Application of Remote Sensing Data for Site-Specific Wildlife Habitat Analysis in the United States [1]

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Abstract.--Remote Sensing is being increasingly utilized for site-specific wildlife habitat analysis by public agencies and the private sector. Unfortunately, the needs of the user group with the greatest capability for productive use of these techniques (i.e., the hands-on field research or management biologists) are going largely unattended.

For the purposes of this discussion, site-specific is defined as that kind of habitat analysis which is total for the area of concern -- i.e., a 100 percent classification, whose components are identified to geographic position and, presumably, subject to location in the field. By contrast, a non-site-specific analysis is considered to be based upon data derived from a sampling scheme providing an estimate of overall habitat types and conditions, but which does not specifically identify all components in the area of interest nor locate them geographically. Both types may, however, involve more than one stage (level) of remote sensing.

Depending upon the management objectives and the operational resources available for its accomplishment, a site-specific analysis may vary in extent from a sizable portion of the earth's surface, all the way down to a unit of landscape less than an acre in size. A unique example of an extensive application is found in the use of VHRR (NOAA) weather satellite imagery to assess snow and ice conditions in the Arctic during the goose nesting period (Reeves et al. 1976). At the other extreme is a locally operational 35mm aerial photography system initially developed by the U.S. Bureau of Land Management for range vegetation and wildlife habitat analysis (Meyer 1973).

Unless the area is small, or the classification scheme very broad, it is a rare instance where the analysis is truly verified for all components and locations. Whether the analysis is made by remote sensing methods and/or field methods, the final solution is normally a product of extrapolation of known conditions at selected locations to areas in between. What is important is the efficiency, economy and accuracy with which these extrapolations are made so as to accomplish a reliable site-specific analysis of the total management area -- be it large or small. It is at this point where remote sensing applications are, increasingly, capable of extending and enhancing to a remarkable degree the wildlife manager's professional capabilities and credibility -- usually without significant increase in overall operational costs.

A shift from conventional ground systems of analysis (many of which already incorporate remote sensing techniques to some degree) to one involving significantly greater reliance upon remote sensing tools is not necessarily a painless process. In this regard, Parker (1977) strongly recommends the following preliminary considerations: (1) the clearest possible definition of the ultimate purpose of the data to be collected, (2) data specifications and consideration of possible methods for acquisition, (3) determination of funding and time

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available, and (4) selection of a suitable means of data analysis.

Despite the availability of a number of proven and cost-effective techniques, a lack of user training and economic constraints (particularly to implementation) have been a major obstacle to a beneficial shift to more productive uses of remote sensing. Traditionally, and in terms of areal extent, complexity and aggregate value of the resources assigned to his responsibility, the average wildlife biologist has had to operate at a disproportionately low staff and funding level, as compared to most other subject matter specialists in the natural resource management arena. Fortunately, this situation is changing, not everywhere and not always quickly or adequately, but progress is significant and continuing.

Concurrently with improvements in the economic sector, increasing numbers of wildlife biologists are receiving training in remote sensing in their college academic programs, at shortcourses and on-the-job training. Entirely too many, however, still have not had the opportunity for suitable training. Even so, some have done an amazing job of self-education, technique development and implementation, often in the face of a lack of facilities and/or encouragement on the part of their parent organizations. As a case in point, and on the basis of a good idea and some "poor boy" out-of-pocket innovation, near-vertical color infrared 35mm aerial photography was very successfully applied by Berg[3] to the development of baseline information, planning, monitoring and analysis of controlled burning to manipulate and improve sharp-tail grouse habitat.

Given some motivation, training and modest funding and facilities, where does the prospective remote sensing applicator turn for useful technique information? Although more remote sensing application items are finding their way into refereed journals of interest to wildlife biologists, the majority of uses are only to be found in such limited circulation documents as Pittman-Robertson reports, environmental impact statements, etc., or are incorporated without fanfare into the management plans or survey analyses whose preparation they served. Obviously, this report cannot provide an enumeration of all, or most, of the useful site-specific wildlife habitat analysis remote sensing applications in the United States. At best, a sample of some basic types will be presented, most of which represent a high degree of familiarity to the writer, either in terms of first-hand information from users, or on the basis of personal involvement. By the same token, the scope of coverage will be further narrowed by concentrating mainly upon the needs of the particular user group whose potential is considered greatest, but whose needs have been largely ignored to this point in time -- i.e., the hands-on, practical field research and management biologists. Any accusations to the effect that this report suffers from parochialism and personal bias will be feebly denied, if at all!

Although intensive local user site-specific remote sensing applications are stressed here, it will be noted that considerable investigative effort is in progress on extensive applications of LANDSAT data and high altitude aerial photography. Representative of studies of this type is an assessment by the Kansas Forestry, Fish and Game Commission (1976) of the utility of these forms of remote sensing to an inventory of wildlife habitat in Kansas. Waddell,[4] a participant in the Kansas study, noted encouraging possibilities, but indicated that local funding for follow-up work is often difficult to obtain. Werth,[5] who is conducting a test of LANDSAT data applicability to wetlands classification in a large portion of the northern hardwoods/prairie border area of Minnesota (a complicated landscape), indicates that, in addition to funding problems associated with LANDSAT data use in a truly site-specific application, other aspects of its procurement and application must also be carefully considered: (1) possible difficulties in obtaining single date or multitemporal coverage at a time, or times, best correlated with important short term habitat features such as plant growth stage, water level, animal or bird activity patterns, etc., (2) the relative ability of the coverage to discriminate and adequately useful range of surfact types, (3) selection and implementation of the best data analysis system, (4) possible inability of the system to discriminate small, but important, habitat units, (5) geographic placement accuracy of the final solution, and (6) possible problems of dealing with categories whose accuracy, in terms of errors of omission and commission, is unacceptable. As a case in point, he related his inability with LANDSAT to reliably detect water bodies below 10 acres in size and encountered unacceptable errors of omission and commission in the discrimination between (and within) some basic broad upland and wetland cover types. Colwell, et al. (1978), in similar investigations in North Dakota appear to have encountered similar problems and have, subsequently, developed a sophisticated system of aircraft underflights

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[3] Pers. comm., Wm. Berg, Wildl. Biol., Minn. DNR, Grand Rapids.

[4] Pers. comm., Bruce Waddell, Wildl. Biol., U.S. Bur. Land Mgmt., Rawlins, WY

[5] Pers. comm., Lee Werth, Res. Assoc., Univ. Minn. Coll. Forestry, St. Paul.

and ground checking to adjust, extend and refine the LANDSAT-based estimates of waterfowl habitat quality for large areas. Reports on this and similar projects being presented at this Symposium will doubtless further clarify and better define the current state-of-the-art of extensive site-specific applications such as LANDSAT.

Not surprisingly, most intensive user applications have been developed by natural resource management agencies, either on an in-house basis or by means of short term sponsored projects involving outside cooperators. An unusually thorough development-training-implementation operation has been developed over the past six years by the Montana State Office of the Bureau of Land Management. Its goal is the use of remote sensing to significantly extend the professional capabilities of personnel at the field level. Its success is in large part due to the fact that the users involved possess the ultimate qualifications to apply remote sensing techniques: (1) training, (2) local familiarity, (3) practical field experience, and (4) direct responsibility for the use and application of the data produced by the remote sensing technique(s) involved. During this period, a support system of 35mm aerial photography and interpretation was developed (Meyer 1973, Meyer and Grumstrup 1978) which is now also widely used by other public agencies and, to some extent, the private sector. This photography serves to document critical small area features such as vegetation transects, browse conditions, prairie dog towns, etc. (U.S. Bureau of Land Management 1974), in support of the 1:31,680 scale 9x9-inch format color infrared aerial photography scheduled for 100 percent coverage of each resource management area on a recurring basis. The necessary viewing and mapping equipment, and training in its use, is provided at as many field locations as possible.[6] A remote sensing specialist position, occupied by an individual combining remote sensing expertise with a professional resource management background and experience, was established in the State Office to provide training and maintain the highest possible level of state-of-the-art technique capability and application. The total vegetation cover and surface feature maps prepared from the 1:31,680 scale CIR photography are used by the wildlife biologists for their management planning and as a base for field examinations.

A very useful application of available photography flown sequentially over the years was accomplished in the Upper Mississippi River floodplain by the Environmental Branch of the St. Paul District, Army Corps of Engineers. Current 1:24,000 scale B&W IR photography was obtained at high pool and low pool river stages between Minneapolis, Minnesota, and northern Iowa. All possible water conditions, terrestrial, emergent and submergent vegetation types, and dredged materials were identified and transferred to overlays registered to 1:6,000 scale photomaps. Based upon available records, maps, interviews, etc., similar overlays at the same scale were developed from 1:20,000 scale 1938-39 USDA aerial photography. Fortuitously, another set of aerial photography, flown by the U.S. Navy in 1929, was discovered and a third historical set of 1:6,000 scale overlays was prepared. The latter coverage was particularly useful since it was taken prior to the establishment of the current structures in the river and, overall, a unique historical analysis of the river floodplain was possible (Olson and Meyer 1976a, 1976b) to which current habitat conditions could be related.

Following the Corp's analysis of historical vegetation changes on the Mississippi River above Guttenberg, Iowa, the U.S. Fish and Wildlife Service's Office of Biological Services in the Twin Cities Regional Office undertook a baseline habitat data collection project on the Mississippi floodplain beyond Guttenberg to Cairo, Illinois (Hagen et al. 1977). The 1:24,000 scale color infrared photography used on this portion of the river proved to be considerably more effective in habitat type delineation than the B&W infrared used on the upper portion (8 open water classes, 14 aquatic and marsh types, sand, mud, 5 terrestrial herbaceous types, 7 woody vegetation types, 5 land use types and 9 dredged material types could be identified). Simultaneously, and because much more detailed habitat information was required than had been collected previously, the critical management portions of the river between Hastings, Minnesota, and Guttenberg, Iowa, were flown at a scale of 1:9,600 with color infrared photography and the 67 identifiable habitat types and land uses were classified down to units less than one acre in size (Minor et al. 1977). In both studies, where extremely complicated habitat types and/or below average commercial photography coverage quality occurred, both 35mm and 70mm color infrared support photography was used to good purpose.

A four-year project recently completed by the U.S. Forest Service's Pacific Northwest Forest and Range Experiment Station on the Chugach National Forest in Alaska, illustrates the utility of both standard 9x9-inch format and 35mm support aerial photography to evaluate waterfowl habitat on large, relatively inaccessible, coastal areas. During this period, 1:15,840 true color 9x9-inch format photography was used to compile vegetation type maps to a 2-acre minimum and evaluate the effects of the

[6]Pers. comm., Fred Batson, Remote Sens. Spec., MSO, USBLM, Billings, MT.

1964 earthquake on the waterfowl habitat on 264,000 acres of the Copper River Delta and on over 123,000 acres of the Bering River Delta (Potyondy et al. 1975, Scheierl et al. 1976, Scheierl et al. 1977, Hagen et al. 1978). Pre-earthquake photography was used in one area to assess the gross effects of the earthquake upon the drainage pattern and general vegetation types. Large scale vertical color and color infrared 35mm vertical photographs of carefully selected key habitat types were taken to provide baseline date for cover type analysis and to serve as controls for future assessment of plant successional changes resulting from the 1964 uplift. All were carefully located on the base maps for future relocation, as were low altitude 35mm true color obliques of typical vegetation types. The obliques were projected onto a screen alongside the interpreter as an aid to recalling key vegetation types and locations when the 1:15,840 scale photographs were being interpreted. Because of time requirements, funding limitations and extremely difficult access problems, this mapping and analysis effort would not have been possible without intensive use of remote sensing techniques.

Simultaneously, a similar project undertaken by Derksen,[7] has been in progress on the North Slope region of Alaska. He is using 1:24,000 9x9-inch format photography as a broad reference and classification base -- supported by vertical, large scale color infrared 35mm aerial photography for the following purposes: (1) assessment of wetland evolution through establishment of photo trend plots, (2) evaluation of the effects of gravel roads on Arctic Coastal Plain wetlands by comparative photo plots, and (3) identifications of vegetation communities preferred by molting geese taking sequential shots along lake shoreline for comparison with the 1:24,000 color photography.

Also indicative of the increasing interest in localized applications of remote sensing on the part of the U.S. Forest Service is the fact that 35mm aerial photography and analysis equipment, along with specialized training has been provided to personnel of the Malheur National Forest in Oregon[8] and the Gallatin, Beaverhead, Helena and Lewis and Clark National Forests in Montana.[9] A primary application is to the analysis of riparian zones, a task now well underway on the Malheur National Forest. Basically, the technique involves development of the past history of critical stream course vegetation on the basis of previous aerial photography, maps and other applicable data. The 35mm system is used to provide current data to compare with the baseline information in order to establish trends, determine possible causes of deterioration and to prepare plans for management.[10] Cuplin (1978) used the same type of 35mm photographic system very effectively for stream inventories and documentation of existing stream habitat conditions, and Miller et al. (1976) found 70mm true color 1:15,840 scale vertical photography effective for identifying white alder in riparian plant communities in Idaho.

The value of past photography in the reconstruction of habitat treatment history as it relates to current wildlife populations is illustrated by a study underway by the U.S. Forest Service's North Central Experiment Station. They are examining the relationship of resident black bear, whitetail deer and moose populations to past vegetation history on a 33 square mile portion of the Superior National Forest, Minnesota.[11] The data base in this study consists of a detailed vegetation map with six registered overlays: (1) plantations, (2) site preparation methods, (3) plantation release, (4) cutting pre-1948, (5) cutting 1948-1961, and (6) cutting 1961-1974 (Hagen and Meyer 1977). The vegetation map was prepared from 1970 B&W summer infrared photography updated with 70mm color infrared photography and field examination of selected areas. The overlays were based upon past aerial photography and Forest Service maps and management records. Wildlife observations are accurately located on the map series and analyzed in terms of site vegetation historical treatment.

Small-format (35mm) vertical color infrared photography has been effectively used by Dr. Robert Eng, Professor of Wildlife Management at Montana State University, as an assessment tool in studies sponsored by the U.S. Bureau of Land Management, Bureau of Reclamation and the Montana Fish and Game Department.[12] Among the applications are: (1) evaluation of age classes of stockponds in relation to basic productivity and waterfowl use, (2) waterfowl preferences as related to pond (stock dam) size, distance apart, etc., (3) evaluation of lake aquatic and terrestrial vegetation changes as related to waterfowl use, and (4) recording changes in island construction by dredging activities and changes in aquatic vegetation.

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[7] Pers. comm., Dr. Dirk Derksen, Wildl. Biol., U.S. Fish & Wildlife Serv., Anchorage, AK.

[8] Pers. comm., Robert Storch, Range Staff Officer, Malheur NF, John Day, OR.

[9] Pers. comm., Neil Howarth, Range Cons., Gallatin NF, Bozeman, MT.

[10] Pers. comm., Charles Sundstrom, Wildl. Biol., Beaverhead NF, Dillon, MT.

[11] Pers. comm., Dr. Lew Ohmann, Ldr., Wildl. Hab. Mgmt. Res., USFS-No. Centr. For. Expt. Sta., St. Paul, MN.

[12] Pers. comm., Dr. R. Eng, Dept. of Biol., Montana State Univ., Bozeman.

Industrial and residential development encroachment upon wildlife habitat is an increasing problem in, and adjacent to, large metropolitan areas. Despite the existence of adequate development codes and permit systems, a recent site-specific inventory of habitat types is necessary. To provide these data, the U.S. Fish and Wildlife Service, Minnesota Department of Natural Resources, Twin Cities Metropolitan Council, U.S. Army Corps of Engineers and the U.S. Soil Conservation Service undertook the classification of the wetlands in the 3,000 square mile 7-county Twin Cities Metropolitan Area in Minnesota. This analysis (Werth et al. 1977, Owens et al. 1978) employed 1:24,000 CIR 9x9-inch format aerial photography flown in early summer. Wetlands below 2½ acres, but not less than 1 acre in size, were classified only as wetlands. The classification scheme used on wetlands 2½ acres in size or larger included 32 vegetation types and 6 surface features (river, open water, lake under 10 acres, mud, sand and non-wetland).

Particularly in the eastern coal-producing states, the U.S. Fish and Wildlife Service faces the monumental task of assessing thousands of current (and future) abandoned coal strip mines from the standpoint of "...the collection of sound technical data, the formulation of reclamation and rehabilitation prescriptions, evaluation of applied treatments and monitoring mining operations...." The problems both of locating and gaining ground accessibility to abandoned mines are considerable. To meet this information need, a system of 35mm vertical aerial photography and image analysis was developed and tested by the Office of Biological Services in Elkins, West Virginia.[13] The technique includes the use of LANDSAT or very small scale altitude aerial photography imagery to select project areas and plan the underflights. The small format photography can be scheduled and flown by a biologist or technician who is best prepared from the standpoint of local experience to select the time and characteristics of photography and locate the selected sites (Grumstrup and Meyer 1977).

Easily one of the best-equipped remote sensing application-integrated wildlife habitat research installations in the country is the U.S. Fish and Wildlife Service's Northern Prairie Wildlife Research Center at Jamestown, North Dakota. In addition to involvement in one of the most definitive tests of LANDSAT application to wetlands classification in the country, the Center is also heavily committed to intensive use of 70mm and 35mm aerial photography in its research projects. Primary applications of the small-format photography are to wetland ecology and documenting mallard duck preferred habitat. The wetland ecology studies involve establishment of selected wetland transects whose terminals are visible from the air -- followed by aerial photography, precise mapping and ground analysis. Periodic reflights and ground enumeration of these transects will ultimately provide indices to successional changes over time.

In the mallard duck habitat preference studies, selected birds are telemetered on their nesting locations marked for air visibility. These test locations are periodically and precisely flown with 70mm color and B&W photography and the nest locations and location characteristics related to surrounding features such as disturbances, open water, other wetlands and agricultural crops. Comparisons are further made on bird survival between the various types of locations and surroundings.[14]

Utilitarian applications of remote sensing to site-specific wildlife habitat are not limited to the public resource management sector. Industries whose activities influence such environmental features as water, soil, vegetation, wildlife and atmosphere are also increasingly dependent upon remote sensing data -- usually provided by consulting firms specializing in these services or, through establishment of in-house environmental staffs. One such consulting firm, in a manner similar to that used by some public agencies, provides the following services to a variety of clients:[15] (1) use of 1:80,000, 1:24,000 and/or 1:12,000 color infrared 9x9-inch format photography to prepare pre-extraction habitat type maps and record a variety of wildlife observations as they relate to waterfowl, upland game birds, deer, antelope, raptors, etc., (2) fly large scale 35mm vertical photography of carefully-selected pre-extraction key habitat areas to serve as controls for future comparisons, (3) establishment of transects with air-visible terminal markers on reclaimed areas, and (4) perform 35mm large scale overflights and analyses on these transects, usually 3-4 times per growing season (Econ Inc. 1976, 1977).

Nearly identical applications are utilized by the environmental staff of a Wyoming firm in connection with their operational mines in Wyoming and Montana. Their 35mm aerial photography system has proven particularly valuable, not only for monitoring rehabilitation areas, but as a means for analysis of wildlife

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[13] Pers. comm., D. Mellgren, Energy Activ. Ldr., USF&WS, Elkins, WV.

[14] Pers. comm., Dr. David Gilmer, Wildl. Biol., USF&WS, No. Prairie Wildl. Res. Center, Jamestown, ND.

[15] Pers. comm., Robert Carroll, Gen. Mgr., Econ Inc., Helena, MT.

activities and habitat on (as yet) undisturbed areas.[16] An unusual use of large scale vertical CIR 35mm aerial photography has been to photograph sagebrush cover types shortly after fresh snowfall to locate sage grouse use areas, obtain estimates of flock size and analyze patterns of differential food and cover use. Individual bird tracks and flight takeoff points are clearly visible on the photographs!

This brief description of a representative number of practical state-of-the-art remote sensing applications to site-specific wildlife habitat analysis suggests some of the possibilities available to prospective users. Many of the techniques are amazingly simple, relatively inexpensive and require little in the way of training and experience to make them profitably effective in the hands of the field biologist. This is somewhat contrary to the notion that (at times) appears to pervade segments of the scientific community to the effect that unless a method is attended by expensive hardware, whistles, bells, myriads of mystic buttons and switches, printouts, flashing lights, PhDs in white lab coats and an incomprehensible technical jargon (even for simple terms used by ordinary folks) -- its worth is subject to question. In rebuttal, one might point out the continuing utility and importance, in our highly complex technological society, of shoelaces and baling wire!

Compared to simple field level applications, a great deal more money is now being spent on the testing and development of sophisticated systems of remote sensing analysis of surface resources, in the hopes of developing some type of reliable, accurate system of monitoring conditions over large land areas. There is no quarrel with this, so long as it does not become so remote from the intended user in its development and application that it becomes the end rather than the means. Unfortunately, the end products of a few of these efforts are deemed questionable because they purport to present applications for use in wildlife management -- or forestry, or range, or hydrology, or whatever -- but which suffer from the lack of input from experienced field professionals in the subject matter area under investigation.

