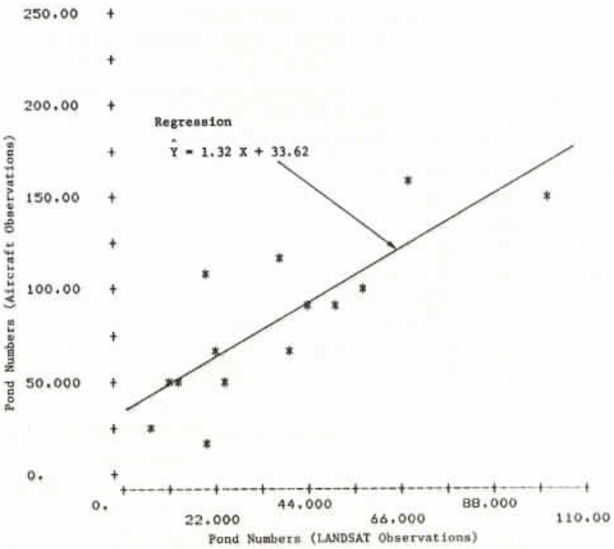

Figure 6.--Sample linear regression of pond numbers (from aircraft data) on pond numbers (from LANDSAT data) for May 1975.

ponds. The double sample-corrected Landsat data for Stratum 46 indicated surface water features to number 168,813 for May and 150,565 for July of 1975. These figures were 108 and 97 percent of FWS pond and lake estimates for the respective survey periods.

MAPPING AND CLASSIFICATION OF VEGETATION

Evaluation of waterfowl habitat is dependent on the ability to assess upland as well as wetland habitat conditions. Upland habitat provides nesting cover for many species of ducks. To determine the utility of satellite sensors in this regard, we selected a

2200 km^2 area as a test site to evaluate vegetation mapping and land-use classification techniques. We were limited in our choice of an optimum phenological period to either May or July Landsat data. Because land cover features in July presented greater spectral diversity, we selected data acquired on 7 July 1973 for analysis.

Recognition maps were produced using a maximum likelihood criterion with statistical pattern recognition techniques. To improve the accuracy of classification, we first identified all water data points using the thresholding technique. Pattern recognition processing using all four Landsat MSS channels was applied only to non-water data points. The water and non-water classification maps were then superimposed to produce the final recognition map (Work 1974).

The classification categories included water, deep marsh vegetation, shallow marsh vegetation, bare soil, row crops (corn and sunflower), small grain crops, and range. These categories were potentially separable using multispectral techniques and were meaningful relative to waterfowl ecology. Categories not included in the seven groups were combined as an "other" category. Similarity of spectral signatures between various types of grasslands necessitated the inclusion of all grassland areas into a "range" category.

Before a recognition map was produced, we performed an analysis to predict classification accuracy and to determine which signature pairs were most likely to be misclassified. This analysis indicated that frequent classification errors were to be expected between the shallow-marsh and small grains. Some classification difficulties were also anticipated for the deep-marsh/small grains, range/shallow-marsh, and deep-marsh/shallow-marsh paired combinations. These results indicated that the differences in spectral reflectance between green herbaceous vegetation present in the scene were relatively subtle.

Examination of our computer generated classification maps indicated that many large land cover features were accurately delineated and that a general land-use pattern was present (fig. 7). This map utilized printer characters to code various land cover features and includes only a small fraction of the area actually mapped. The final recognition map was in fact produced at a smaller scale and utilized a system of color coded imprints rather than the printer characters shown. Based on an analysis of selected areas within the mapped scene, an approximate overall classification accuracy of about 75 percent was indicated. In spite of the overall accuracy achieved, the misclassification was sufficient to detract from the usefulness of