What is more disturbing, however, is the lack of effort currently being put into equipping the practicing field professional with functional remote sensing tools. It is obvious from some of the working examples presented here that, with a little training and some relatively simple remote sensing equipment -- at the approximate cost of a used (high-mileage) pickup truck -- capability and efficiency can be substantially and cost-effectively enhanced. It is to be hoped that, increasingly, some of the methods now in use in some of the public resource agancies and private firms will be noted and beneficially incorporated into the operations of other equally capable potential users.

[16] Pers. comm., Robert Legoski, Remote Sens. Spec., Peter Kiewit Sons Co. Mining Dist., Sheridan, WY.

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Remote Sensing for Wildlife Habitat Analysis in Canada, An Overview[1]

Glen D. Adams[2]

Abstract.-- Recent applications of remote sensing to wildlife habitat surveys in Canada were reviewed by region and related to three phases: inventory, monitoring and habitat analysis. Remote sensing has been stimulated by northern biophysical and resource impact surveys; but classification criteria need to be integrated with indexes of wildlife habitat use. Most agencies are employing airborne sensing techniques, but usage of Landsat data is increasing.

INTRODUCTION

The synoptic view of the earth's surface provided by space-borne remote sensing has enabled man to perceive and monitor habitats of living organisms from an entirely new perspective. This development has stimulated integrated resource studies causing investigators to examine interactions in the whole ecosystem, rather than studying its isolated components. In a broad sense habitat is a structural manifestation of ecosystems, as it connotes the natural environment of living organisms, often expressed by encompassing plant communities (Schwarz, Thor and Elsner 1976). Since many environmental remote sensing surveys usually embrace some aspects of surface vegetation cover, they have direct or indirect applications to the analysis of wildlife habitat.

Information must be compiled from many diverse subjects including interdisciplinary studies, to obtain a national perspective on an applied field of remote sensing. This review attempts to draw upon current unpublished information as determined from questionnaires and reports, as well as published literature sources. Although emphasis has been placed upon studies conducted by federal and provincial government agencies, individual researchers and private consultants across Canada were contacted. The author does not vouch for completeness of survey results since some applications were probably overlooked, some reports were not available, and there were some non-respondents. Almost 100 potential investigators were initially contacted, and all contributors to this review were acknowledged.

Reviews of Environmental Remote Sensing

Several important review papers have dealt with the development or role of remote sensing in environmental studies, including some wildlife applications in Canada.

Parry (1973) presents an historical review of the development of air photo interpretation in Canada. Considerable progress occurred in the field of forestry where techniques such as densitometry and tree species recognition were applied using panchromatic and colour infrared (CIR) film. Aerial photo studies, especially in northern Canada established criteria which are now used for evaluation of northern wildlife habitats. Aerial photography was used by the Canadian Wildlife Service (C.W.S.) and other wildlife agencies, to confirm and supplement visual aerial estimates of populations of bison *(Bison bison)*, moose *(Alces alces)*, beaver *(Castor canadensis)* and caribou *(Rangifer tarandus)*. Heyland (1972) conducted an extensive review of the literature concerning animal census by aerial photography.

McQuillan (1975) outlined the potential multiple use benefits of remote sensing, especially Landsat, in northern resource developments. Benefits include the establishment of baseline data for environmental impact assessment, providing a space-time reference system for dynamic phenomena, storing physical and biological data in digital and retrievable reference formats, and the provision for supervised and automated processing and updating of remote sensing data. Critical northern areas where wildlife habitat studies are in progress or needed include transportation and energy corridor route selections such as the Mackenzie Valley, and offshore oil exploration areas such as the Beaufort Sea. There are requirements

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for more detailed inventories and monitoring of wildlife migration, breeding and wintering areas, with particular concern for endangered species.

In a discussion of applications of remote sensing to Arctic ecology, Lavigne and Falconer (1975) stress the role of Landsat in providing a means to map and monitor critical wildlife ranges, and to update Arctic ecology map series. A general review of applications to arctic ecosystems by Lavine, Øritsland and Falconer (1977) outlines the potential of Landsat to map habitat types, record snowmelt progression and determine dynamics of arctic ecology.

Sayn-Wittgenstein and Aldred (1976) document uses of remote sensing for environmental monitoring purposes. In forestry there is a trend to adopt multistage sampling techniques using Landsat imagery and multiscale photography for selective detection of environmental parameters at varying heirarchical levels. Remote sensing contributes to wildlife habitat studies, by means of vegetative mapping, forest inventories and agricultural surveys.

INVENTORY AND CLASSIFICATION

Arctic and subarctic Regions

Biophysical Studies

Biophysical studies which utilize terrain types or land systems as their basic map units, have important wildlife applications especially in northern Canada. On Boothia peninsula in the Northwest Territories, Tarnocai, and Netterville (1976) have conducted a biophysical inventory, mapping genetic landforms, soils and vegetation cover from 1:60,000 panchromatic photography and Landsat imagery. Similarly, in the Mackenzie Delta, Reid and Calder (1977) mapped and catalogued terrain types, vegetation units, wetlands, and permafrost features from medium scale photography. Near Rankin Inlet, Rowe, Cochran and Anderson (1977) interpreted large scale aerial photography for delineating and studying the relationships between terrain and vegetation units. Reid and Janz (1974) sampled ground plots in the taiga of the Mackenzie Valley, using 1:24,000 colour and panchromatic photography to map and correlate terrain units with vegetation types. In a comprehensive biophysical survey on caribou range near Lockhart River, Rowe and Tarnocai (24.) are using Landsat imagery and 1:30,000 aerial photography to map ecological regions and classify land systems. They are documenting historical forest burn-overs which have implications for evaluating plant successional relationships on caribou range. Another inventory in northern Manitoba is attempting to relate caribou movements to mapped biophysical units (6.).

A major biophysical inventory being undertaken in the Hudson Bay Lowlands of Ontario, is assessing soil-vegetation gradients, zones of paludification, wetland classes and shore habitat (Cowell, Wickware and Sims 1978). Visual mapping and automated classification of Landsat digital data show promise for delineating critical habitats for geese, ducks, shorebirds and the rare Eskimo curlew *(Numenius borealis)* (Anon. 1978).

Vegetation Mapping

Various studies have employed aerial photographic interpretation to detect and map vegetation for evaluation of arctic and subarctic caribou range. Parker (1975), Miller (1976) and Thomas (Thomson 1975) of the C.W.S., mapped vegetation cover and habitat types from variable scale photography using visual techniques. Problems arose in identifying features because of terrain shadows. Parker was able to identify moisture regime gradients and most range-types, but distinguishing between alluvial shingles and eskers, and discriminating moss-sedge-lichen meadow types were difficult. Miller (1976) used aerial photographs to map and interpret types of forest burns. Investigators for Arctic Gas Company applied visual interpretation methods for the initial inventory phases along the proposed pipeline routes in the Mackenzie Delta (Reid and Calder 1977) and the Mackenzie Valley (Reid and Janz 1974). Vegetative communities, tree cover and wetlands were mapped and classified. In attempting to assess potential impacts of the Mackenzie Highway construction on waterfowl use, Kemper, Thompson, and Quinlan (1977) interpreted aerial photography to delineate and obtain baseline data on representative wetland ecosystems. Pakulak, Sawka and Schmidt (1974) also demonstrated the feasibility of using CIR film for classification of eight vegetation types which are appraised for Canada goose *(Branta canadensis)* nest selectivity in the Little Seal River of Manitoba.

Digital analysis and computer classifications of Landsat have been tested for detection of arctic vegetation types. Tarnocai and Kristoff (1976) used band ratioing and cluster analysis to classify 14 terrestrial and eight aquatic classes in the Mackenzie Delta. Distinguishing features for most vegetation types was not feasible, although vegetated and unvegetated areas were discriminated. There was overlap in signatures of water, wetlands and bare soil. In the district of Keewatin, Thompson, Klassen and Cihlar (1978) applied a visual-digital approach using Landsat data to classify and map tundra vegetation cover for determining suitability of areas for caribou. Four vegetation complexes were identified by cluster analysis and were delineated visually on Landsat scenes. Cowell et al. (1978) used Landsat to develop classification signatures for fresh water marshes, swamp and fen classes in the Hudson's Bay Lowlands. Kozlovic and Howarth (1977) employed a supervised classification of Landsat, using a maximum likelihood decision to demonstrate thematic hue-tone signatures for 15 classes such as sedge meadows, peat meadows and salt marshes. These vegetation and wetland classes are important components of migratory bird habitat.

Boreal Regions

One of the first major operational uses of airborne remote sensing in Canada for wildlife habitat inventory purposes was the Peace-Athabasca Delta study. Concern for wildlife habitat alteration due to water regime changes caused by the Bennett Dam on the Peace River, prompted C.W.S. to initiate studies in 1968 (Dabbs 1971; Dirschl 1972; Dirschl and Dabbs 1972; and Dirschl, Dabbs and Gentle 1974). A multistage, and multitemporal photo sampling scheme employing 70 mm panchromatic, colour and CIR film, was established to record baseline data and monitor change along survey transects. A subjective key, assigning signatures to vegetative types, was based upon tonal, textural, stereoscopic form and colour characteristics (Dabbs 1971). Vegetative cover was correlated with water regime as a first step in appraising habitat suitability for waterfowl, muskrats *(Ondatra zibethica)*, moose and bison. Incorporating the 11 habitat types identified by Dirschl et al. (1974), Townsend (1973a) used 1:24,000 aerial photography to inventory and cover-map a large block of the Peace-Athabasca Delta.

Wickware (1978) continued to monitor water regime changes on the delta, but employed digital Landsat data to recognize most of the habitat types described by Dirschl et al (1974). Supervised and unsupervised computer classifications could not distinguish all classes; but visual interpretation of textural colour patterns assisted in differentiating vegetation and hydrological regimes. He had difficulty extracting spectral signatures to separate coniferous forest habitat from successional stages in the fen class.

The Athabasca Oil Sands area of Alberta, site of extensive petroleum developments, has been another focus for remote sensing inventories in the boreal forest. Syncrude Canada (1974) provided a review of remote sensing applications for obtaining baseline environmental data and for evaluating damage to terrain and stress to vegetation. Variable scale colour and CIR film was used in combination with Landsat imagery for mapping forest areas and muskeg, and for locating construction sites and exploration leases. Hursey (21.) described the use of multistage remote sensing in the visible and thermal infrared spectrum to map landforms, soils, vegetative communities, aquatic habitat and land use. Digital analyses as well as visual interpretation were conducted on Landsat scenes. Stringer (1976) reported on a preliminary vegetation survey, whereby vegetation types, fens and bogs were mapped from 1:21,000 scale infrared black and white film. Signatures corresponding to Munsell tonal values, texture and form, were ascribed to vegetation types. Additional ground truth studies correlated migratory bird use to these habitat types within the Oil Sands Area (Sharp, Birdsall and Richardson 1975).

R.M. Hardy and associates assessed sites for proposed heavy oil processing plants and coal mines in the Cold Lake and Swan Hills areas of Alberta (33.). From interpretation of 1:25,000 photography, they achieved accuracies of 85% to 95% in recognition of vegetation types. Computer enhancement techniques and density slicing of Landsat imagery did not achieve the same classification accuracies. Near Whitecourt, Alberta, a study is employing multistage vegetation mapping from enhanced CIR photography to develop a heirarchical legend classification for boreal forest and marsh-fen vegetation (Johnston 1978). Seventeen vegetative types were identified with an average accuracy of 93%. These results have applications for analysis of moose habitat in the boreal forest.

At Churchill Falls, Labrador, Bajzak (1975) described the use of variable scale panchromatic and CIR film to map vegetation types, surface deposits and wetlands along a 5-mile-wide perimeter of a reservoir. Classification of the shore zones had application for rating waterfowl habitats in the zones subject to inundation. In the James Bay territory, Quebec, C.W.S. biologists used variable scale airborne imagery to inventory stream and lake shore habitat for waterfowl (Soc. de Développement de la Baie James 1976).

In 1972, a joint federal-provincial program was initiated to carry out a 4-year program of biophysical inventories and other environmental studies to permit the assessment of potential impacts of proposed hydroelectric developments in the James Bay Territory, Quebec (Soc. de Développement de la Baie James 1976). The agreement included inventories and classification of land capabilities for waterfowl, moose, caribou and beaver. Landsat and airborne imagery were applied to a heirarchical breakdown of the Territory from land regions to the basic units: ecological land types. Vegetative classifications were apportioned quantitatively to these mapped land types in order to appraise wildlife habitat potential.

In northwestern Ontario, the Ontario Ministry of Natural Resources is engaged in a study using visual and analogue processing of aerial photography and Landsat imagery to map ecosystem types and determine distribution of vegetative cover, logged areas and forest burns (Boissonneau 1976). Habitat types discriminated by densitometric analysis, have been correlated with moose movement patterns. In southwestern Newfoundland Dixon (1972) claimed that 1:120,000 CIR was useful for mapping tree stands and for delineating large areas of softwoods damaged by moose. Boissonneau and Jeglum (1975) classified boreal forest wetlands near Timmons, Ontario, applying visual mapping techniques and densitometry to airborne and Landsat imagery. Using a VP8 image analyzer they were able to classify treed, low shrub and graminoid bogs on Landsat images. More detailed classifications were obtained from 1:15,840 scale panchromatic photographs whose tonal gradients were correlated with gradients of water regime and wooded cover on bogs. Results from this study could be applied to the analysis of moose and caribou habitats.

The Forest Management Institute is conducting several remote sensing inventories of boreal forests in Pukaskwa Park, Wood Buffalo Park, and in Quebec and other areas (Sayn-Wittgenstein and Wightman 1975). Thematic maps have been generated depicting vegetative types, recent burnovers, spruce-budworm damage or logged-over areas. The institute has experimented with various sensors covering the visible light, infrared, thermal and microwave bands. These thematic maps have potential applications for evaluating wildlife habitats in the boreal forest.

Cordilleran Forest and Range

In the intermountain region, wildlife-related remote sensing activities are primarily related to impact assessments or range inventories.

On the site of the reservoir to be created by the proposed Dunvegan Dam on the Peace River, Bernard and Kemper (1976) conducted a pre-project inventory of habitat utilized by passerine birds, merlins *(Falco columbarius)*, and golden eagles *(Aquila chrysaetos)*. Colour infrared film and an infrared scanner (1.4-1.8 microns) were used to cover-map vegetation and to evaluate ground transects in the proposed zone of inundation.

An inventory of ungulate winter range in the southern Rocky Mountains of Alberta assessed conditions prior to potential coal mining and recreational developments (Jaques 1976). Winter snow-free habitat for Rocky Mountain sheep *(Ovis canadensis)* and goat *(Oreamnos americana)* was identified and mapped effectively from high altitude CIR film. An 80% success rate was achieved for identification of eight vegetative communities from September imagery. In the Alberta Willmore Wilderness Area, alpine and subalpine wildlife ranges were mapped by Image 100 analysis of Landsat data (Johnston 1978). At lac du Bois, British Columbia, Watson, Murtha and Ryswyk (1978) are carrying out a classification and inventory of open grassland and forested range as a pilot study for a total rangeland inventory of the province. Both multidate and multiscale colour and CIR diapositives and Landsat imagery are being used to produce a heirarchical classification legend which may be extended to other regions.

A detailed study of black-tailed deer *(Odocoileus hemionus columbianus)* habitat in the Nimkush Valley of British Columbia applied visual and densitometry techniques to filtered CIR film (1:2,000 to 1:8,000 scale), to record the distribution and abundance of arboreal lichens an important deer food (Stevenson 1978). There was no statistical difference between trees with low versus high lichen biomass, but generally trees with higher biomass showed relatively higher reflectance values in the red band.

Prairie-Parkland

In the prairie and parkland regions, existing habitats of waterfowl, passerine birds and white-tailed deer *(Odocoileus virginianus)* are being threatened by encroaching agricultural practices. Remote sensing affords a more feasible means of inventorying habitat in these agricultural areas.

Whereas most waterfowl habitat inventories have been airborne visual surveys, there have been some attempts to map or count ponds from aerial photography and Landsat imagery. Although in North Dakota, some progress was made with computer classifications using proportional estimation techniques (Work and Gilmer 1976), the spatial resolution limits of Landsat digital data preclude accurate inventories of small prairie potholes at present. The Canada Land Inventory employed extensive air photo interpretation to delineate soil-topographic boundaries and to rate for waterfowl production, land units classified according to density and dispersion of wetlands (Perret 1970, Solman 1973). Currently C.W.S. is conducting a prairie-wide waterfowl habitat inventory, using 1:80,000 panchromatic photographs to map and interpret distinct physiographic areas which are designated as habitat management subzones (18.). These subzones are sampled by current 1:12,000 photography and ground surveys to estimate the distribution of available waterfowl nesting cover and wetland types.

Inventories of terrestrial wildlife habitat are being conducted in Saskatchewan, where small scale aerial photography is used to appraise and map wildlife habitat according to a biophysical and land use stratification (Hart, Barber, Pepper and Stelfox 1978). Critical wildlife habitats are identified for consideration in programs for management and habitat acquisition. Similar biophysical inventories using airborne and Landsat imagery are being conducted in national parks (Gimbarzevsky 1976). In an inventory of the proposed Grassland National Park near Val Marie, Saskatchewan, Abouguendia and Coupland (1977) interpreted 1:25,000 scale CIR film, mapping land forms, vegetative types, and saline and eroded areas. White-tailed deer, mule deer *(Odocoileus hemionus)* and pronghorn antelope *(Antilocapra americana)* are ungulates inhabiting this area.

High altitude CIR and digital Landsat data were combined to detect and map plant communities and to locate denuded areas on grazed ranges in the Suffield Military Reserve of Alberta (Jaques 1977). Ground truth verification was necessary to assist in differentiating tonal signatures for semiarid herbaceous communities. On a Manitoba agricultural area containing high quality white-tailed deer habitat, Rubec and Thie (1978) demonstrated the feasibility of general land use detection and mapping from Landsat digital data. They achieved identification accuracies of 82-84% for cultivated and improved pasture, and 94 to 106% for wooded land recognition.

Other Regions

C.W.S. has embarked upon an extensive inventory and monitoring program in southwestern Ontario, to assess land use and map forest cover from Landsat and other imagery (15.). There is concern for deteriorating waterfowl and migratory bird habitat. A more detailed habitat inventory using aerial photography is being conducted along the recreational waterway known as the CORTS corridor (14.).

MONITORING AND IMPACT ASSESSMENT

Arctic - Subarctic

Most inventories are planned as a prerequisite to assessing environmental changes or studying impacts on resources; but few studies progress to the monitoring stage. In the arctic and subarctic environmental changes may be conveniently grouped into climatic or seasonal phenomena, and man-induced impacts.

Highly mobile wildlife species are greatly influenced by seasonal changes such as snow and ice thaw. Monitoring of the breeding status of greater snow geese *(Anser caerulescens atlantica)* (Heyland 1975) and lesser snow geese *(A. c. caerulescens)* (Kerbes and Moore 1975; Reeves, Cooch and Munro 1976) was based upon analysis of sequential Landsat and NOAA imagery to map the chronological progression of snow melt, and to determine the percentage of snow and ice cover remaining on the goose nesting grounds on Bylot Island, Baffin Island, and the Hudson's Bay coast. The phenology of snow melt and ice thaw, which can be determined from Landsat images, is also useful for predicting use of offshore ice pans and leads by polar bears *(Ursus maritimus)*, harp seals *(Pagophilus groenlandicus)* and beluga whales *(Delphinapterus leucas)* (Lavigne et al. 1977); and overland caribou movements may be predicted as well (McQuillan 1975). Visual monitoring of Landsat and NOAA images to determine ice break-up on the Mackenzie River may assist in forecasting chronology of bird migration (Dey, Moore and Gregory 1977).

Studies by Arctic Gas (Reid and Calder 1977; Reid and Janz 1974) are concerned with mapping and monitoring terrain for stability and plant successional responses to disturbances due to pipeline construction. Studies by Thomas (19.) and Parker (1975) used photographic sensing to monitor and assess lichen standing crops on arctic caribou range. Possible impacts to wetlands, vegetation and drainage along the Mackenzie Highway corridor may be predicted from ecosystem mapping (Kemper et al. 1977). The potential of environmental monitoring with remote sensing techniques has been discussed in detail by Thie and Wachman (1974), McQuillan (1975) and Sayn-Wittgenstein and Aldred (1976). Monitoring of flooding, erosion and clearing is feasible using Landsat, as is the monitoring of forest fires and fire damage (Thomson and Dixon 1975).

Boreal Regions

Plant successional responses to water regime changes were monitored on the Peace Athabasca Delta from 1968 to 1971 (Dirschl and Dabbs 1972, Dirschl et al. 1974). Long term successional trends, geomorphological processes and hydrological dynamics of the delta were predicted using sequential cover mapping from airborne photography and vegetation sampling. Using black and white photography, Townsend (1973b) recorded habitat types and measured 3-year changes in area and perimeter of surface waters. Topographic control was correlated with spatial areas of cover types to determine the rate and extent of habitat changes caused by declining water levels. Remedial mitigation works for controlling water levels were proposed.

Cordilleran Forest and Range

Apparently there are few studies involving monitoring of wildlife habitat in the intermountain regions but several of the inventories previously mentioned may develop into monitoring programs. Alpine and subalpine winter ranges in the Willmore Wilderness and Kananaski's areas of Alberta were monitored using digital Landsat data (Johnston 1978). Near Stavely, Alberta, Intera consultants are applying airborne visible and thermal sensors with Landsat, to monitor range condition and estimate biomass production at four levels of grazing intensity (Thompson 1978).