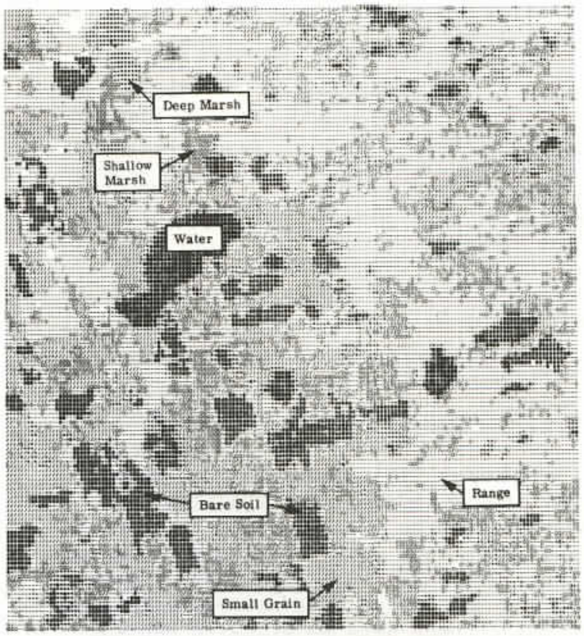

Figure 7.--Example of a character coded recognition map for a 115 km^2 area near Woodworth, North Dakota. The final map was color coded and included 2200 km^2.

the map for a detailed habitat evaluation. The discrimination of upland land-use patterns appeared to be more consistent and accurate than of wetland vegetation types. This inability to accurately delineate wetland vegetation can be attributed to a lack of spectral contrast when compared to upland features and to the limited areal extent of many prairie wetland features coupled with the coarse resolution capabilities of the current Landsat scanner. The discrimination of prairie wetland features presents greater difficulties than the mapping of many coastal wetland areas that are frequently characterized by the occurrence of extensive areas of homogenous often monotypical vegetation (Reimold et al. 1973, Klemas et al. 1975).

The need for improved accuracy prompted us to experiment with a multitemporal approach to terrain classification. Data from a selected scene was obtained at two different phenological stages (15 July and 6 September 1975). The two data sets were superimposed and an optimum subset of four bands were selected for processing. The results described by Colwell et al. (1978), indicated a greatly enhanced classification accuracy over that obtained with data from a single date. The tabulation shows the theoretical probability of correct classification by categories for both the multidate and single date analyses. Improved accuracy was particularly evident in the shallow marsh and small grain categories.

	(Multidate) 1975	(Single Date) 1973
Bare Soil	96.4	90.4
Deep Marsh	86.4	60.6
Shallow Marsh	86.2	48.1
Small Grain	85.3	36.5
Row Crop	89.9	74.8
Range	79.8	68.1

SUMMARY AND CONCLUSIONS

Resolution limitations in the Landsat scanner system reduced our capability for detecting features such as ponds and various habitat units that were in the size range of 0.4 ha or smaller. In the opinion of some biologists this presents a serious limitation in applying these data to wildlife habitat assessment. We were able to alleviate this difficulty somewhat by the use of an aircraft/ Landsat double sample.

Classification accuracy of Landsat data was limited in the prairie pothole region because of the similar spectral response produced by agricultural crops (mostly small grains) and natural upland and wetland vegetation. Selection of MSS data obtained during the late summer or early fall may facilitate vegetation classification because spectral signatures from different plant communities may show greater variation than at other times due to plant senescence and moisture stress conditions. The availability of a wide range of wavebands would also improve classification potential. Multitemporal analysis provided a significant improvement in our classification accuracy. However, this approach was time consuming due to the need for precise geometric registration of data sets. As a result we made limited use of the technique. In the future the geometric fidelity of Landsat data can be expected to improve (National Aeronautics and Space Administration 1978) which will facilitate multitemporal processing.

Costs must be considered in most research or operational analysis of remotely sensed data. Various kinds of computer processing require more computer time and therefore result in greater expenses. Analysis of a single channel of data was the least expensive of our processing techniques. The cost of processing was approximately $1.30 per 100 km^2 with the single-channel thresholding technique. Pattern recognition processing, a multispectral analysis technique, required the handling of multiple data channels. For this reason computer costs were higher by approximately a factor of ten. These are all estimated costs which do not include software development. Processing and storage of large volumes of data requires care in data handling procedures if economy is to be optimized.