Prairie-Parkland

Most environmental changes in the prairie-parkland are related to the impact of agricultural practices. Goodman and Pryor (1972) interpreted 1949-50 and 1970 aerial photographs to ascertain changes in numbers and areas of wetlands altered, drained or destroyed in the black soil zone. They recorded an overall loss rate of 4.5% of wetlands and 12.9% of wetland acreage, and about 6.2% of ponds were drained. Merriam (1978) used the same sampling frame and photography, sampling Alberta wetlands between the periods 1949-50 and 1974, to show changes in wooded margins. Substantial losses of shrubs occurred, and 32% of wetland edges were cleared. Adams and Gentle (1978) compared changes in spatial data from 1964-74 on digitized photomaps, documenting declines of 31% in grassland and 23% in wooded cover on one study area. Sequential cover-mapping from 70 mm CIR film is being employed by Ducks Unlimited to monitor changes in aquatic plant cover in response to stable water regimes on large marshes (26.).

Near Red Deer Alberta, investigations using Landsat imagery are underway to determine the extent of land clearing and the subsequent successional status of vegetation following clearing (Johnston 1978). Effects of livestock grazing on the Suffield Military Reserve were monitored with high altitude CIR and Landsat imagery between 1972 and 1975 (Jaques 1977). Spectral radiance values were correlated with four levels of grazing intensity. In Manitoba, the Department of Renewable Resources and Transportation Services is using Landsat to study trends in white-tailed deer winter habitat as affected by land use changes (6.). Also in Manitoba, Rubec and Thie (1978) applied Landsat digital data to monitor land use changes between 1972 and 1976. They documented land use changes, recording that 49% of wooded areas, and 26% of cultivated areas were shifted to other uses. Problems were encountered in separating spectral signatures for some classes such as grassland and cropland, and in precise registration of corresponding features in repeated Landsat scenes.

HABITAT ANALYSIS AND WILDLIFE RATING

The next step in the inventory and monitoring sequences, is to develop correlations of wildlife use with remotely sensed environmental data, so that wildlife behaviour or population recruitment rates may be predicted from changes in the detected parameters. Few remote sensing studies in Canada have progressed to this analysis stage.

Analysis of satellite imagery to determine seasonal distribution of snow cover, resulted in predictions of poor to good nesting success rates for arctic geese (Heyland 1975, Kerbes and Moore 1975, Reeves et al. 1976). Parker (1975) correlated caribou carrying capacities to range types and lichen standing crops, but there were problems in quantifying forage productivity. Thompson, et al. (1978) related caribou use to four vegetative complexes identified from cluster analysis of an unsupervised classification of Landsat data. Miller (1976) related caribou winter habitat use to vegetative types and historic burns as mapped from colour photography. In the Hudson Bay Lowlands, C.W.S. is attempting to rate habitat suitability for ducks and geese and shorebirds, by relating population usage to baseline data and mapped ecosystem units determined in the biophysical surveys (Anon. 1978, Cowell et al. 1978).

On the Peace Athabasca Delta, Townsend (1973b) developed simulation programs that predicted the effects of various water regime schemes on habitat and populations of waterfowl, muskrat, bison and moose. Estimates of species carrying capacity were prorated to quantified habitat types mapped from aerial photographs. In Ontario, Boissonneau (1976) reported on a study relating moose habitat use to imaged cover types. Taking planimetric measurements from air photographs, Renouf (1972) related waterfowl densities to size, successional stage and brood cover of beaver ponds in New Brunswick.

In the James Bay Territory, Traversy (1975) used large scale (1:7,920) CIR film to detect at least 10 of 12 known active beaver colonies as indicated by the presence of food caches and used lodges. Criteria for visual separation of abandoned from occupied sites were based upon tonal variations and colour contrasts. The vegetation types of feeding zone habitats near water (0-50 m) were classified according to potential beaver use and related to mapped ecosystems. Estimates of beaver densities per colony, and aerial inventories of colony distribution were then prorated to spatial land systems (Soc. de Développement de la Baie James 1976). Remote sensing imagery was also utilized to rank each ecological land type according to apportioned frequency values of browse classes, into five capability classes which determine the capability of the land type to support moose populations (Soc. de Développement de la Baie James 1977).

In the cordilleran region, Stevenson (1978) using optical density signatures, attempted to rate the quality of black-tailed deer habitat according to arboreal lichen productivity. Johnston (1978) reported on a study which determined productivity indexes of Rocky Mountain sheep winter ranges, by showing high correlations between Landsat infrared reflectance and above-ground forage production in three types of fescue *(Festuca spp.)* grassland. Estimates of range productivity from ratioing red-green densities appears promising on foothill ranges (Thompson 1978). Also carrying capacity estimates for Rocky Mountain sheep on alpine ranges may be feasible from analysis of airborne CIR photography (Jaques 1976).

In the parkland, C.W.S. studies have applied airborne CIR film to detect, map and measure spatial habitat parameters which were correlated with waterfowl use and productivity. In Saskatchewan, mapped land systems are being rated according to habitat suitability for white-tailed deer, elk *(Cervus canadensis)*, antelope and upland game birds. Relating the degree of grazing intensity to Landsat spectral radiance values, Jaques (1977) was able to demonstrate that overgrazing of parts of the Suffield Reserve had reduced wildlife carrying capacity about 65%. However, Klumph (22.) reported on unsuccessful efforts to evaluate Landsat and airborne imagery for assessing range condition and biomass productivity in the Big Valley area of Alberta. Evaluation proved difficult because of inherent characteristics in the vegetation complex.

CONCLUSIONS

Although most wildlife agencies in Canada recognize the value of aerial photography as a habitat mapping tool, few biologists or resource managers are exploiting the potential uses of remote sensing, especially Landsat applications, in operational inventory or monitoring programs. Most of the reviewed remote sensing projects are inventory in nature, some are only demonstrated feasibility studies, and few utilize Landsat data (Table 1). Almost half of the projects using Landsat still employ visual mapping techniques rather than digital analysis. There has been a slow trend to the use of sophisticated analyses, but most projects still depend heavily upon airborne photographic sensing as opposed to satellite sensing. This tendancy is probably related to the inaccessibility of computers and image analysis systems; but the lack of all-weather capability severely limits Landsat acceptance in some monitoring studies.

Table 1.--Summary of remote sensing projects[1] by agencies, determined from cited references and respondents, having applications to wildlife habitat studies in Canada.

	Number of projects having applications					
	Inven.	Mont.	Tot.	Landsat		Aerial[2]
				Vis.[3]	Comp.[4]	
Fed.	9	4	13	1	10	7
CWS	9	8	17	3		15
Prov.	11	2	13	6	1	9
Univ.	9	2	11	3	2	11
Priv.	9	3	12	2	3	10
Total	47	19	66	15	16	52

[1]This is a conservative estimate since some projects were unreported.
[2]Total airborne projects include 18 combined with Landsat analysis.
[3]Visual interpretation or mapping from standard or enhanced Landsat imagery.
[4]Computer processing or digital analysis.

Technological advances in applied digital analysis, image enhancement and classification programs are usually confined to research centers such as the Canada Center for Remote Sensing (Goodenough 1977), the Forest Management Institute (Sayn-Wittgenstein and Wightman 1974), the Lands Directorate (Schubert, Thie and Gierman 1977) and some universities. These centers promote interdisciplinary studies and may assit in analyzing habitat-based data for wildlife agencies. However, a technological gap has developed between the instrumentation and analytical programs, and our capabilities to apply this technology for finding practical solutions to problems in monitoring the environment. Generally large scale integrated resource surveys of areas such as the Pipeline Corridors, the Peace-Athabasca Delta, the Athabasca Oil Sands, the Hudson Bay Lowlands and James Bay, have supported wildlife studies and furnished biophysical data. However, unless good coordination exists between biologists and other investigators, the integrated studies will not extract classified habitat data in the format desired for interpreting wildlife use or capability.

Since some parameters detected or imaged by sensors may not be useful indicators of wildlife habitat use, researchers need to define limits of species habitat requirements in terms of remote sensing criteria. Both spatial and temporal features of habitat should be indexed and assessed for determining phenological changes. Present spectral signature extraction methods using Landsat digital data show variable and often conflicting success rates depending upon the spectral nature of the selected features, the size of the imaged elements, and the ecological complexity of the scene. Certainly pixel size and radiance overlap between pixels have restricted the useable scale, making some features such as small prairie potholes and discrete vegetation zones undetectable. However, improvements in sensors in the new generation satellites such as SEASAT and Landsat D may surmount some resolution problems.

Landsat appears to be more adaptible for large area surveys, for mapping ecological regions or monitoring seasonal phenomena or resource impacts. Landsat visual and digital classifications have been successfully applied on Arctic tundra for mapping seasonal progression of snow and ice cover, and for classifying vegetation and water. In forest habitat, Landsat imagery has applications for monitoring clearing, forest fire damage, flooding, changes in water regimes, and for classification of peatlands in the Hudsons Bay Lowlands. There are also promising applications in range inventory and in land use monitoring.

There is a need to incorporate a supervised textural classification with spectral data in order to make full use of Landsat radiance values, and to improve definition of classes. Schubert (1978) stressed the visual classification of colour, texture and contextual information which could be derived from computer-enhanced displays of Landsat data for land use classification. More research is needed in the assignment of spectral and pattern signatures to unique cover classes, and in the generation of radiance-corrected thematic maps. However, where high resolution is still a priority, aerial photography with ground verification, will still remain an effective alternative to satellite imagery.

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Habitat Mapping and Inventory in the Chenier Plain of Louisiana and Texas

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Abstract.--Comparison of the ability to identify fourteen habitats on a pilot study area of the Chenier Plain of Texas and Louisiana resulted in the continued use of manual procedures rather than digital analysis of Landsat II imagery. Manual procedures provided better resolution and facilitated the reconstruction of past habitat distributions with the use of historic aerial photographs.

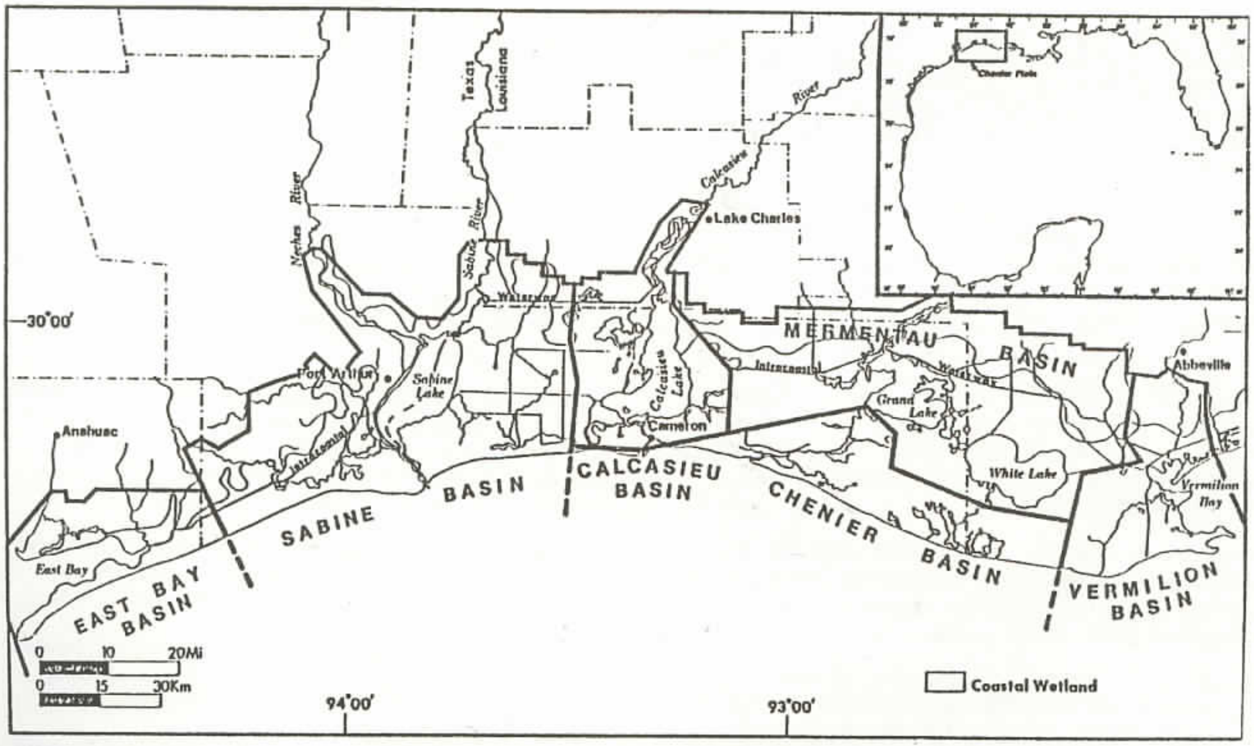

Figure 1.--The Chenier Plain region is composed of six basins, within which water is the primary integrating element.

INTRODUCTION

The coastal area in southwestern Louisiana and southeastern Texas is a large integrated system, most of which developed during the past 5,000 years (fig. 1). Deposited riverine sediments, mostly from the Mississippi River, coupled with the continual erosion, sorting, reworking, and longshore transport of these sediments by marine forces, built the coastal

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area commonly called the Chenier Plain (Howe et al., 1935).

Recently, after thorough review and synthesis of information about the biotic and abiotic components of the region, a comprehensive "ecological characterization of the Chenier Plain" was produced by the United States Fish and Wildlife Service with the Coastal Ecology Laboratory, Center for Wetland Resources, Louisiana State University, serving as the prime contractor. As a portion of that "description of the essential character or quality" of the Chenier Plain, the region was classified and mapped into 14 functional habitats. This report summarizes the mapping and inventory effort, and it evaluates the usefulness of old (i.e., 1952) black and white aerial imagery used with recent coverage, as an aid in determining rates of habitat change through time.

To place the habitat inventory in perspective, a brief review of the organization of the ecological characterization is appropriate. The Chenier Plain ecosystem was modeled as a hierarchy of nested subsystems in order to handle the problems raised by the enormous spatial and biotic diversity of the region and to resolve problems of differing time scales for different kinds of processes. At the top of the hierarchy is the entire Chenier Plain ecosystem. It consists of a group of individual drainage basins, each of which is further subdivided into functional units--habitats--with characteristic organismic communities and physical components. The habitats contain characteristic species that form the lowest level of the hierarchy (table 1).

TABLE 1--UNITS WITHIN THE CHENIER PLAIN ECOSYSTEM HIERARCHY.

BASINS	HABITATS	POPULATIONS AND/OR SPECIES
VERMILION MERMENTAU CHENIER CALCASIEU SABINE EAST BAY	WETLANDS IMPOUNDED MARSH SALT MARSH BRACKISH MARSH INTERMEDIATE MARSH FRESH MARSH SWAMP FOREST AQUATIC NEARSHORE GULF INLAND OPEN WATER UPLAND HABITATS RIDGE BEACH UPLAND FOREST AGRICULTURE RICE PASTURE URBAN	MENHADEN AND OTHER FINFISH SHRIMP, OYSTER, BLUE CRAB, CRAWFISH, CLAM AND OTHER SHELLFISH NUTRIA, MUSKRAT, RACCOON, DEER, AND OTHER MAMMALS ALLIGATOR AND OTHER REPTILES BULLFROG WATERFOWL AND OTHER BIRDS

At each level of the hierarchy, dominating processes and time scales differ. The whole Chenier Plain region is best described by geomorphic and climatic events that have occurred over the past few thousand years. Drainage basins are controlled by hydrologic processes and cultural activities that have caused significant changes in physiography and land use over the past 100 years. Ecological processes that characterize habitats and populations are likely to concern events that change seasonally, or even diurnally.

The habitat concept, as used in this study, played a pivotal role in the hierarchy, and hence in the ecological characterization. At one level a habitat was considered a functionally unique community that could be described in the classical terms of community ecology--by energy flow, trophic structure, characteristic species, diversity, and carrying capacity. Habitats also had an areal component: that is, each habitat occupied a discrete space within a drainage basin that could be mapped and inventoried. The ability to distinguish habitats from areial imagery without extensive ground truth observations was an important consideration in habitat definition.

Each drainage basin is characterized by a number of habitats of differing areal extent. These habitats describe the ecological use of the areas of each basin in a manner analogous to cultural land use classifications. Indeed some of the habitats--agricultural and urban--are classical land use designations that reflect the importance of human activities in the Chenier Plain. Since each habitat has a carrying capacity for certain species, the particular mix of habitats in each basin results in the unique set of living resources.

CHENIER PLAIN HABITAT DELINEATIONS

For mapping purposes the Chenier Plain region was divided into 14 habitats (table 2). These habitats, as defined, were based on a combination of natural characteristics and land uses that were not always mutually exclusive. Cultural processes intrude in every habitat. However, 10 of the 14 habitats--salt, brackish, intermediate, and fresh marshes; swamp forest; nearshore gulf; inland open water; ridge; beach; and upland forest--are landscape units that function more or less naturally. Three other "habitats"--agricultural) rice and pasture) and urban--are clearly culturally modified areas in which natural processes have been dramatically changed by cultural needs. The remaining habitat, impounded marsh, is rather diverse and contains areas where natural processes predominate, as well as others where agricultural processes are

TABLE 2--DEFINITIONS OF THE HABITATS OF THE CHENIER PLAIN.

AQUATIC HABITATS

NEARSHORE GULF - ALL WATERS BETWEEN THE COASTLINE AND THE 9 M (30 FT) DEPTH CONTOUR IN THE GULF OF MEXICO. INTERMITTENTLY EXPOSED MUDFLATS ARE CONSIDERED PART OF THIS HABITAT.

INLAND OPEN WATER - ALL INLAND LAKES, RIVERS, BAYOUS AND CANALS, INCLUDING INTERMITTENTLY EXPOSED MUDFLATS.

NATURAL EMERGENT WETLAND HABITATS

SALT MARSH - SALINE INTERTIDAL MARSHES AND ASSOCIATED SMALL PONDS DOMINATED BY SMOOTH CORDGRASS (SPARTINA ALTERNIFLORA), WITH SALT GRASS (DISTICHLIS SPICATA) AND BLACKRUSH (JUNCUS ROEMERIANUS) COMMON.

BRACKISH MARSH - INTERTIDAL MARSHES AND ASSOCIATED SMALL PONDS DOMINATED BY SALT MEADOW CORDGRASS (SPARTINA PATENS) AND SALT GRASS; SALINITIES GENERALLY LESS THAN 10‰.

INTERMEDIATE MARSH - MARSHES AND ASSOCIATED SMALL PONDS, PERIODICALLY FLOODED WITH NEARLY FRESH WATER, BUT OCCASIONALLY BY BRACKISH WATER. DOMINATED BY SALTGRASS, BULLTONGUE (SAGITTARIA FALCATA), AND JOINTGRASS OR SEASHORE PASPALUM (PASPALUM VAGINATUM).

FRESH MARSH - MARSHES FLOODED BY FRESH WATER, AND WITH A DIVERSE FLORA DOMINATED BY MAIDENCANE (PANICUM HEMITOMON), BULLTONGUE, AND ALLIGATOR WEED (ALTERNANTHERA PHILOXEROIDES).

SWAMP FOREST - FORESTED FRESHWATER WETLANDS WITH DIVERSE FLORA DOMINATED BY BALD CYPRESS (TAXODIUM DISTICHUM) AND TUPELO (NYSSA AQUATICA).

IMPOUNDED MARSH - MARSHES SURROUNDED BY DIKES, SPOIL BANKS, OR NATURAL LEVEES THAT MODIFY NORMAL FLOODING. THESE EXIST IN SALINE TO FRESH AREAS. THEY MAY BE PERMANENTLY FLOODED OR PUMPED DRY, BUT ALL ARE DOMINATED BY NATIVE EMERGENT WETLAND VEGETATION (AS OPPOSED TO IMPOUNDED AGRICULTURAL LAND).

UPLAND HABITATS

RIDGE (CHENIERS, LEVEES, SPOIL BANKS, PLEISTOCENE ISLANDS) - LANDFORMS ELEVATED ABOVE NORMAL FLOOD LEVELS. LINEAR FEATURES WITHIN THE WETLANDS EXCEPT FOR PLEISTOCENE ISLANDS. USUALLY FORESTED EXCEPT FOR RECENT SPOIL BANKS.

BEACH - NARROW STRIP OF LAND ALONG THE GULF, COMPOSED OF FINE SAND AND SHELL FRAGMENTS. SPARSELY VEGETATED.

UPLAND FOREST - AREAS OF BOTTOMLAND HARDWOOD AND PINE FOREST ON THE UPLAND PLEISTOCENE TERRACE.

AGRICULTURE HABITATS

RICE FIELD - CROPLAND PLANTED TO RICE OR OTHER CROPS, WHETHER LEVEED OR NOT. OFTEN ROTATED WITH PASTURE (SEE BELOW).

PASTURE - LAND IMPROVED FOR GRAZING BY PLANTING OF IMPROVED GRASSES AND BY FERTILIZATION. OFTEN ROTATED WITH RICE FIELD.

URBAN AREAS

URBAN - LAND AREAS DEVELOPED FOR RESIDENTIAL AND INDUSTRIAL USE. A LAND USE CATEGORY BUT NOT DESCRIBED AS A HABITAT FOR NATIVE FAUNA.

controlling. Impounded marsh is recognized by straight spoil bank or levee boundaries that isolate the impoundment from surrounding wetlands and water bodies. Controls on these levees range from "flap gates," which prevent the inflow of surface water but allow excess rainwater to run off; to permanently flooded impoundments without control gates; and to impoundments that are routinely drained by pumping and are used for grazing cattle. These drained impoundments are distinguished from pasture habitat by the fact that they are dominated by native vegetation.

Table 3 shows the 1974 areal extent of habitats in the Chenier Plain and the proportion of each.

TABLE 3--CHENIER PLAIN HABITATS AND THEIR AREA, 1974.

HABITAT	AREA (HA)[1]	PERCENT OF TOTAL	PERCENT OF INLAND AREA[2]
AQUATIC			
NEARSHORE GULF	371,257	28.2	--
INSHORE OPEN WATER	200,844	15.2	21.2
WETLANDS			
SALT MARSH	17,155	1.3	1.8
BRACKISH MARSH	100,855	7.7	10.6
INTERMEDIATE MARSH	84,843	6.4	9.0
FRESH MARSH	116,331	8.8	12.3
SWAMP FOREST	6,538	0.5	0.7
IMPOUNDED MARSH	161,781	12.3	17.1
UPLANDS			
RIDGE (CHENIERS, LEVEES, SPOIL BANKS)	59,761	4.5	6.3
BEACH	6,164	0.5	0.6
UPLAND FOREST	15,864	1.2	1.7
AGRICULTURE			
RICE FIELD	60,298	4.6	6.4
PASTURE	90,125	6.8	9.5
URBAN	26,137	2.0	2.8
TOTAL	1,317,953		

[1]1 HA= 2.47 ACRES

[2]INLAND AREA EXCLUDES THE NEARSHORE GULF HABITAT

CHENIER PLAIN MAPPING PROCEDURES

Previous studies have proven the usefulness of remote sensing techniques as cost-effective, efficient, and relatively accurate tools for coastal mapping. The degree of accuracy, however, depends upon the resolution desired. Techniques tested to devise a methodology suitable for delineating present habitat distribution for this ecological characterization study were Landsat II imagery, black and white and color infrared imagery, aerial and ground observations, and various combinations of these.

Landsat imagery was the first technique tested. The most sophisticated equipment available at Bendix Corporation, Ann Arbor, Michigan, and National Aeronautical and Space Administration (NASA), Slidell, Louisiana was used during this effort. Training sites were adequately identified by ground truth to identify spectral signatures displayed on Landsat II imagery. Maps were efficiently generated by this procedure and quantitative data were displayed according to the frequency of various signatures.

Resolution appeared to be within acceptable limits. However, field checks of the maps generated in this manner revealed that there was not always a distinct signature for each habitat; consequently, map displays sometimes differed significantly from actual conditions.

The overall inadequacy of the Landsat imagery technique for this study was attributable to several factors. The broad coastal marshes of the Chenier Plain are not characterized by large homogeneous areas. A single marsh habitat characteristically is a mixture of several plant species, and this mixture differs from place to place, changing the Landsat signature. Furthermore, boundaries are often indistinct because transition zones between marsh habitats are usually broad gradients except where cultural or natural physical boundaries occur. Even when a single species dominates, different signatures may result from changes in density and/or vigor. This variation in signature appeared to be particularly characteristic of salt meadow cordgrass.

Linear features such as canals and associated spoil banks were generally poorly defined on the Landsat imagery. These features are often narrower than the resolution capabilities of the satellite, although they may be continuous for many kilometers. "Averaging" the signatures of spoil and bordering habitat often leads to erroneous interpretations. While these linear features do not compose a large percentage of the area, their distribution, relative location, and continuity are important for understanding the area.

Finally the Landsat imagery failed to differentiate upland habitats adequately at the same time the wetlands were delineated. This can be explained in part by the training sites chosen. Rice fields, for example, can never be accurately delineated unless all are flooded or all are dry at the time the image is taken. Presumably that never happens; consequently, flooded rice fields often appeared as marsh.

The Landsat imagery was used successfully to delineate a few marsh species of rather wide distribution. Salt marsh, for example, was depicted fairly accurately, possibly because of the few species involved.

The procedure we finally used to delineate present habitat distribution employed the use of NASA color infrared imagery (Mission 289-1974) and U.S. Geological Survey (USGS) 1:24,000 orthophoto quads (1974-1975 Advanced Prints), along with supplemental black and white air photos. The mapping procedure was entirely manual with the USGS 1:24,000 quadrangle sheets used as the base. Standard 9" x 9" NASA infrared film positives were enlarged to approximately 1:24,000 scale. Initial interpretations were field checked by both ground reconnaisance and low altitude overflights. The low overflights were particularly important in determining the various marsh habitats. The ability to identify quickly plant types from low-level flights over the area was a strategic part of this type of mapping.

Habitats were delineated directly on the USGS quadrangles after field verification. Area statistics were generated by using a point count method developed by Gagliano and Van Beek (1970), after comparing this method with results obtained using a Calmagraphic II digitizer. Using the digitizer as the standard, the point count method is within approximately 3 percent accuracy for the size and number of habitats involved. Accuracy decreases with decreasing area and/or increasing number of habitats. The advantages of the point count method are its low cost, speed, and simplicity.

Although the study area is large for manual mapping (over 1.3 million ha), size alone does not appear to be a limiting factor for a constant classification system because increasing familiarity with signatures of the habitats increases speed of delineation. However, even under optimal conditions the operation is labor intensive.

In this study the odd configuration of the study area was a further deterrent to using Landsat imagery. A minimum of two overpasses and four images were required to cover the entire study area, which increases the verification difficulties. While the number of color infrared images needed is at least an order of magnitude greater, there is much greater consistency of signatures from frame to frame for the types of habitats we delineated.

RECONSTRUCTION OF HISTORIC HABITAT CHANGES

In addition to mapping the present distribution and area of habitats, we analyzed areal changes that had occurred since 1952. The examination of habitat changes through time is not a new idea. Geographers and others have monitored changes in land use on the surface of the earth for some time and we used the same approach.

The mapping of habitat change was accomplished by using the present habitat distribution maps (as previously described) as a base and then working backwards through time. Existing aerial imagery was assessed to determine the earliest available comprehensive coverage of the Chenier Plain.

The Agricultural Stabilization and Conservation Service and the Soil Conservation Service photographed, between them, nearly all the United States, at approximately 1:20,000 scale, mostly with black and white panchromatic film. This coverage is available for the Chenier Plain (1954), but we used United States Navy (USN) black and white infared (approximately 1:20,000), because of the film type and the earlier date (1952).

The signatures of habitats in color infrared imagery were compared to black and white infrared taken at about the same time. The black and white imagery used was primarily USGS orthophoto quadrangles (1:24,000). Only enough frames were compared to establish reliably the habitat signatures on black and white infrared film. Unless changes are occurring dramatically, it is not imperative that the two sets of imagery be from the same year. For instance in the Chenier Plain study one of the more significant changes was the deterioration of emergent marsh vegetation to open water. In this example, the seasonal change can often be greater than the year to year change. Thus photography taken during the same season was of greater concern than any two sets of imagery that had been taken 1 or 2 years apart.

After establishing the relationship of habitat signatures on black and white infrared with color infrared the present (1974) habitats were overlayed on the 1952 USN photos. We did not try to reduce the photos to our standard 1:24,000 scale. There were enough reference points from which we could hand trace changes onto Mylar overlays. The resulting plotted areas of change were then measured using a Calmagraphic II digitizer.

The net changes in habitats are shown in table 4. The habitats listed in this table do not correlate exactly with the 14 habitats previously described. The four natural marsh habitats have been combined because there was no accurate method to determine the 1952 distribution of each type of marsh individually. (Impoundments and swamp forest could be delineated.)

TABLE 4--NET HABITAT CHANGE, 1952-1974[1] (HA).

HABITAT	NET AREA CHANGE	NET PERCENTAGE HABITAT CHANGE
AQUATIC		
NEARSHORE GULF	+ 1,539	+ 0.4
INLAND OPEN WATER	+28,026	+16.2
NATURAL EMERGENT WETLAND		
NATURAL MARSH[2]	-81,276	-20.3
SWAMP FOREST	- 396	- 5.7
IMPOUNDED MARSH	+38,112	-30.8
UPLAND		
RIDGE (CHENIERS, LEVEES, PLEISTOCENE ISLANDS)	- 1,247	- 3.8
RIDGE (SPOIL)	+ 5,365	+23.1
BEACH	- 116	- 1.8
UPLAND FOREST	- 1,247	- 7.7
AGRICULTURE		
RICE	+ 2,787	+ 6.7
NON-RICE AGRICULTURE	+ 1,826	+29.0
PASTURE	+ 1,181	+ 1.3
URBAN	+ 5,446	+23.3

[1]1954-1974 FOR THE EAST BAY BASIN

[2]COMBINES SALT, BRACKISH, INTERMEDIATE AND FRESH MARSH

The resulting changes in the areal extent of habitats clearly shows that natural habitats are being preempted for man-related habitats. The loss of natural marsh is the major habitat change. Much of this change can be accounted for by impoundment of marshes, a practice designed to optimize wetlands for waterfowl and marsh mammals. The increase in open water area is largely at the expense of natural marsh. This change results from both natural processes (e.g., subsidence and shoreline erosion) and man-related activities (e.g., dredging).

SUMMARY AND CONCLUSIONS

It is perhaps only a matter of time before digital analysis of satellite-collected data provides the wildlife biologist with a low cost, high resolution product. In the ecological characterization of the Chenier Plain, however, manual methods with color infrared photography were deemed to be the best cost-effective approach to habitat mapping. Although the manual methods were more labor intensive than analysis of satellite imagery, the overall resolution was better and the dollar cost was estimated to be less. In addition, the manual approach enabled us to document habitat changes through time, using early (1952) black and white aerial photographs. The general availability of old aerial photographs, the simplicity of the manual procedure, and the minimal requirements of hardware combine to provide an available tool to a large number of potential users.

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The Interpretation of Winter Wildlife Habitat in Eastern South Dakota on Landsat Imagery

Robert G. Best and Signe Sather-Blair

Abstract.--A technique to interpret the quantity and quality of available winter wildlife habitat on Landsat imagery is presented. Six classes of winter habitat were interpreted with an overall classification accuracy of 76.6% in a test of the procedures. The use of Landsat imagery for seasonal monitoring and spatial distribution of habitat is illustrated.

INTRODUCTION

Availability of protective cover for wildlife during the winter is an important survival factor in the midwestern region of the United States (Green 1938, Hammerstrom and Blake 1939, Grondahl 1953, Lyon 1954, Gates 1971, Ozaga and Gysel 1972). Not only can direct mortality losses due to winter weather severely reduce a wildlife population (Green 1938, Kimball 1948, Lyon 1959) but lower reproduction success the following spring has also been associated with winter weather severity (Gates 1971, Verme 1977). Clearly, in the past wildlife biologists have not placed enough importance on availability and quality of winter cover.

Land use practices in eastern South Dakota have limited winter habitat for wildlife to primarily wetlands, shelterbelts, riparian areas, and farmsteads. Agricultural fields also provide protective shelter and food periodically.

Little quantitative research has been done on the use of the above mentioned habitat areas by wildlife during the winter. Most of what has been done has concerned pheasants. Green (1938) and Grondahl (1953), working in Iowa both observed heavy pheasant use of wetlands in early winter. Since the wetlands on their study area were relatively small (3.2 ha) these filled with snow as the winter progressed and thus lost their value as protective cover. In northern Illinois wetlands constitute the most important winter cover for pheasants (Robertson 1958). Gates (1974) concluded that population density tended to be roughly adjusted to the amount and distribution of wetland cover availability, and that as wetland habitat progressively disappeared pheasant numbers dropped accordingly in Wisconsin. He found 78-88% of the wintering pheasant population on his study areas associated with wetland cover.

Several investigators have found shelterbelts to be of value to wintering pheasant populations (Green 1938, Bue 1949, Grondahl 1953, Lyon 1959). Several shelterbelt characteristics however appear to determine their level of use. Grondahl (1953) found that the smallest shelterbelt (0.5 ha) was not used on his study area even though food was available only 122 m from it. The larger shelterbelts were regularly used for roosting. Besides size, the age of a shelterbelt as well as its juxtaposition to other cover and food source seems to strongly influence its use by pheasants (Green 1938, Bue 1949, Grondahl 1953, Lyon 1959).

Depending on cover availability and density along riparian areas it can potentially be excellent protective habitat for wildlife. Lyon (1954) speaking of pheasant winter cover preferences in eastern Colorado states "Where the river bottom was not grazed or burned, it offered a variety of food and cover unsurpassed by any other type." He found, however, that due to land use practices the quantity of this quality habitat was minimal. Human disturbance also appears to significantly affect pheasant use of farmsteads although limited use has been noted especially during adverse weather conditions (Green 1938, Grondahl 1953).

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[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. SDSU-RSI-J-78-13.

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Because of fall plowing and/or short stubble height during most years, agricultural fields offer little cover (Westin 1954, Gates 1974). During years where fields are left unharvested or tall stubble (>.3 m) is present this cover type can provide cover as well as food provided snow depth is limited (Bue 1948, Westin 1954).

Suitable habitat for winter protection is being destroyed and/or reduced in quality by such practices as fall plowing, wetland drainage, removal of shelterbelts and overgrazing. In view of these land use practices assessment and inventory of available winter habitat should be of prime concern to wildlife management agencies. A method to achieve this goal that is both time and cost efficient would be a valuable aid. Remote sensing technology has been demonstrated to be useful in these regards (Varney et al., 1973, Frentress and Frye 1975, Gilmer et al. 1975, Scheierl and Meyer 1976, Best and Moore 1977). Landsat imagery has been found to be particularly suited for photo-interpretation of winter wildlife habitat due to the contrast between the highly reflective snow cover and relatively lower reflectance of vegetation emerging through the snow (Best and Sather 1978).

The objective of this study was to analyze winter Landsat imagery to provide information concerning the availability of winter wildlife habitat.

CHARACTERISTICS OF LANDSAT

The Landsat program began in June 1972 with the launch of Landsat 1. The program was expanded to include Landsat 2 and 3, launched 5 January 1975 and 5 March 1978, respectively. The satellites orbit the earth in circular, sun-synchronous, near-polar orbits at an altitude of approximately 915 km. Each satellite orbits the earth approximately 14 times per day and views the same scene on earth every 18 days. Until 6 January 1978, when Landsat 1 malfunctioned and was shut down, Landsat's 1 and 2 were providing repetitive coverage on a 12/6 day schedule. The orbit of Landsat 3 has been adjusted to provide 9 day repetitive coverage in conjunction with Landsat 2.

The Data Collection System (DCS) on Landsat 1 and 2 is comprised of a 4 band Multispectral Scanner (MSS) and a 3 channel Return Beam Vidicon (RBV) camera. The DCS on Landsat 3 has a 5 band MSS and single channel double resolution RBV. Table 1 is a summary of the spectral sensitivity of the sensors in the Landsat DCS.

Table 1.--Spectral sensitivity of sensors in Landsat DCS.

	Sensor	IPF Band Code[1]	Wave-length(µm)	Color Rendition
		1	0.475-0.575	green
	RBV	2	0.580-0.680	red
		3	0.690-0.830	near-infrared
Landsat 1 and 2		4	0.5-0.6	green
		5	0.6-0.7	red
	MSS	6	0.7-0.8	near-infrared
		7	0.8-1.1	near-infrared
	RBV		0.505-0.750	green-red
Landsat 3		4	0.5-0.6	green
		5	0.6-0.7	red
	MSS	6	0.7-0.8	near-infrared
		7	0.8-1.1	near-infrared
		8	10.4-12.6	thermal infrared

[1] Image Processing Facility

The data are transmitted from the satellites to the NASA Image Processing Facility. The data can be purchased from the EROS Data Center in the form of photographic 24 by 24 cm or 70 by 70 millimeter transparencies, contact or enlargement prints and/or computer compatible tapes (CCT's) in a digital format. Each image provides a near-orthographic view of a scene having dimensions of 185 x 185 km. The minimum resolution of the MSS is approximately 0.45 hectares. The 915 km altitude of the satellites and the narrow field of view of the sensors provide the capability to image this broad scene without the frame by frame characteristics of low altitude aircraft imagery.

PROCEDURES

The interpretation procedures reported herein are designed for use with Landsat transparencies or positive prints at any scale. The authors suggest the use of enlargement prints at scales from 1:125,000 to 1:60,000.

The criteria for interpretation of image features are tone, texture and shape. Photographic tone is the lightness or darkness on the imagery and corresponds to the reflectivity of the scene feature. Texture, the impression of smoothness or roughness on an image, is formed by tonal variations in groups of objects which are too small to be discerned as individual objects. The shape of an image feature at a given scale can be identified by the regularity and placements of tones and textures. Size and orientation of features are also used as interpretation aids. The following is a photo interpretation key designed to facilitate the interpretation of available winter habitat.

Key to Photo Interpretation of Winter Habitat In Eastern South Dakota on Landsat Imagery

1a Predominant image feature, light tone, smooth texture........snow covered landscape

1b Dark tones, variable size and texture regular and irregular shapes.............. 2

- 2a Image features with irregular shapes, usually with mottled texture, may have light tones, smooth textured areas interspersed, size variable........wetlands with persistent emergent vegetation or municipalities[1]

- 2b Image features with regular shapes, may be linear, rectangular or circular.............................. 3

  - 3a Linear features, length 5x greater than width, tone and texture variable depending on species composition and density........................... 4

    - 4a Straight linear features, length less than one mile, smooth or mottled texture, usually oriented E-W or N-S..................shelterbelt

    - 4b An irregular linear feature, usually evident for several miles, meanders in any direction...............riparian

  - 3b Non linear, regular shaped features.......................... 5

    - 5a Square or rectangular features, tone and texture variable.......unharvested crops

    - 5b Circular features............. 6

      - 6a Large circular features ($\geq$160 acres).....unharvested crops under center pivot irrigation

      - 6b Small circular features "dots"............farmsteads

An example interpretation of a snow covered Landsat scene is presented in figure 1.

Two township sized areas were photo-interpreted by five interpreters each with varying degrees of experience. Interpretation accuracies were calculated using a modification of procedures as described by Kalensky and Sherk (1975).

RESULTS AND DISCUSSION

Vegetation emerging through snow cover is readily apparent on the imagery because of the reflectance contrasts between the highly reflective snow and the relatively lower reflectance of the vegetation. Only those sites which are not covered with snow and have sufficient vegetative density to be apparent on the imagery are considered by the authors to provide winter habitat. Some suitable areas may be smaller than the resolution of the sensor. Table 2 is a confusion matrix presenting the results of five interpreters who

Table 2.--Confusion matrix illustrating the classification accuracy winter habitat by 5 different interpreters.

CLASS		INTERPRETATION							OMISSIONS		
		A	B	C	D	E	F	TOTAL	No.	%	M_I%
Wetlands (A)		60	2	2	24	0	0	88	28	32	50
Shelterbelts (B)		1	63	4	7	0	0	75	12	16	73
Crops (C)		11	3	22	0	0	0	36	14	39	49
Farmsteads (D)		19	4	3	191	0	0	217	26	12	72
Municipalities (E)		0	0	0	0	5	0	5	0	0	100
Other (F)		3	2	0	16	0	0	21			
TOTAL		94	74	31	238	5		442			
Commissions	No.	34	11	9	47	0					
	%	36	17	29	20	0					
Overall Classification Accuracy K%		76.6									

[1]Confusion between wetlands and municipalities can be prevented by locating the municipalities with the aid of available road maps.