In spite of certain resolution and classification limitations, the Landsat data acquisition system combined with computer aided analysis techniques provides a unique tool for rapidly assessing regional terrain conditions. Perhaps the most significant aspect of the Landsat remote sensing systems is the repetitiveness of its coverage. Because of this feature, it is now possible for biologists to gather temporal data, revealing long and short term habitat changes. This feature makes Landsat particularly promising for assessing the dynamic nature of waterfowl habitat in the prairie pothole region.

LITERATURE CITED

COCHRAN, W. G. 1963. Sampling techniques. J. Wiley, New York. 413 pp.

COLWELL, J. E., D. S. GILMER, E. A. WORK, D. L. REBEL, AND N. E. G. ROLLER. 1978. Use of Landsat data to assess waterfowl habitat quality. Final Rep. prepared for National Aeronautics and Space Admin., Greenbelt, Maryland. 83 pp.

CRISSEY, W. F. 1969. Prairie potholes from a continental viewpoint. Pages 161-171 in Saskatoon wetlands seminar. Can. Wildl. Serv. Rep. Ser. 6. 262 pp.

DREWIEN, R. C., AND P. F. SPRINGER. 1969. Ecological relationships of breeding blue-winged teal to prairie potholes. Pages 102-115 in Saskatoon wetlands seminar. Can. Wildl. Serv. Rep. Ser. 6. 262 pp.

GEIS, A. D., R. K. MARTINSON, AND D. R. ANDERSON. 1969. Establishing hunting regulations and allowable harvest of mallards in the United States. J. Wildl. Manage. 33(4):848-859.

KLEMAS, V., D. BARTLETT, AND R. RODGERS. 1975. Coastal zone classification from satellite imagery. Photogrammetric Engineering and Remote Sensing 41(4):499-513.

MILLAR, J. B. 1969. Some characteristics of wetland basins in central and southwestern Saskatchewan. Pages 73-101 in Saskatoon wetlands seminar. Can. Wildl. Serv. Rep. Ser. 6. 262 pp.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION. 1978. Landsat newsletter, No. 20. Missions Utilization Office, Goddard Space Flight Center, Greenbelt, Maryland.

NELSON, H. K., A. T. KLETT, AND W. G. BURGE. 1970. Monitoring migratory bird habitat by remote sensing methods. Trans. North Am. Wildl. Nat. Resour. Conf. 35:73-84.

REBEL, D. L., AND E. A. WORK. 1977. Mapping of prairie surface water features for an extended temporal period using Landsat data. Final Rep. 25500-7-F. Environmental Research Institute of Michigan, Ann Arbor. 30 pp.
REIMOLD, R. J., J. L. GALLAGHER, AND D. E. THOMPSON. 1973. Remote sensing of tidal marsh. Photogrammetric Engineering 39(5): 477-488.
SMITH, A. G., J. H. STOUDT, AND J. B. GOLLOP. 1964. Prairie potholes and marshes. Pages 39-50 in J. P. Linduska ed. Waterfowl Tomorrow. U. S. Gov. Printing Office, Washington, D. C. 770 pp.
STEINER, D., AND A. E. SALERNO. 1975. Remote sensor data systems, processing, and management. Pages 611-803 in R. G. Reeves (ed.). Manual of Remote Sensing, Vol. I. American Society of Photogrammetry, Falls Church, Virginia. 867 pp.
STEWART. R. E. 1975. Breeding birds of North Dakota. Tri-College Center for Environmental Studies, Fargo, North Dakota. 295 pp.
WORK, E. A., AND F. J. THOMSON. 1974. A study of waterfowl habitat in North Dakota using remote sensing techniques: phase II. Tech. Rep. No. 101000-12-T. Environmental Research Institute of Michigan, Ann Arbor. 96 pp.
_________. 1974. Application of the Earth Resources Technology Satellite for monitoring the breeding habitat of migratory waterfowl in the glaciated prairies. MS Thesis. Univ. of Michigan, Ann Arbor. 107 pp.
_________, AND D. S. GILMER. 1976. Utilization of satellite data for inventorying prairie ponds and lakes. Photogrammetric Engineering and Remote Sensing 42(5):685-694.