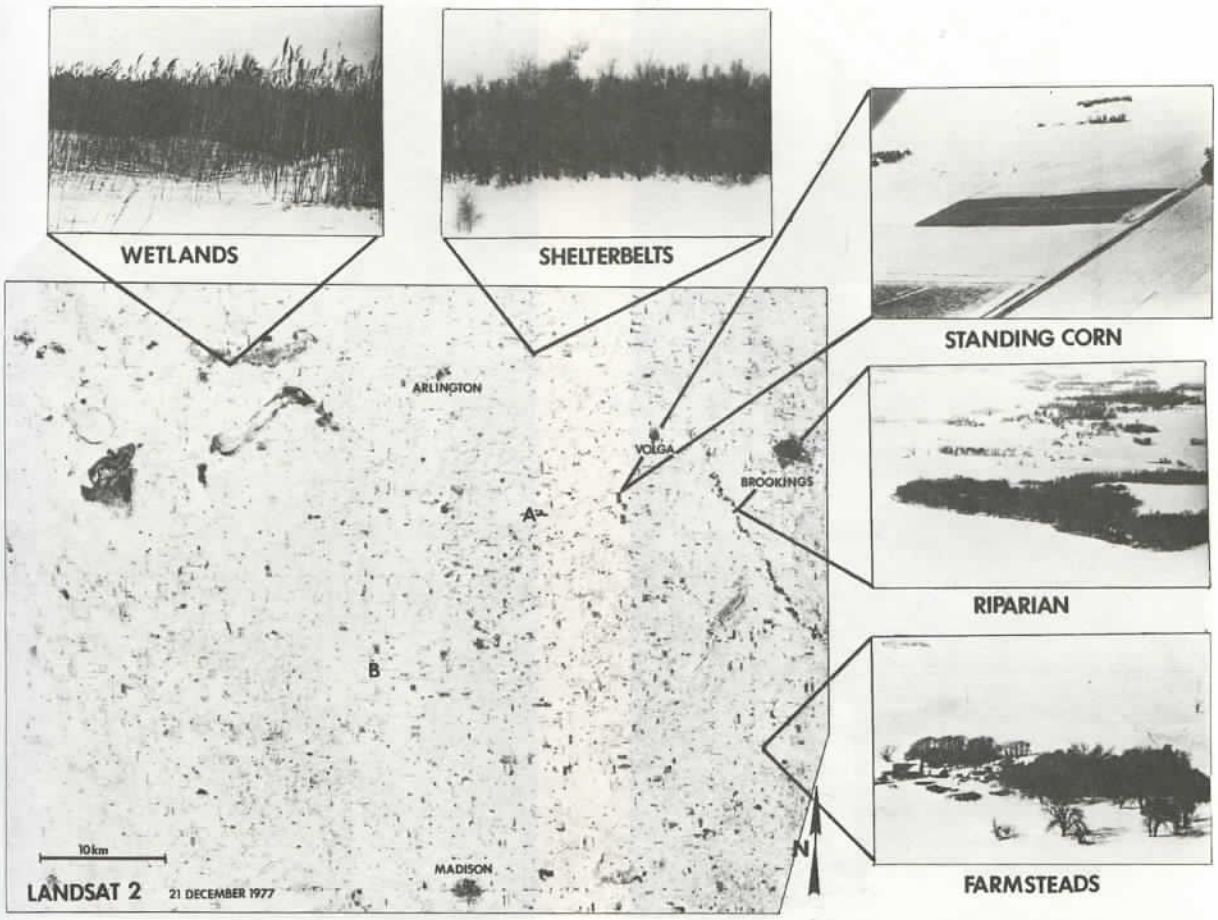
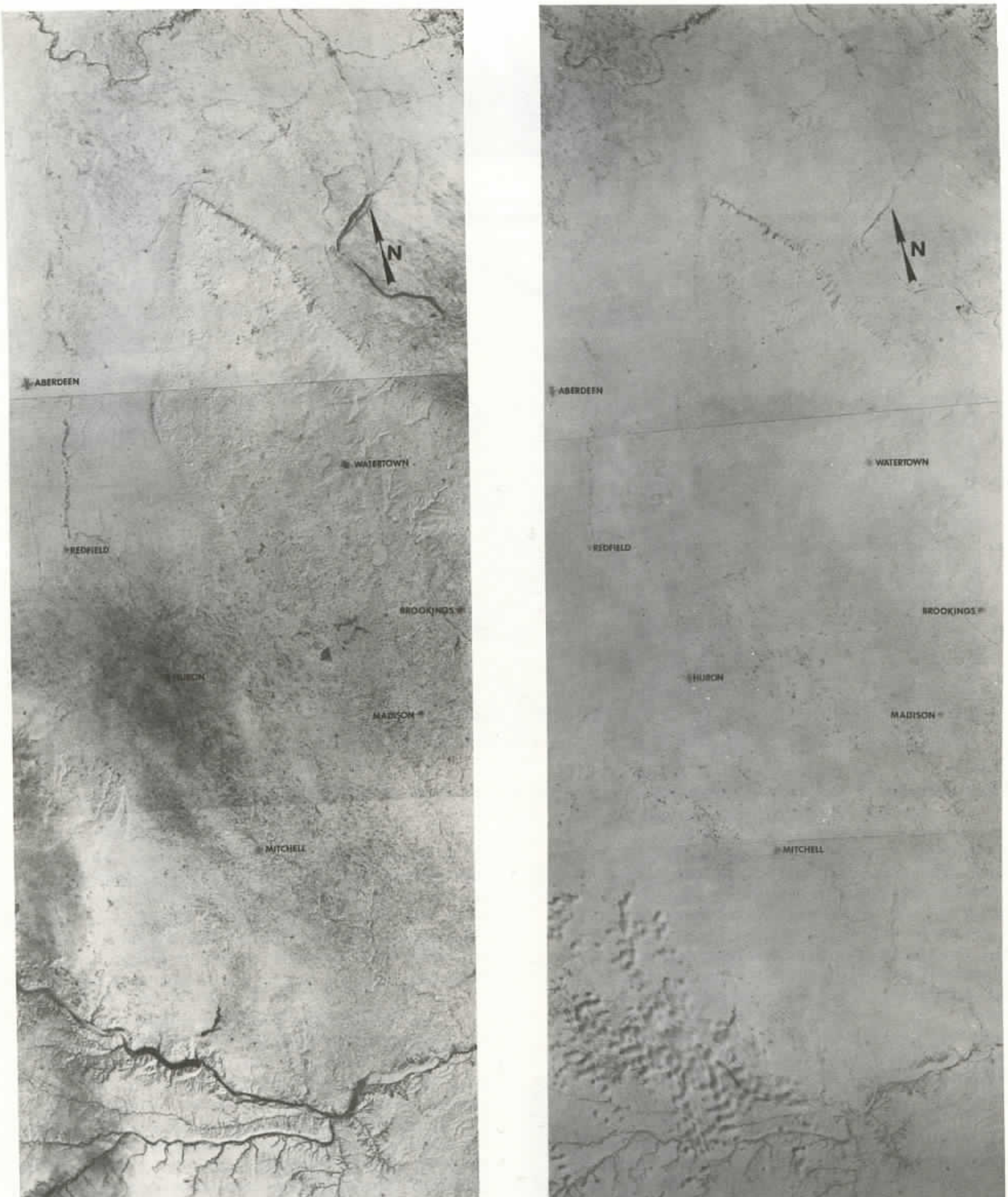


Figure 1.--Illustration of interpretation of winter habitat on Landsat imagery.

interpreted a two township size area on a 1:125,000 scale enlargement print. The overall classification accuracy was 76.6%. The largest source of confusion exists between the classes of wetlands and farmsteads. In almost every case there was no misclassification of large wetlands but the confusion occurred in distinguishing very small wetlands from farmsteads. The confusion between crops and wetlands can be attributed to the irregular shapes of some fields of crops because of greater snow depth in some portions of the fields due to the prevailing winds.

The reflectance of the vegetation emerging through the snow cover and resulting tone on the imagery, is a function of vegetative density and depth of snow cover. Assuming the density of vegetative cover is the criteria for determining the quality of habitat, than darker tones on the imagery indicate the best winter habitat. The dark toned "T" shaped feature at "A" (fig. 1) is a shelterbelt composed primarily of a dense stand of conifers. This can be contrasted with the shelterbelt composed primarily of deciduous trees at "B". Furthermore only wetlands with stands of persistent emergent vegetation are obvious on the imagery. Those wetlands with the most dense vegetative cover have the darkest tones and least mottled texture.

The repetitive coverage characteristics of Landsat allow seasonal or yearly monitoring of wildlife habitat. As the winter season progresses and snow depths increase more winter habitat becomes covered causing additional stress for wildlife populations. Figure 2 illustrates the loss of available winter habitat from 21 December 1977 to 3 March 1978. Numerous shelterbelts, wetlands and crops are available for cover and food in December and winter habitat is probably not a limiting factor. Heavy snowfall during January and February has limited the amount of available habitat by March.



21 Dec 1977 3 March 1978

Figure 2.--Mosaics of winter Landsat imagery (MSS7) illustrating regional differences and seasonal monitoring of available winter habitat in eastern South Dakota.

During normal winters agricultural fields have little or no value as winter wildlife habitat because residual vegetation is knocked down during harvesting and is easily covered by snow. When weather prevents harvesting of crops they may represent a significant proportion of available habitat and also provide a source of food. Numerous unharvested corn fields can be interpreted on the 1977 imagery.

Photomosaics of several snow covered scenes can be used as a regional map of the spatial distribution of winter habitat. Generalized differences in the quantity of available habitat are obvious (fig. 2). The Lake Dakota Plain (between Aberdeen and Redfield) in northeastern South Dakota is extensively farmed. The only available winter habitat is shelterbelts and the reparian habitat associated with the James River. The numerous wetlands in the Prairie Coteau provide abundant winter cover except in years of heavy snowfall.

The areal extent or the linear extent in the case of shelterbelts and riparian habitat can be measured on enlargement prints at scales of 1:60,000. The distance between areas of cover can also be measured. The spatial density of available winter habitat can be estimated from these measurements.

SUMMARY AND CONCLUSIONS

Wildlife losses resulting either directly or indirectly from winter exposure are important limiting factors in wildlife populations. Seasonal and yearly monitoring of available winter habitat in conjunction with ambient temperature data could provide data useful for predicting the severity of winter on wildlife populations. Wildlife management plans, in the Northern Plains States, should include winter habitat availability as one of the major components.

Winter habitat can be photo interpreted on Landsat imagery. Wetlands with persistent emergent vegetation can be identified by their irregular shape and mottled texture. Shelterbelts appear as dark toned straight linear features. The tone and texture may vary depending on the width, density and species composition of the trees present. Unharvested agricultural crops, which provide both escape cover and food for wildlife can be interpreted by dark tones and regular rectangular, square or circular shape. Riparian habitat, primarily shrubs and trees in the immediate flood plain of the rivers and waterways, can be interpreted by the presence of a meandering linear pattern. Farmsteads appear as small black dots resulting from the low reflectance of buildings and surrounding windbreaks. Urban areas can be confused with wetlands and should be interpreted with the aid of a supplemental map. Highway maps can be superimposed during printing to aid in spatially locating specific habitat.

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Production of Vegetation Type-Maps from Landsat Digital Data[1]

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Abstract.--The Texas Parks and Wildlife Department has developed and implemented methodology for producing statewide vegetation type-maps from Landsat digital data. Such maps will be utilized to delineate ecological management units, determine acreages of various cover types, measure changes in land use and assist in formulating natural resource management decisions.

Maps have been published for eleven Landsat scenes covering central, eastern and southern portions of Texas with four other scenes in production.

INTRODUCTION

Rapidly accelerating changes in land use are presently occurring in Texas. These changes include significant land clearing for increased crop and livestock production, consistently high rates of urbanization, increased timber production and harvest, and continued construction of large water impoundments. All are having serious detrimental effects on the state's wildlife resources by decreasing available habitat during a period of increased wildlife-oriented recreational demand. This situation creates a vital need to inventory and monitor the remaining natural vegetation.

Vegetation mapping work has been done previously on both regional and statewide levels but is unsatisfactory for Department needs due to a lack of standardization and inadequate portrayal of specific boundaries of different types of ground cover.

Procedures were developed and implemented to inventory major plant associations within the state by processing Landsat digital data into vegetation type-maps. The maps will assist in establishment of management units which are essential in surveying wildlife population trends and making wildlife management recommendations. They will also be used in long-range planning by providing identity, location, and quality of natural habitats as part of an overall data base information system.

MATERIALS AND METHODS

A preliminary experimental pilot project was conducted in 1974 to outline and develop operational procedures applicable to large-area analyses (Frentress and Frye 1975). The results of this experimental project indicated that operational plans could be developed for subsequent use in large area mapping. Although procedures established from this initial study were significantly altered to accommodate a more efficient analysis design, results indicated the need for having accurate, standardized type-maps constructed in a manner which would allow taxonomic and geographical delineation of plant associations rather than specific land use practices. The vegetation components would be defined by dominant species composition and physiognomy including average height and canopy cover. To facilitate this end a set of physiognomic criteria based on Haas and McGuire (1974) and Frentress and Frye (1975) was devised and implemented into the analysis scheme (Table 1). Further evaluation indicated that the data analysis system should be designed to function on a small general purpose computer with all peripheral data processing subsystems self-contained within the Wildlife Division. Subsequent operational procedures were designed to meet these requirements. A summary of these

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Table 1.--An abbreviated listing of major physiognomic classes used to standardize map nomenclature[1]

Grasses	Herbs (grasses, forbs, and grasslike plants) dominant; woody vegetation lacking or nearly so (generally 10 percent or less woody canopy coverage).
Desert Shrub	Individual woody plants less than 9 feet tall widely scattered throughout desert or semi-desert (11-30 percent woody canopy coverage).
Parks	Woody plants mostly equal to or greater than 9 feet tall generally dominant and growing as small clusters, or as randomly scattered individuals within continuous grass or forbs (11 to 70 percent woody canopy cover overall).
Brush	Woody plants mostly less than 9 feet tall dominant and growing as random or evenly spaced individuals, small clusters or closed canopied stands (greater than 10 percent canopy cover).
Woods	Woody plants mostly 9-30 feet tall with closed crowns or nearly so (71 to 100 percent canopy cover): midstory usually lacking.
Forest	Deciduous or evergreen trees dominant; mostly greater than 30 feet tall with closed crowns or nearly so (71 to 100 percent canopy cover); midstory generally apparent except in managed monoculture.
Young Forest	Immature deciduous or evergreen trees generally equal to or less than 30 feet tall (greater than 30 percent canopy cover); midstory absent; potential to form mature forests; usually encountered in associations under silvicultural treatments.
Marsh	Emergent herbaceous plants dominant in inundated areas; woody vegetation lacking or nearly so (generally 10 percent or less woody canopy coverage).
Crops	Includes cultivated cover crops or row crops (excluding pasturelands) used for the purpose of producing food and/or fiber for either man or domestic animals.
Sparsely Vegetated	Includes intensively overgrazed pastures, eroded terrain, arroyos, and areas containing little vegetation.
Urban	Includes roads, industrial, commercial and residential developments.
Water	Streams, lakes, ponds, estuaries, lagoons, flooded oxbows, and water treatment facilities.

[1]Most ground cover was classified into those classes listed above, however, additional physiognomic criteria was established to cover less significantly occurring types.

operational procedures is given in Table 2.

Development and Implementation of Computer Programs

A set of computer programs collectively known as PATREC (Pattern Recognition) was obtained from the Earth Resources Laboratory of the National Aeronautics and Space Administration. Significant program alteration was required to tailor the system to specific project needs. All software was revised for an IBM 360-50 computer linked to a remote job entry terminal and line printer. A portable image display system (PIDS) was acquired to display reformatted Landsat digital data for selection of training fields and portrayal of classified results. A user's manual (Anderson 1977) was written which documented PATREC processing steps and provided instructions for obtaining

Table 2.--Vegetation type-mapping process utilizing "supervised" approach to classification

Step	Procedure
1	Selection of appropriate Landsat scenes
2	Collection of supportive information
3	Collection of on-site ground truth for each expected *a priori* vegetation type
4	Examination of unclassified satellite data on digital image display system
5	Selection of training fields
6	Calculation and analysis of training field statistics
7	Calculation of training field divergence values to determine class separability and selection of final signature parameters
8	Classification of bulk data utilizing a "table look-up" classifier
9	Geometric correction of classified scene
10	Field verification of classification accuracy
11	Rendition of classified results into a colored map product

desired output. Additional summaries of the PATREC analysis system have been published (Texas Parks and Wildlife 1976, 1977).

Ground Truth Collection

The PATREC system required procedures governed by the "supervised" approach to classification in which specific types of ground cover are identified and located prior to the classification process. Consequently, *a priori* knowledge of all desired ground cover classes was needed. Fortunately, maps depicting gross delineations of vegetation types were available for most counties within the wildlife regulatory districts across the state. However, type nomenclature was not uniform statewide, precluding comparisons. Therefore, the district biologists were requested to utilize standardized criteria (Frentress and Frye 1975) in revising the nomenclature for the existing county type-maps. Additionally, unmapped counties were added to the repertoire to provide complete statewide coverage. From these basic county vegetation maps project personnel prepared a master list of ground cover classes for each Landsat scene. These lists included major plant associations and other ground cover classes such as crops, urban and water, with their respective locations.

Guided by these lists, project biologists acquired photography in the form of county index sheets from the Agricultural Stabilization and Conservation Service. This photography provided coverage for each vegetation type denoted by the master lists.

Collection of ground truth proceeded as follows. Materials were assembled which included: (1) a guide sheet linking the desired vegetation types to their geographical location (i.e. county and Landsat scene); (2) aerial photography covering types on list in (1) above; (3) generalized county type-maps for all types on list in (1) above; (4) ground truth forms (Training Field Record). With the materials assembled project personnel proceeded to the respective areas where the types occurred. The guide sheet provided information on the name of the type, county of occurrence, code number of type within the county, and Landsat scene number. The county type-map was then used to locate the general locale of the type's occurrence. The appropriate photography for the area of interest was utilized at this point. The photography was studied on site to determine an area of adequate size (preferably 40+ acres) and homogeneity. The field was delineated with red pencil on the aerial photography, and an associated ground truth form listing floristics, physiognomy and supplemental information was completed. This process was repeated for each vegetation type.

Ground truth material was organized and filed with a view toward efficient data retrieval when computer processing began. All Training Field Records for each of the respective Landsat scenes were filed together by Landsat scene number. Additionally, the training field form was designed for logging training field coordinates from the data tape displayed on the PIDS. In this way all information pertaining to each training field was condensed onto one data sheet and all sheets for each Landsat scene were retained in one file. The aerial photography was stored alphabetically in a flat-file and was retrieved when training field selection began on the PIDS.

A combined statewide a priori list of ground cover classes for all Landsat scenes was compiled from the master guide sheets. This a priori list facilitated selection and class assignment of various color shades used on the final map products. The same color shade portrays any given plant association or variation thereof regardless of the Landsat scene involved.

Ground truth was reviewed prior to the classification process of a scene to insure availability of adequate field data and eliminate the chance of overlooking a particular class. The Soil Conservation Service range site descriptions for each county in the scene were surveyed and climax and degraded vegetation types for each range site were recorded. This list was compared to the a priori ground truth collected. If a vegetation type was overlooked during the primary collection, then additional ground truth was added before beginning the classification process.

Training Field Selection, Signature Development and Classification of a Scene

Ground truth sites delineated on aerial photographs were located within the Landsat digital data using the PIDS. Training field coordinates recorded as satellite data scan-lines and pixels (scan-pix) were selected for generally homogenous areas within the site. Areas were considered homogenous if they were displayed as the same color (within the same range of reflectance values input onto the PIDS) or as a contiguous block of pixels exhibiting color similarity.

The PATREC system was utilized to compute statistical data for each training field. Several options were available to aid analysis of these statistics. Histograms of reflectance values from each of the four bands were analyzed in terms of Gaussian distribution. This procedure was rapid and less abstract than other methods. Histograms approaching normal distributions served as indicators of good field quality. Unacceptable histograms were manipulated through adjustment of boundary coordinates on a printout of the field to obtain increased homogeneity. Fields were usually discarded if refinement was not possible or combined if band means were similar. Fields were "clustered" if necessary. This process reduced the variance for training field data by eliminating pixels that were strongly dissimilar. Other options available for analysis were a listing of reflectance values and their frequency of occurrence, two band scatter plots, and band spectral plots which illustrated the "spread" of reflectances for each band. This was shown by standard deviations around the mean value. Divergence values computed from the training field signature (band means and four-band co-variance matrix) were used to measure the "separability" between different classes and were indicators of how well the data analysis was proceeding. Refinement and development of a separable "finalized" signature for a particular type of ground cover required iterative utilization of one or more of the above options. The "signature file" for the scene was recorded on direct access disk storage for incorporation into a look-up table (Eppler 1974, Jones 1974) which was utilized by the computer to classify each of the pixels within the entire scene.

The classification tapes contained data coded pixel by pixel into different classes according to the signature guidelines input into the table look-up classifier. The classification tape was geometrically corrected to allow precise latitude-longitude coordinate orientation with standard U. S. Geological Survey maps. Identifiable features such as road intersections were located on the PIDS and recorded as satellite data scan-pix. These data "control points" were correlated to the known latitude and longitude plotted from USGS 7½-minute quadrangle maps and rectification equations were computed that geometrically transformed the data. This process allowed reciprocal conversion of geodetic (Lat-Long), universal transverse mercator (UTM), Texas State Plane, and Landsat scene scan-pix coordinates.

Classification Accuracy Assessment

Procedures were developed for obtaining measurements of performance of the computer classifier. Evaluation of training field performance was conducted to determine the number of original training field pixels which were classified into other classes. This information provided evidence of the magnitude of confusion among classes of ground cover. These data also indicated overall training field quality by reflecting the extent of ground cover homogeneity within the original training fields.

To obtain additional estimates of classification accuracy, biologists verified classes of ground cover by a series of field checks of the computer-generated classification throughout the scene area. Stratified sample sizes were determined in proportion to the percent occurrence of the respective classes in a Landsat scene. This usually resulted in the establishment of 40-70 verification sites.

Three parameters were used in determining accuracy during field verification: (1) vegetation height, (2) canopy cover, and (3) floristic composition. If any one of these parameters was incorrect, then the particular geographical location was considered incorrectly classified. The classification accuracy value was represented by the total number of correctly classified areas expressed as a percentage of the total number of all areas checked.

Field verification information was also utilized to guide the derivation of the final legend nomenclature for each map. If two or more _a priori_ plant associations were significantly confused, they were combined. If at least one of the combined types appeared in the area verified then the area was scored as correctly classified according to the combined nomenclature in the final accuracy summarization.

Modifications of a Classified Scene

Modifications were made in some classified scenes to delineate two or more vegetation types that were spectrally confused but were geographically separable. The procedure allowed changing an erroneously classified type of ground cover within a specified area to the correct class. This was accomplished by changing the classified digital values of pixels belonging to the erroneous class to another value which represented the correct class. These changes were forwarded through the remaining analysis procedures. _A priori_ vegetation types spectrally confused, but inseparable, were combined in the legend nomenclature with the most dominant class listed first.

Cartographical Rendition

A digital tape containing geometrically corrected classified data bounded by Landsat nominal scene borders (McEwen and Schoonmaker 1975) was supplied to a private firm which displayed the data as a colored vegetation type-map at a scale of 1:300,000. The nominal scene boundaries required minor alterations on some scenes to correct for satellite drift.

A supplemental pamphlet was provided with each published type-map. The format included a general description of map contents, a brief discussion concerning plant association nomenclature, physiognomic descriptions, and a list of potentially occurring plant associations which were ecologically similar to those listed on the map legend. Additionally, the acreage of each of the classes portrayed on each map was supplied and a description of the derivation of the map legend nomenclature was made available. Orientation overlays at 1:300,000 portraying roads, drainages, and topography were developed from photographically reduced 1:250,000 USGS topographic maps.

Geographical Smoothing of Classified Results

A capability for smoothing any classified scene into a more generalized product was developed. Higher levels of land-use planning and vegetational analysis could preclude the need for the detailed distribution of individual pixels and other associated "noise" in lieu of a much broader portrayal of ground features. The smoothing process provided a method for objectively delineating these ground features, thus allowing the display of broad-based ecological areas over an entire scene. The smoothing process began by randomly selecting one pixel from a 10x10 block of classified pixels to reduce the entire scene. Following this reduction, each pixel was individually examined in relation to the classes of a 5x5 block of pixels that surround it. This block was weighted binomially such that the class of the center pixel received a value of 6, each pixel adjacent to it 4, and each outside pixel 1. A decision matrix determined if the center pixel was to be changed to a different class. Values assigned to classes within the matrix governed the amount of change from one class to another. Water pixels were not changed to land classes and vice versa. The unclassified category was manipulated such that it would be changed into any class other than itself, and that no other class would be changed into unclassified. Approximately seven iterations were required before the boundaries stabilized between the smoothed classes. Resulting products included a digital tape of the smoothed scene which could be displayed on the PIDS and a computer printout containing the smoothed boundaries which could be overlayed over the original unsmoothed vegetation type-maps portrayed at a scale of 1:300,000.

RESULTS AND DISCUSSION

Data Analysis Chronology

After a two-year implementation period, vegetation type-maps are now produced and published at regular intervals. Procedural steps were established to allow classification analyses to proceed in an orderly, stepwise fashion and to maintain uniformity of effort.

Utilizing established procedures to process a Landsat scene from raw data into a visual map product with accuracy assessments and other additional supplemental materials required approximately 45 man-days and 100 hours of computer processing (CPU) time. Approximate time requirements regarding individual processing steps are provided in Table 3.

Table 3.--Time requirements for one remote sensing analyst to process one Landsat scene

Scene production process	Approximate required time
Ground truth collection	4 Days
Ground truth review[1]	2-3 Days
Training field selection	4-5 Days
Signature development (TR FLD Input; Refine; Combine; Divergences)	10-12 Days
Surveying production of classified tape[2]	0.5 Day
Preliminary pattern analysis of classified tape	2 Days
Geometric correction	2-3 Days
Training field performance evaluation	1 Day
Preparation of 2nd classified tape[3]	2 Days
Surveying production of classified tape[3]	0.5 Day
Selection of verification sites	2-3 Days
Field verification	4-5 Days
Final accuracy evaluation & legend derivation	3 Days
Modifications of the classified scene	1-4 Days
Map tape production	2 Days
Preparation of map legend supplement	1 Day
Preparation of map overlay	1 Day
	Minimum 40 Days
	Maximum 52 Days

[1]Assumes most ground truth previously collected.
[2]Analyst's time only; not computer time.
[3]If necessary.

Summary of Classified Portions of Texas

Digital data from 15 Landsat scenes have been classified into both vegetative and non-vegetative types of ground cover (fig. 1) according to standardized criteria discussed previously. Eleven of these scenes have been published while four others are awaiting re-classification or publication at a future date. Those published scenes comprise approximately one-third of the total area of Texas. These scenes include central, eastern and southern portions of the state.

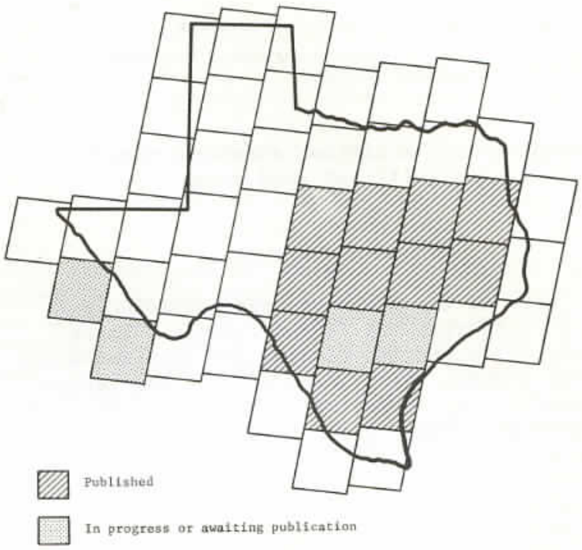

Figure 1.--Status of vegetation type map coverage.

Areas covered by two scenes in south Texas having acquisition dates in early spring (fig. 1) were classified with less than satisfactory results. Vegetative phenology records for those areas indicated that maximum foliage conditions had not yet been reached. Consequently, additional data having acquisition dates later into the growing season will be used to enhance spectral discrimination.

Success of Discriminating A priori Classes

Analyses procedures leading to a classification of each Landsat scene were designed to portray a priori vegetation types occurring within the scene. For the eight scenes listed in Table 4, 69 percent of the total number of original a priori classes listed for those scenes were portrayed individually or in combination with other classes. The remaining 31 percent of those classes were not portrayed. These classes generally were similar ecologically to another class and included under that

Table 4.--Relationship between *a priori* types for which mapping attempts were made and resulting legend classes actually portrayed

Scene	Total no. of *a priori* types determined to occur prior to classification	No. of *a priori* types discriminated from classification[1]	Percent discriminated	No. of map legend class categories portrayed[2]	No. of map legend classes portrayed having combined nomenclature
Eagle Pass	30	18	60	13	5
Austin	26	20	77	14	5
Houston	23	20	87	11	6
Kerrville	23	13	57	10	3
Laredo	21	11	52	10	3
Bryan	20	13	65	7	4
Corsicana	20	13	65	9	3
Lufkin	13	12	92	8	3
$\bar{X}$	22.0	15.0	69.4	10.3	4.0

[1]*A priori* type could have been discriminated in combination with one or more other *a priori* types.
[2]Excluding "unclassified category".

a priori name as a similar plant association or covered insignificant land areas.

Inventory Results

Nine of the eleven scenes published portray 45 different map legend classes. These include 41 vegetative classes and four nonvegetative classes which were derived from various combinations of 38 individual *a priori* names. A condensed summary of acreages by physiognomic classes is given in Table 5.

Table 5.--Condensed listing of physiognomic categories indicating sizes of individual classes and percent of total area

Physiognomic class	Acres	Square miles	Percent of total area
Grasses	7,203,913	11,256.3	15.3
Parks (Sparse)/Grasses	7,728,846	12,076.2	16.4
Parks (Sparse)/Brush	154,461	241.3	0.3
Parks (Dense)	4,112,073	6,425.1	8.7
Brush	4,218,396	6,591.3	8.9
Woods	4,517,147	7,058.2	9.6
Forest (Mature Bottomland)	2,782,819	4,348.3	5.9
Forest (Mature Upland)	6,309,496	9,856.7	13.4
Forest (Young)	218,804	341.9	0.5
Crops	1,454,199	2,274.1	3.1
Crops/Mud Flats	424,802	663.8	0.9
Sparsely Vegetated/Urban	2,748,231	4,294.2	5.8
Water	1,660,875	2,595.2	3.5
Marsh/Cultivated Wetlands	101,745	159.0	0.2
Cloud Cover	312,905	489.0	0.7
Unclassified	3,225,747	5,040.3	6.8
TOTAL	47,174,459	73,710.9	100.0

During the analyses of several different scenes the broad canopy cover range of parks was subdivided into "sparse" parks having a canopy cover range generally from 11-50 percent and a "dense" parks from 51-70 percent. Over one-third of the area currently mapped exhibited sparse ground cover. This included those areas containing grasses, sparse parks, and sparsely vegetated or urban areas. Woods, forests, and heavy parks constituted 38 percent of the area classified. Less than 6 percent of the total area was identified as bottomland forest, a class considered critical habitat in Texas.

Assessment of Map Classification Accuracy

Training field performance information and on-site verification of classified results were used to obtain estimates of class confusion, training field homogeneity, and classification accuracy. Training field performance values calculated for each of the published scenes averaged 92 percent (Table 6). This indicated that an average of 92 percent of the pixels contained within training fields used in the nine separate classifications were classified correctly by the computer. These values do not represent a true measure of classification accuracy, but rather indicate qualitative characteristics of the training fields including degrees of uniformity and similarities or differences in spectral reflectance.

Field verification of areas classified by the computer provided information relating to individual class performance and indicated necessary combinations of similar classes highly confused. Classification accuracies calculated after scene modification and combination of any spectrally confused classes ranged from 81 to 96 percent by scene according to legend nomenclature. The average accuracy value was 87.7 percent correct for all scenes.

Considerable "lumping" of floristic categories was required in many cases, but physiognomic classes were less confused. This suggests that the Landsat scanner system is more sensitive to canopy coverage and vegetative density than to floristic composition.

Some classes of ground cover tended to be

Table 6.--Summary of training field data used in deriving signatures (SIGS) for scene classification in relation to training field performance and classification accuracy

Scene	No. of fields	No. of fields used in SIG development	No. of SIGS used	$\bar{X}$ Fields per SIG	$\bar{X}$ Size of SIG (pixels)	Training field performance	Classification accuracy[2]
Austin	268	93	32	3	89[1]	92.0	96.3 (55)
Lufkin	116	21	20	1	51	96.8	95.6 (23)
Eagle Pass	263	107	37	3	99	90.0	89.8 (49)
Corsicana	188	44	35	1	87[1]	81.3	89.1 (46)
Houston	211	91	41	2	52[1]	94.1	83.9 (50)
Corpus Christi	269	68	28	2	258[1]	96.0	83.8 (31)
Kerrville	202	67	24	3	138	92.3	83.6 (49)
Laredo	175	29	14	2	698[1]	91.2	83.3 (24)
Bryan	274	128	39	3	158[1]	93.9	81.3 (32)
$\bar{X}$ For all scenes	218	72	30	2	181	91.9	87.7 (359)[3]

[1]Excluded fields of water having large acreages.
[2]Based on field verification of classified areas; represents percent correct of total sites checked--total number field checks in parenthesis.
[3]Verification based on legend nomenclature--95% C.I. for sample size 359 with 315 correct: $83.7 \leq 87.7 < 90.8$.

less spectrally separable than others. Sparsely vegetated ground cover, including eroded terrain and grassland areas experiencing heavy grazing pressure, were highly confused with urban, residential and built-up areas in each scene classified. These were combined into a single legend class category. Additional misclassification occurred between this class and other physiognomic classes exhibiting high reflectances such as barren cropland and heavily overgrazed sparse parks or brush. Parks and brush were often misclassified with each other. This was expected since canopy coverage was similar and height differences were often minimal. Woods and forests, also physiognomically separated by a height criteria, were similarly confused with each other. The conformity in canopy between the physiognomic types in both of the above situations apparently exerted more influence in spectral response than height.

Adequate portrayal of wetland areas was sporadic and highly varied between scenes. Marshes were generally confused with cultivated wetlands including flooded rice fields. The marsh category could not satisfactorily be subdivided spectrally into fresh, brackish or saline types.

Extensive efforts were made to determine the feasibility of mapping submergent vegetation along the Texas coastal zone. Attempts were made to correlate patterns shown by unitemporal Landsat digital data with areas of submergent vegetation which were located within the bay systems of Aransas and San Patricio Counties. Results indicated no significant correlation existed between patterns shown by the digital data and patterns of submergent vegetation located in the bay systems. Other factors such as water turbidity and water depth could have affected the intensity of reflected light in addition to those effects, if any, created by the submergent vegetation. These findings were corroborated by examination of higher resolution conventional aircraft photography. No significant correlation was indicated by this method. Findings indicated that attempts to map submergent aquatic vegetation utilizing unitemporal Landsat data should be supplanted by a review of wetlands maps produced by other workers.

CONCLUSIONS

Implementation of a pattern recognition system for processing Landsat digital data into vegetation type-maps has been completed and type-map production is now fully operational. Analysis results indicate that procedures for collecting, processing, and evaluating ground truth are adequate. In contrast to the smoothness of ground truth collection operations, program conversion of the PATREC system was considerably more involved than initially expected. The necessity to rewrite computer programs to provide advantageous revisions and subsequent testing of these revamped programs prolonged the implementation schedule. Establishment of standardized criteria for describing physiognomic classes and an a priori list of major plant associations with corresponding allocated color shades was necessary to eliminate confusion of types from map to map. Intermap interpretation of habitats is essential to development of wildlife management units over broad areas.

Classification results from 11 Landsat scenes indicate that not all major plant associations could be discriminated. A slightly higher accuracy was achieved in discriminating physiognomy than species composition. Results indicate the digital data are providing generally adequate vegetative discrimination for multicounty or statewide analyses.

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Measuring Trout Habitat as an Indication of Population on Large Scale Aerial Color Photographs [1]

Wallace J. Greentree and Robert C. Aldrich[2]

Abstract.--Large-scale 1:1584 normal color photography is a valuable tool for evaluation of instream and streambank habitat conditions. For some conditions color infrared photographs at the same scale showed the stream features more clearly. The largest scale (1:600) photographs were better for detailed description of stream conditions. Once the habitat condition have been measured population ranges may be determined.

INTRODUCTION

Wildlife managers may determine population ranges by measuring stream trout habitat on large-scale aerial color photographs. Results of a recently completed study showed where the photography would be most useful to the wildlife manager, and described techniques and aids for measuring habitat conditions (Greentree and Aldrich 1976).

Two series of color and color-infrared photographs at three relatively large scales (1:600, 1:1584, 1:6000) were taken of a 3.5-mile portion of Hat Creek, in northeastern California. One series was taken in 1968 before a joint effort was made by Federal, State, and private conservation organizations[3] to rehabilitate the stream. A second series was taken in 1969 to assess the rehabilitation program.

Past methods required instream sampling measurements of habitat parameters and fish population. Instream measures are time consuming and expensive and may not provide enough data for good habitat evaluation. Sampling with aerial color photography will improve measurements for some parameters and give more information at lower cost. These photo sampling techniques, together with some ground measurements, can provide baseline data of the habitat under various flow conditions.

METHODS

Most of the methods presented in this paper were originally designed for use in forestry. In applying them to the special problem of trout habitat evaluation, we sometimes tried more than one method. For some measurements, we designed and made specific photo aids.

Aerial Photography

Two photographic flights in consecutive years (1968, 1969) were made from a Forest Service Aero Commander using dual Maurer[4] KB-8 70-mm cameras (with 6-inch focal-length lenses) mounted inside to obtain the photography (fig. 1). One camera contained Anscochrome D/200 (color) and the other EKtachrome Infrared, type 8443 (CIR). The cameras were exposed simultaneously with 60 to 80 percent overlap for stereoscope viewing.

Before the photographic flights, four transects were located along the stream banks representing various habitat conditions, and

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

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[4]Trade names and commercial enterprises or products are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

Figure 1.--Two 70-mm cameras mounted inside the aircraft. The tall, vertical piece of equipment is a forward looking navigation scope.

aerial markers were set out on the banks. The marker consisted of 10-foot long panels placed 100 feet apart for later photographic scale determinations (fig. 2).

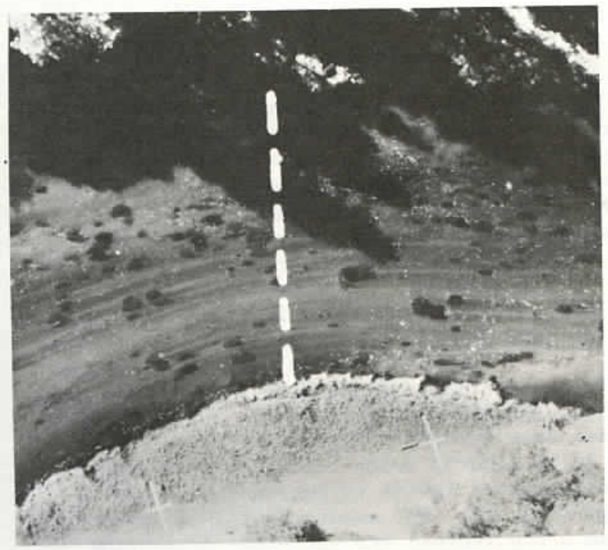

Figure 2.--The dashed line across the stream marks one transect; the two crosses on the streambank are 100 feet apart and are the ground marker panels.

Photo Analysis

In preparation for the photo interpretation, we needed to define important features that could be measured on a vertical photograph. A review of the literature and an examination of the large-scale photographs helped us to separate these features into two broad groups - instream and streambank conditions (table 1).

Table 1.--Trout stream habitat criteria[1] in California

Instream Conditions

Aquatic vegetation	Cover types
Emergent	Logs, debris, and boulders (above water)
Submergent	Logs, debris, and boulders (below water)
Bottom types	Man-made structures
Silt	Shade (overhead)
Sand	Turbulent surface water
Gravel, fine (>1.0 inches)	Surface velocity
Gravel, coarse (1 to 3 inches)	Slow-less than 1.0 f/s, surface smooth
Rubble, fine (3 to 6 inches)	Fast-greater than 1.0 f/s, surface rough
Boulders (12+ inches)	General habitat
Bedrock	Pools
Plant waste	Runs
Water depth	Riffles
Less than 0.5 ft.	
0.5 to 1.5 ft.	
1.5+ ft.	

Streambank Conditions

Bank cover types	Bank types
Deciduous (d), evergreen (g)	Low, undercut
Weeds and shrubs; 0 to 4 ft	Low, no undercut
Trees; 15 to 50 ft. 50 to 100 ft; 100+ ft.	High, undercut
Annual grasses, brown or green	High, no undercut
Gravel, rocks, boulders	Eroded bank
Bare soil	
Bedrock	
Overhanging vegetation or debris	

[1]Based on Lagler 1956, White and Brynildson 1967, and correspondence with Dr. Roger A. Barnhart, Leader, California Cooperative Fishery Unit, Humboldt State College, Arcata, Calif., 1969, and with Fisheries Research Center, Division of Wildlife, Fort Collins, Colorado, 1973.

Once the habitat conditions had been defined, conventional photo interpretation techniques were used to determine how these conditions could be measured. The photographs were examined on a light table with the aid of an Abrams Stereoscope (fig. 3).

Figure 3.--An Abrams stereoscope on a Richards light table was set up for stereoscopic viewing of 70-mm color transparencies.

Instream Conditions

Aquatic vegetation was identified by appearance and color. Bottom types were classified by size of particles and physical appearance. A scale of particle sizes was developed (fig. 4) as an aid in categorizing bottom types into one of four size classes. The transparent film aid was placed on the photo image in question and moved until the particle size on the film equalled the average condition on the stream bottom.

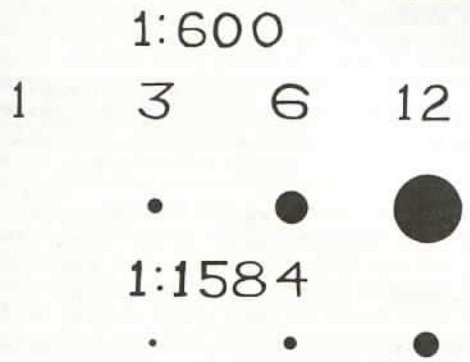

Figure 4.--A particle-size scale was devised for categorizing stream bottom types into one of four size classes.

Water depth estimates were made with parallax measuring devices designed for use on 70-mm film. Both a parallax bar and a parallax wedge were used with measurements taken on the photo at one point on the water surface and another on the bottom of the stream.

Another method tried for estimating water depth required measurement of optical film densities. We used an automatic scanning microdensitometer (MDT) to measure film densities along each of the four transects on both color and CIR transparencies. The MDT was programmed to record automatically the film density along the transect lines. The recorded densities were used with water depth measurements in regression analysis to test the hypothesis that water depth can be predicted from optical film density.

Conventional photo interpretation techniques were used for identifying cover types, surface velocity, and general habitat types on the four study areas.

Stream Bank Conditions

Shoreline vegetation, such as bushes and trees, provides most of the shade cover on the stream. Also, certain bushes and trees help to govern the quantity of land insects and plant litter entering the stream. We worked out a method to determine which bushes and trees contribute to these relationships. Essentially, it required finding values for solar azimuth and solar altitude for the time, date, and latitude of photography. The solar values were used for determining shadow position and tree heights from length-of-shadow measurements on the photographs. The solar values were expanded for every hour of the day and were used with stream direction to determine those bushes and trees affecting the stream habitat.

The other streambank vegetation types - bare soil, gravel, rocks, boulders, and grasses - were classified by conventional photo interpretation.

Photointerpretation and Ground Tests

A photo interpreter examined trout habitat conditions at each of 100 dots on a grid template overlaid on a photograph (fig. 5) and classified each point according to the classes listed in table 1.

Ground measurement truths were collected at each of the four transects by wading the stream and recording bottom types and water depths at 1-foot intervals across the stream. Total heights of 48 bushes and trees along the stream were measured for use in checking the accuracy of heights estimated from parallax or shadow-length measurements on the photographs. Photo habitat classifications were checked in the field at 95 points.

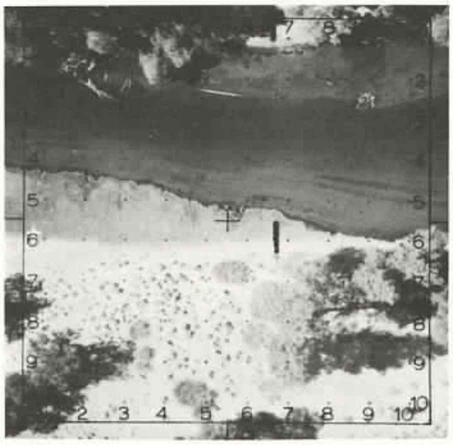

Figure 5.--A 100-dot grid was overlaid on each photograph for interpretation of habitat conditions.

RESULTS AND DISCUSSION

We evaluated two color films and three photographic scales for classifying stream trout habitat conditions present in four study sites. We found the 1:1584 normal-color photographs gave the best overall results in a photo interpretation test. On properly exposed color photographs at this scale, the photo interpreter can readily discern the form, shape, and color of instream and streambank features.

Instream Features

Aquatic vegetation was easier to identify on the CIR photography than on normal color. Healthy vegetation appears bright red which makes it easier to identify beds of vegetation and determine their vigor. Aquatic plants were shown in more detail on the 1:600 and would be the most useful scale for a fisheries biologist. One problem at this scale though is that it is difficult for a fixed wing aircraft to follow the center of a stream to get bank-to-bank coverage. A helicopter because of its slower speed and maneuverability may be the better aircraft for obtaining large scale photography. Aquatic vegetation was correctly identified by the photo interpreter in all cases where it was visible and not obscured by overhanging vegetation, shade, or rough surface water.

Stream bottom types were best described on the 1:600 color photographs. The interpreter had some difficulty in differentiating fine (3-to-6-inch) and coarse (6-to-12-inch) rubble types when using the 1:1584 scale aid. This difficulty was overcome with the larger 1:600 scale aid. Other underwater features that can be seen best at the 1:600 scale includes submerged logs, brush, limbs, and boulders. These features can be classified and evaluated for their value as cover for trout and habitat for certain trout stream insects.

Water depth was difficult to measure with either a 70-mm parallax bar or a parallax wedge because differential parallax (dp) readings are uncertain. The dp value is directly affected by the ability of the interpreter to locate and measure parallax accurately at the surface and on the bottom of the stream. It was nearly impossible to get surface measurement on clear smooth surface water or in shadow areas. A dp reading was easier to obtain on boulder or rubble bottoms than on sandy or silty bottoms. Where stream conditions permitted dp readings to be made, we found that depth estimates were within $\pm$ 2 feet of the actual value. Our best estimates were made on 1:1584-scale color or CIR photographs that had been properly exposed for the stream.

Measurement of optical film densities across the stream on film transparencies with a microdensitometer is another way to obtain stream depths. From these measurements correlation coefficients were calculated for the two film types and four transects (table 2).

Table 2.--Correlation coefficients for the relation between optical film density and water depth, according to film type and transect (1968 photography, 1:1584 scale, Hat Creek, California)

Transect no. and water surface	Film density/water depth correlation coefficient(%)	
	Color	CIR
1, rough	0.560	0.651
2, smooth	.818	.891
3, smooth	.860	.790
4, rough/smooth	.716	.496
Mean	.764	.735

Figure 6 shows actual depths and optical film densities plotted across transect 4. Density values, on a range of 0.00 (clear) to 4.00 (opaque), showed that increases or decreases were comparable to changes in water depth.

This first attempt at measuring optical film densities shows that prediction of water depths were most reliable on normal-color transparencies and when there are the least

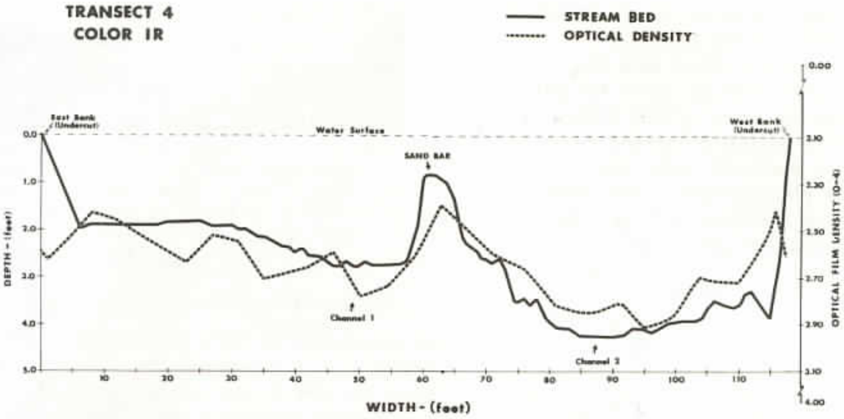

Figure 6.--A comparison of optical film density and water depth was made for transect 4 across Hat Creek. Film density was measured on color infrared film at a scale of 1:1584.

water surface effects. Further work using this approach to depth measurements should enable us to more fully understand the variations in correlation.

Surface velocity classes were best estimated on the 1:1584 photography although we were able to classify them on the 1:6000 scale. The two classes (fast and slow) were inspected for water surface characteristics. Water classified as "fast" has a rough, rippled appearance with many white reflecting surfaces interspersed with clear water. "Slow" water has a smooth surface and appears clear. Reflections from rough surface water in full sunlight are more apparent on CIR than on color photographs. On CIR film, however, no surface details are visible in dense shadow (black) areas. One word of caution when looking at surface characteristics is that slow and fast water types can be misleading if winds are affecting these surfaces at the time of photography.

After bottom types, water depths, cover types, and surface velocity types have been determined, the interpreter can further categorize the stream into general habitat types such as pools, runs, and riffles. The 1:1584-scale color and CIR photographs were useful for this purpose. We preferred the color photographs because surface details in shadow areas can be seen better.

Streambank Features

Undercut banks, which offer excellent cover for trout during the day, were easier to identify on CIR photographs -- the moist grasses which occur along undercut banks appeared in hues of bright red and are more apparent then the green hues of normal color photographs.

Bank features found along margins of the stream may be part of streambank conditions or part of instream conditions. A scale of 1:600 was best for identifying water line features such as overhanging limbs, debris washed up on the bank, undercut banks, cattail marshes, and mouths of tributaries. Bank cover types such as annual grasses, rocks, gravel, sand, and bare soil, can be assessed at the stream margins for signs of erosion or other possible causes for unstable bank conditions at the 1:600 scale.

Stream margin conditions up to 50 ft. from the water's edge can be evaluated adequately on the 1:1584-scale. All the conditions identified on the 1:600 scale can also be seen at the 1:1584, but the detail is not as good. Additional features seen at this scale are signs of cattle grazing, roads, trails, and ecological zones such as wooded reaches, meadows, and marshy stretches.

At distances greater than 50 feet, the 1:6000 photographs gave a more comprehensive view of streambank and surrounding terrain. Color or panchromatic photographs at this scale would be useful for preparing a drainage basin map or for preparing a photo mosaic to update a map or overlay.

A distance-measuring scale aid was used at the actual scale to make length or width determinations of various stream features. Careful measurements between two points, using the proper scale factor, were within $\pm$ 0.5 ft. Distance measurements and actual scales could be made using either the 1:600 or 1:1584 aid on the appropriate photography.

Streambank vegetation (bush or tree) heights were measured by using the 70-mm parallax method and the shadow length method and the vegetation categorized into one of five height classes. Incorrect heights were often made using the parallax bar to measure bushes or small trees without well defined tops and shapes as viewed on the photograph. Our data indicate that a ± 0.10-mm deviation from the true dp could affect total height by 10 feet or less depending on the height of the vegetation. We preferred the shadow method because of the relative ease of measuring shadow lengths with either an inch rule or shadow wedge.

Identification of conifers, deciduous hardwoods, and brush was adequate on the 1:1584 color photographs. Delineation of these types makes possible assessment of cover value for trout as determined by seasonal shade. Shade effect tables were developed for the photography (tables 3, 4, and 5). Table 3 converts shadow length in inches at 1120 hours on October 8, 1968, to height class in feet.

Table 3–*Relation of shadow length to height class on 1:1630 (actual scale) photographs taken on October 8, 1968, at 1120 hours PST,*[1] *Hat Creek, California*

Shadow lengths measured on photo (inches)	Vegetation height class (feet)
0.000 to 0.040	5 (0 to 5)
0.041 to 0.080	10 (6 to 10)
0.081 to 0.160	20 (11 to 20)
0.161 to 0.240	30 (21 to 30)
0.241 to 0.320	40 (31 to 40)
0.321 to 0.401	50 (41 to 50)
0.402 to 0.481	60 (51 to 60)
0.482 to 0.561	70 (61 to 70)
0.562 to 0.641	80 (71 to 80)
0.642 to 0.721	90 (81 to 90)
0.722 to 0.801	100 (91 to 100)

[1] Latitude 40°58'20" N; longitude 121°33'11" W.

Table 5–*Shadow position by hour of day–October 8, 1968, Hat Creek, California*

Time (PST)	Shadow azimuth	Time (PST)	Shadow azimuth
0800	297°36'19"	1200	355°45'27"
0900	310°23'12"	1300	23°30'23"
1000	325°46'12"	1400	40°59'42"
1100	344°04'36"	1500	55°12'37"
[1] 1120	350°41'42"	1600	67°08'29"

[1] Time of photography in this study.

For example, if the shadow of a pine tree is measured and found to be 0.171 inches, it falls in the 0.161 to 0.240 group, and is in the 30-foot height class. Once the height class is known, the tree's shadow length and position on the stream for any time of day can be determined from tables 4 and 5. For example, from table 4 a 30 foot tree (height class 30 feet) at 0800 hours, would have a shadow length value of 0.608 inches; from table 5 the position of the tree's shadow on the stream is 297°36'19".

With this information it is possible to assess the effects of the tree's shadow on the stream throughout the day. The example (fig. 7) shows shadow effects of two trees – one on the east bank and one on the west bank of a north-flowing stream, and how changes in shadow position during the day might affect trout cover.

CONCLUSIONS

The need of trout to seek a spot under or around submerged logs, boulders, aquatic plants, undercut banks, fast surface water, shade, etc. for protection and feeding purposes during the day prevents their detection on large-scale aerial color photographs. On the other hand, aerial photography described in this report can be a valuable tool for evaluating stream

Table 4–*Shadow lengths*[1] *by hour of day–October 8, 1968, Hat Creek, California*

Time (PST)	Shadow length at vegetation height-class (feet) of . . .										
	5	10	20	30	40	50	60	70	80	90	100
						Inches					
0800	0.101	0.203	0.405	0.608	0.810	1.013	1.215	1.414	1.621	1.823	2.026
0900	.065	.131	.262	.393	.523	.654	.785	.916	1.047	1.178	1.309
1000	.049	.098	.196	.294	.392	.490	.587	.685	[illegible]	.881	.979
1100	.041	.083	.165	.247	.330	.412	.495	.577	[illegible]	.742	.825
[2] 1120	.040	.080	.160	.240	.320	.401	.481	.561	.641	.721	.801
1200	.040	.079	.158	.238	.317	.396	.475	.554	.633	.713	.792
1300	.040	.080	.159	.239	.319	.398	.478	.557	.637	.717	.796
1400	.054	.109	.218	.327	.436	.544	.653	.762	.871	.980	1.089
1500	.077	.154	.307	.461	.614	.768	.921	1.075	1.228	1.382	1.535
1600	.131	.262	.524	.785	1.047	1.309	1.571	1.833	2.094	2.356	2.618

[1] Shadow length values are for the upper limit of each height class.
[2] Time of photography.

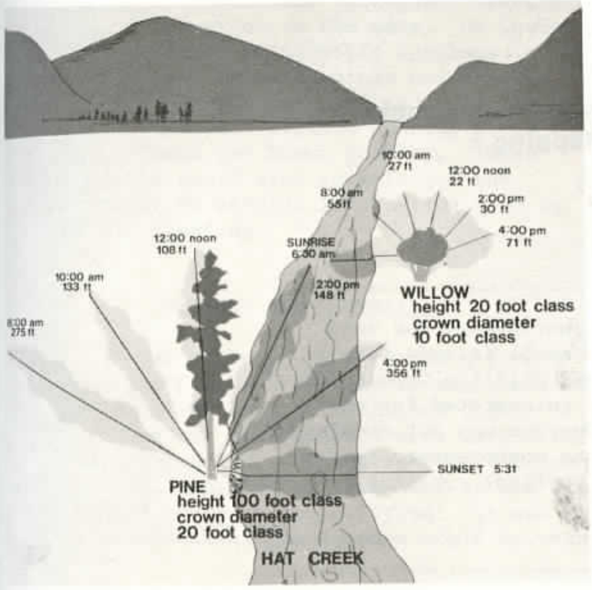

Figure 7.--The effects of shade caused by two trees on a portion of Hat Creek-October 8, 1968-are shown diagramatically.

trout habitat and inferences about trout populations ranges can be made based on those measurable habitat conditions.

Most characteristics of trout streams are visible and are described directly on the photographs. Some conditions such as average size of stream bottom aggregates, depth of water, and heights of streambank vegetation are estimated using special measuring aids developed or adapted for this study. Degree of shade on the stream can be evaluated using a technique that includes measurement of vegetation shadow lengths and vegetation positions in relation to the stream and the use of solar position formulas. Habitats supporting trout stream insects production can potentially be evaluated using the photographs as a base from which to sample and collect this biological data.

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Application of Small Format Aerial Photography for Wildlife Habitat Mapping[1]

Elizabeth Hertz[2]

Abstract.--Hand-held 35 mm aerial photography was used to make base and land-cover maps of two small islands for the United States Virgin Islands Fish and Wildlife Commission. Color infrared slides were enlarged and interpreted for cover type information. Although vertical coverage was not obtained, it was possible to make relative resource measurements from these maps. Recommendations to insure vertical coverage are made for future mapping projects.

INTRODUCTION

Small format photography has proven a useful tool for the resource manager in evaluating wildlife habitat, rangeland and forest resources, watershed management, and mineral exploration (Miller, 1974; Scheirel and Meyer, 1976; Grumpstrup and Meyer, 1977). Relative low cost, ease of operation and availability of equipment make the 35 mm photographic system a valuable tool in projects concerned with resource monitoring. Careful selection of film/filter combinations and scale allow specific information to be gathered and certain environmental conditions to be enhanced. Environmental monitoring frequently involves separating ecological communities that do not exhibit distinct boundaries. Transition zones, where one community grades into another make accurate boundary location difficult when working on the ground. Definition of ecological communities can frequently be accomplished more easily from an aerial perspective. The small format aerial photographic system is well suited to projects requiring repeated coverage of a small area in which mapping camera accuracy is not required (Clegg and Scherz, 1975).

This paper discusses the use of 35 mm photography in wildlife management projects to be carried out by the United States Virgin Islands Fish and Wildlife Commission on two small islands in the Virgin Islands. On one island, Leduc, southeast of St. John, United States Virgin Islands, the wildlife biologist plans to use radiotelemetry techniques to learn more about the natural history and bioenergetics of the mongoose (Herpestes sp.). The mongoose, introduced onto the islands to control snake populations, now exerts heavy predation pressure on passerine bird populations and has become a pest near population centers. It is hoped that information gathered through electronic tracking can be used to develop more effective management control programs. The second island, Cockroach, northwest of St. Thomas, U.S.V.I., is used as a nesting colony by several species of sea birds. For one species, the Blue-faced Booby (Sulá dactylâtra), it is the only nesting colony within the territorial United States. Nesting studies are underway to monitor nesting success of the Blue-faced Booby and possible effects on the population due to competition with the Brown Booby (Sulá leucogâter) for nesting sites.

OBJECTIVES

The objective of this project was to produce base maps showing the outline of the islands and land-cover maps of each island using 35 mm aerial photographs. On Leduc, accurate placement of landmarks (e.g., single trees, exposed boulders) and vegetation boundaries was necessary for location of

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

[2]Masters candidate, Rackham School of Graduate Studies, The University of Michigan, Ann Arbor, Michigan, 48109.

telemetered animals and subsequent transfer of this information to the maps. On Cockroach, it was necessary to identify openings in the grassy areas. These openings and exposed boulders and rocks were plotted onto the base maps to evaluate available nesting sites for the Blue-faced and Brown Boobies. These photographs would also be enlarged and interpreted to provide information used in habitat evaluation.

METHODS AND MATERIALS

Aerial photographs were taken from a high-winged Cessna 172 using several hand-held camera and lens combinations (table 1). Each island was photographed with each film/filter combination. Photographs were taken through the starboard window port as the plane was banked over the target areas. It was hoped that near-vertical photographs would be obtained.

Table 1.--Camera, film/filter combinations and scale for each film type used

Camera	Lens	Film	Filter	Scale
Konica	35-100 mm	Kodak Ektachrome Color Infrared 2236	Wr25	1:17,417
Olympus OM-2	35-100 mm	Panatomic X FX135	Wr12	1:17,417
Nikon	70-210 mm	Panatomic X FX135	Wr25	1:13,062
Olympus OM-2	70-210 mm	Black-and-white Infrared HIE135	Wr89b	1:13,062

The color infrared film (CIR) was processed commercially to slides. The two black-and-white films were processed to negatives and prints. A 5"x7" color positive transparency was made of Leduc.

Two techniques were used to create base maps of the islands: (1) A carousel slide projector was used to project a 35 mm CIR slide onto a piece of white paper taped to the wall. The desired resource information was delineated on mylar overlays; (2) The 5"x7" positive transparency was mounted on a Bausch and Lomb zoom transfer scope and the base map information was delineated from the projected image onto mylar overlays. (Figs. 1 and 2).

Cover type mapping was carried out in the same manner. (Figs. 3 and 4). Land-cover types were distinguished on the basis of differences in color, texture, shape and location apparent on the CIR photographs. (Figs. 5 and 6, tables 2 and 3). On Leduc, an effort was made to locate landmarks such as single trees and boulder outcrops that could be used to orient one's self on the ground. On Cockroach, openings in the grassy areas were delineated.

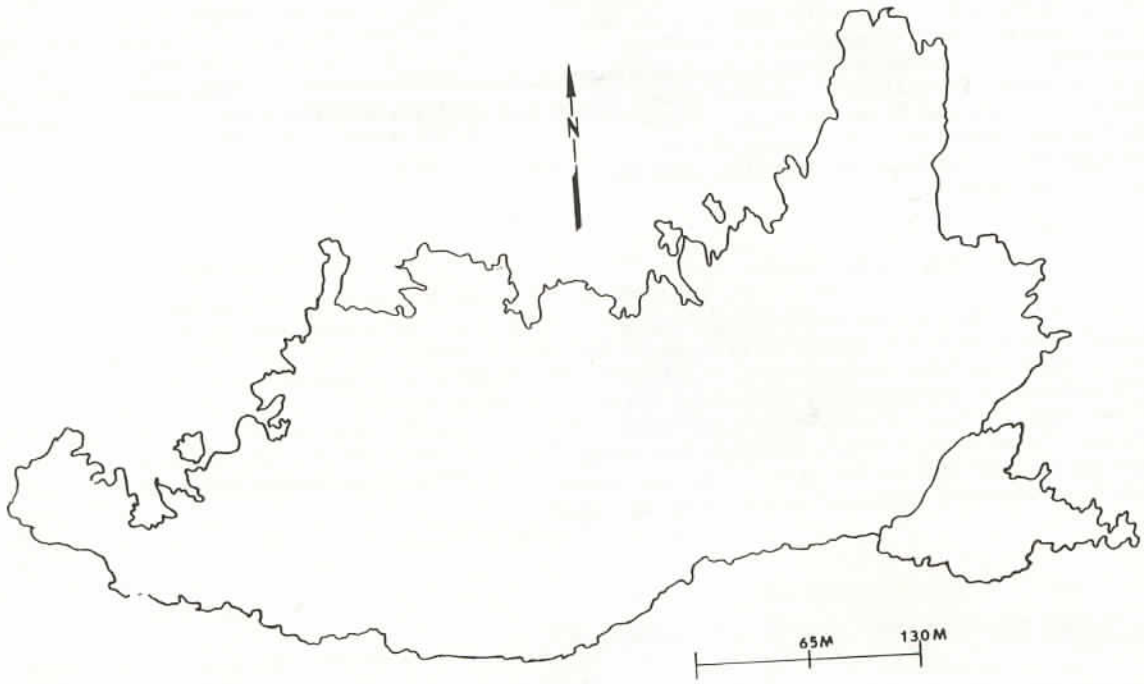

Figure 1.--Base map of Cockroach made from projected image of CIR 35 mm slide.

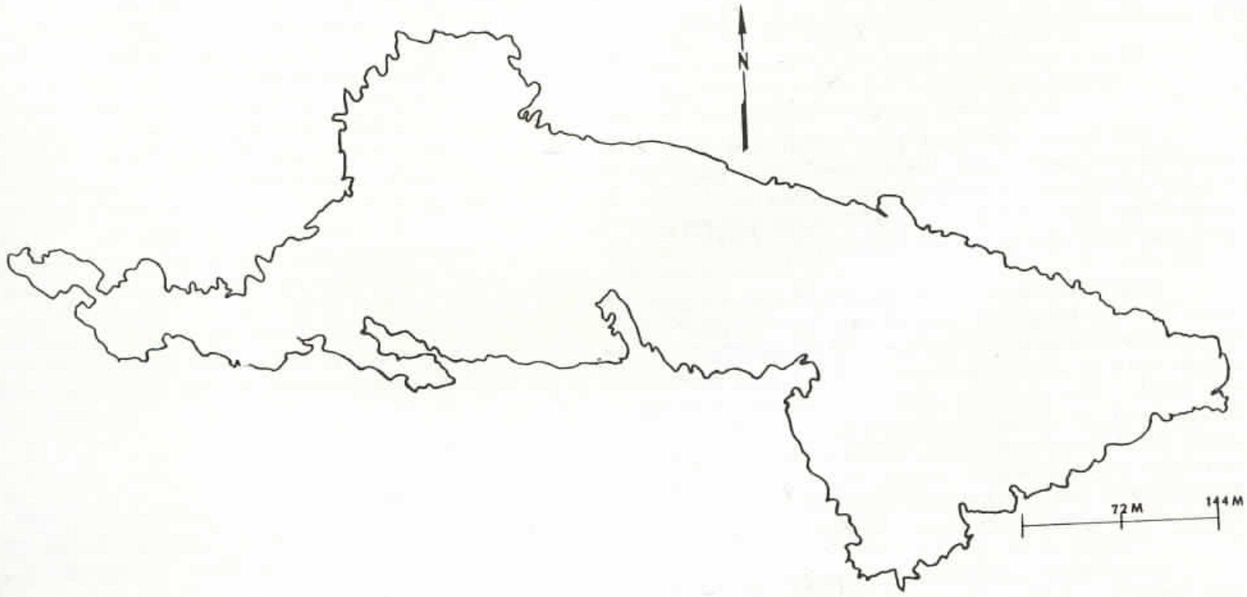

Figure 2.--Base map of Leduc made from projected image of positive color transparency using zoom transfer scope.

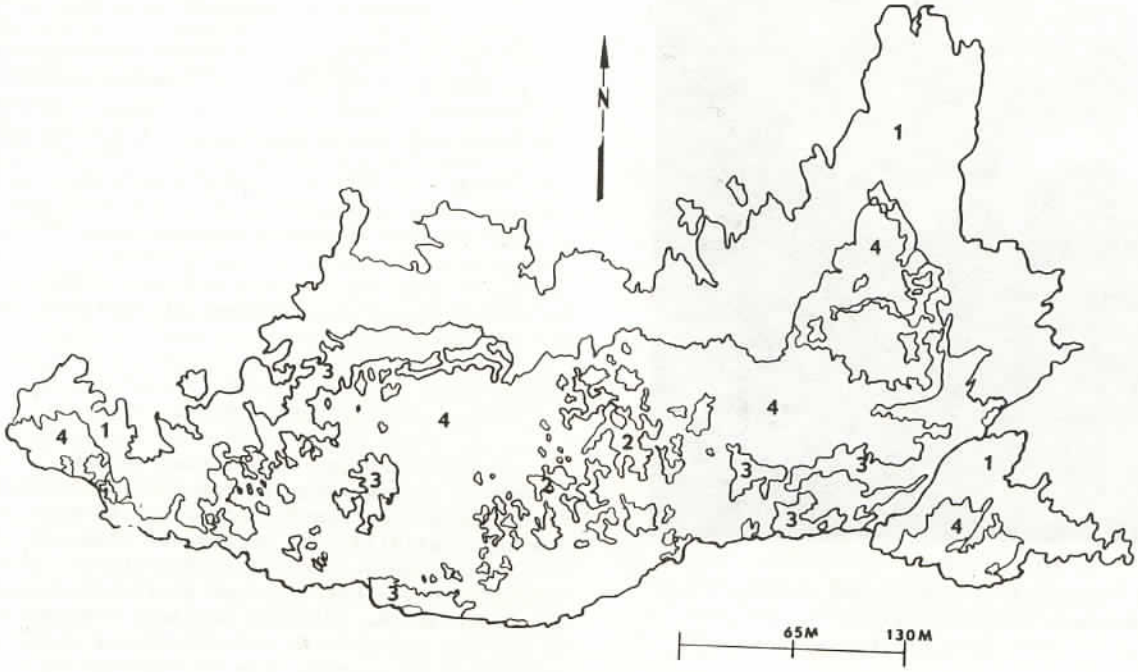

Figure 3.--Cover type map of Cockroach made using 35 mm CIR slide. See Table 2 for land-cover types.

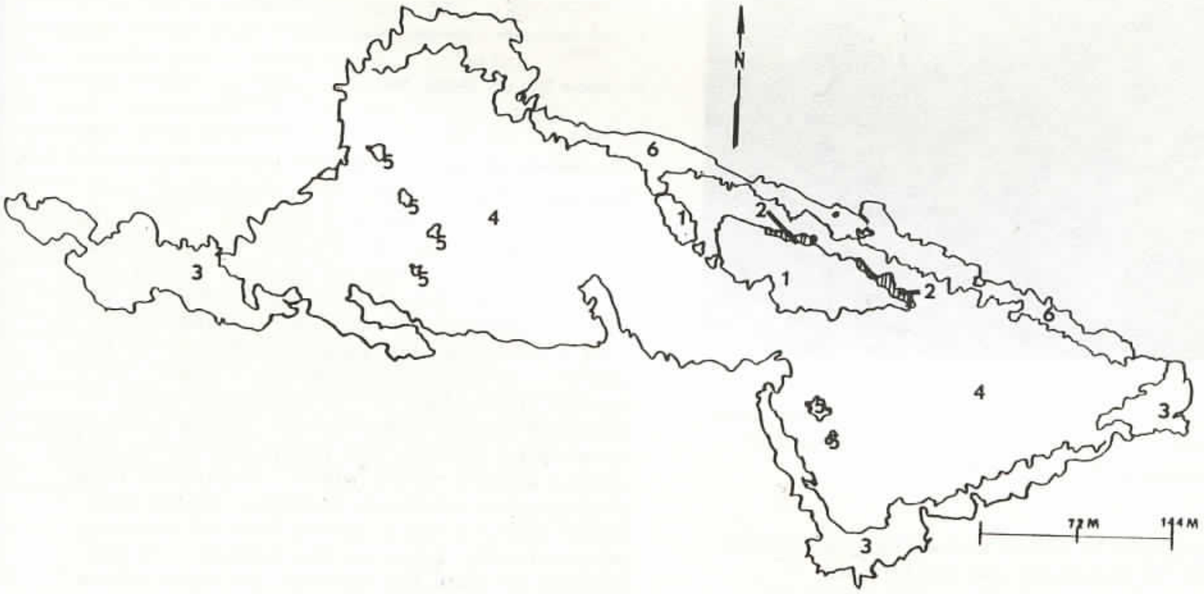

Figure 4.--Cover type map of Leduc made using 5x7 positive transparency and zoom transfer scope. See Table 3 for land-cover types.

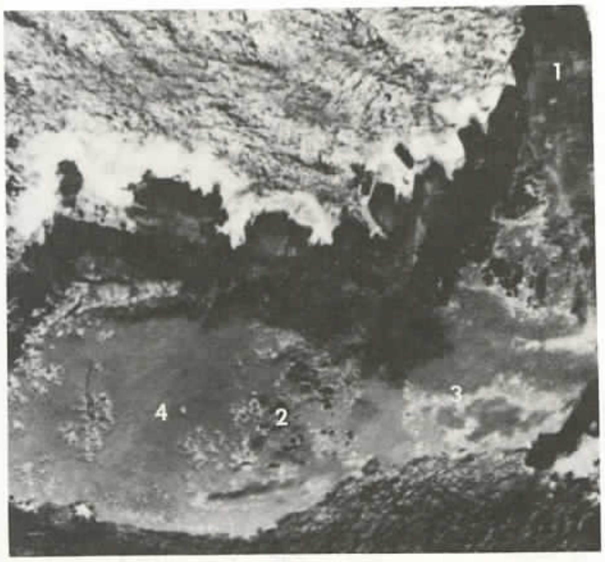

Figure 5.--Portion of photograph of Cockroach used in photo interpretation. Black-and-white print made from CIR transparency.

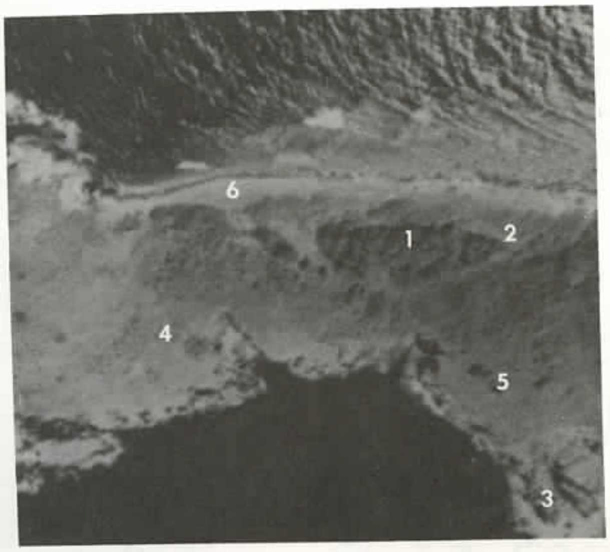

Figure 6.--Portion of photograph of Leduc used in photo interpretation. Black-and-white print made from CIR transparency.

Panchromatic black-and-white photographs were used as ancillary information to substantiate interpretations made from the CIR photography. Mylar overlays were prepared of the island boundaries and of the land-cover types. These overlays were copied onto white

Table 2.--Photo interpretation key for Cockroach

Feature	Color	Shape	Texture	Location
1. Exposed Rock	Black	Variable	Smooth	Shoreline
2. Rocky Opening	Greenish Black	Variable	Rough	Mid-Island
3. Opening	Green	Variable	-	-
4. Low Veg Cover	Pale Red	-	Varied	-

8½"x11" paper, a more convenient form for use as field maps.

RESULTS

A major problem encountered was the hand-held photography did not produce vertical coverage of the islands. An aircraft mount was not initially used because of time and cost constraints. However, without one, it was discovered that vertical photographs could not be obtained. Without vertical coverage, it was not possible to accurately map shoreline boundaries or to make area determinations

Table 3.—Photo interpretation key for Leduc

Feature	Color	Shape	Texture	Location
1. Mangrove Lagoon	Red-Red Orange	Triangular	Rough	Low Area
2. Opening	Green	Elliptical	Smooth	Low Area
3. Exposed Rock	Black	Variable	Smooth	Shoreline
4. Low Vegetation Cover	Reddish Green	-	Variable	Hillside
5. Single Tree	Bright Red	Circular-Elliptical	Smooth	Hilltop
6. Beach	Tan	Long and Narrow	Smooth	Shoreline

without first rectifying the scenes, an extremely time-consuming process. This placed limitations on the utility of the photographs for reaching the initial goals. However, a great deal of information was contained in the oblique photographs and they proved useful to test resolution and interpretability of the system. A second problem was a result of faulty processing of the black-and-white infrared film. The film was fogged during the developing process and the resulting negative strips were entirely black. Replacing this photography, although possible, would have meant introducing a second date of coverage substantially later in the season. It was decided to make the initial interpretations from the existing photographs and to reconsider which film/filter combinations to use for the final photography.

The scale of the CIR slides, 1:17,417, proved adequate for vegetation mapping. Differences in tones and textures were quite clear when the slide was enlarged to a scale of 1:2,000 as well as on the 5"x7" positive transparency at a scale of 1:3,958. Projecting a CIR slide with a slide projector and tracing the projected image produced a convenient system from which to map. Major drawbacks of this system were eyestrain and the possibility of melting the slide when working for over 15 minutes at one time. Working with the positive transparency and the zoom transfer scope created less eyestrain and eliminated the problem of potentially melting the slide. Varying the illumination behind the transparency enhanced subtle differences between cover types not otherwise detectable facilitating land-cover mapping. On Leduc, single trees and small clumps of bushes were resolved and the mangrove lagoon along the north shore of the island was easily mapped. Openings in the grassy areas of Cockroach were distinguishable although it was difficult to discern which openings were rocky and which were not. Areas of heavy surf obscured portions of the shoreline on both islands.

CONCLUSIONS

The small format camera system described in this paper offers the wildlife manager a practical tool with which to map wildlife habitat. Low cost, availability of equipment, ease of operation and repeatability makes this system valuable in studies requiring repeated coverage of an area. Low oblique CIR photographs proved adequate for relative cover type mapping and could be used to monitor vegetation changes over time. With vertical 35 mm photographs, it would be possible to make accurate base maps and land-cover maps from which resource measurements could be made. For future flights of this project, it is recommended that an aircraft mount be used to insure vertical coverage and that cameras used be wired together so one cable release would trip all shutters simultaneously and that the rewind mechanisms be powered by motor drive. With careful planning and equipment selection the resource manager can tailor this type of small format camera system for project work in which the metric accuracy of mapping cameras is not required.

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Remote Sensing-Aided Assessment of Wild Turkey Habitat [1]

Edwin F. Katibah[2]

W. C. Graves[3]

Abstract.--Potential wild turkey habitat comprising known vegetation associations were identified using the Landsat 2 data, for a study area within Mendocino County, California. Areas having established wild turkey populations were used as training sites to identify the vegetation association mix. This classified Landsat data will allow specialists to determine areas within Mendocino County that are potentially suitible for wild turkey introduction.

INTRODUCTION

One of the most prized game birds in California is the wild turkey (*Meleagris gallopavo*). Although not native to California, they were first introduced in 1877 to Santa Cruz Island (an island off the Southern California coast) by ranchers. The first public releases of these birds were made by the California Fish and Game Commission (now the California Department of Fish and Game) in 1908 and were continued through 1951. Although during that period over 3,000 pen reared turkeys were released throughout the state, only three sustaining populations became established (Burger, 1954). A turkey release program using only wild trapped birds from existing California flocks or from established populations in other states gained new support following the release in 1959 of 62 wild trapped Rio Grande (*M.g.gallopavo*) turkeys from Texas. This new program was highly successful with several populations established and several counties later opened to turkey hunting (Harper, 1977). Turkey populations are continuing to increase from natural dispersion of established flocks and through continued trapping and stocking programs.

In order to aid in the establishment of the wild turkey as a key game species in California, the California Department of Fish and Game developed a document titled "The Wild Turkey Management Plan" (Harper *et al.* 1973). This plan attempted to determine the location and extent of potential turkey habitat throughout the state of California and to identify future release sites. Using conventional mapping methods 5,800,000 hectares (14,500,000 acres), or 14.5 percent of the land area of California, was identified as potential turkey habitat (prior to this study, release sites were selected subjectively following field inspection of sites within areas previously identified as potential habitats). Following this procedure 45 sites were stocked with wild turkeys prior to 1975. Sustaining populations were established in 66 percent of these areas. Because of the time and expense involved in capturing and moving turkeys, and because only a few sites are available for stocking each year, it soon became obvious that a more objective procedure was needed to identify suitable habitat and release sites. The ongoing research which is briefly documented in this paper, has been designed to (1) provide site specific habitat information that is needed to determine the exact locations where wild turkeys might be successfully introduced, and (2) to delineate the extent of that potential habitat.

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[1]Paper presented at Pecora IV, the Application of Remote Sensing Data to Wildlife Management, Souix Falls, South Dakota, Oct. 10-12, 1978.

[2]Assistant Specialist, Remote Sensing Research Program, University of California, Berkeley, California.

[3]Wildlife Biologist, California State Department of Fish and Game, Chico, California.

METHODOLOGY

Mendocino County (located on the north coast of California) was selected for testing remote sensing and ancillary data analysis techniques for mapping turkey habitat (see Figure 1).

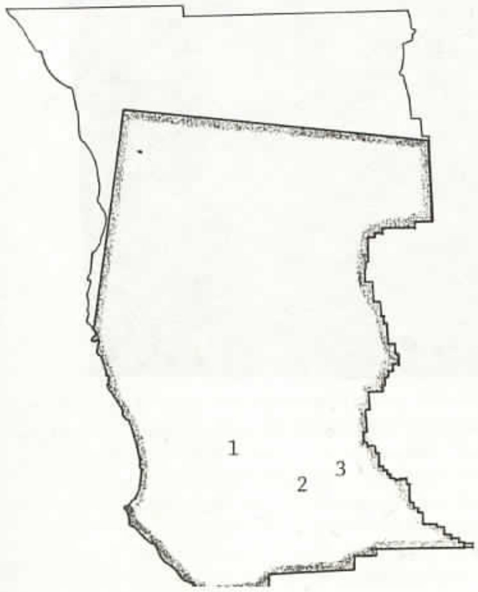

Figure 1.--Map of Mendocino County showing the study area (dark shading) and the training and testing sites (1.Bonneville; 2.Yorkville; 3.Hopland).

Using conventional mapping techniques, 42,241 hectares (104,300 acres) or 4.5 percent of the county, were identified as potential turkey habitat. Eight sites within this habitat have been stocked with turkeys: four areas have sustaining turkey populations with an estimated total population exceeding 1,000 turkeys; two areas were considered unsuccesful releases; and the stocking level in two areas is unknown.

Due to the large land area involved it was evident that remote sensing analysis techniques could provide the necessary data for assessing potential turkey habitat. To minimize the cost and amount of time needed to analyze an area as large as this study area a multi-information package was needed. The basis for this remote sensing-aided assessment of wild turkey habitat was the integral use of Landsat 2 digital data, high altitude (1:33,500) 9x18" conventional color and color infrared aerial photography, supplemental map data, and ground sampling.

Prior constraints dictated the development of a procedure for Landsat data analysis that could be implemented quickly and inexpensively. Towards this end only one Landsat date was used for analysis. The date chosen, June 27, 1976, was considered to be the best date to separate spectrally the principle vegetation associations.

The data analysis was performed in three distinct steps: preprocessing, in which a sample area was selected to generate spectral training data; processing, in which the sample area was clustered to produce training statistics which were submitted to the maximum likelihood classifier that classified the entire study area; and post processing, in which the classified output was analyzed by wildlife experts to determine potential turkey habitat locations.

Preprocessing

The primary goal of this step was to select training and testing areas of all vegetation features that would be present in good wild turkey habitat. Only those areas in which wild turkey population had been introduced and established were selected as the training and testing sites.

Three good turkey sites were present within the study area: Booneville, Yorkville, and Hopland. The Booneville site was selected as a training site because it has had a sustaining turkey population since 1970, and it presently serves as a trapping area to supply stock for releases in new areas. The Yorkville and Hopland sites were selected as testing sites.

These three areas were located on USGS topographic maps and then transferred to aerial photos (1:33,500, color and color infrared) which were acquired in May 1978. Then, through the use of an interactive color display system, the Landsat coordinates of these areas were determined with the aid of the aerial photos, and the spectral data from the areas were extracted from the Landsat scene.

Processing

The spectral data from the Booneville site were submitted to the algorithm ISOCLAS which automatically generated 23 spectral clusters about the band means. After the clustering of the training site had been completed, and prior to submitting the training statistics to the classification algorithm, each of the 23 clusters had to be labeled as one of the five major vegetation associations present in the site (Table 1). To facilitate this labeling procedure, the clusters were ranked on the basis of the ratio of two times the mean cluster value in the infrared band (Band 7) to the mean cluster value in the red

Table 1.--Definitions of the major vegetation associations for the Booneville test site

Vegetation association	Definition
Bare soil	Urban, rock, bare ground, etc.
Grassland	Complex of annual grasses and forbes
Oak/Grassland	Grassland with scattered oaks(primarily *Quercus Douglasii*)
Oak	Predominately oak stands composed of *Quercus Garryana*, *Q. agrifolia*, *Q. Kelloggii*, with some *Lithocarpus densiflora*
Conifer	Stands composed largly of *Sequoia sempervirens*, *Pseudotsuga Menziesii* with some *Lithocarpus densiflora*
Other	Various brush types, water, etc.

band (Band 5) as shown in Table 2.

Table 2.--ISOCLAS cluster ordering by 7/5 ratioing of Landsat band means with major vegetation associations

Order	Cluster number	7/5 ratio	Major vegetation association
1	6	1.20	Bare soil
2	1	1.29	Bare soil
3	5	1.39	Grassland
4	9	1.43	Grassland
5	2	1.58	Oak/Grassland
6	14	1.58	Oak/Grassland
7	10	1.63	Oak
8	15	1.73	Oak
9	11	1.75	Oak
10	13	1.76	Oak
11	3	1.77	Oak
12	21	1.94	Oak
13	16	2.11	Oak
14	17	2.12	Oak
15	20	2.20	Oak
16	12	2.22	Oak
17	8	2.54	Oak
18	4	2.62	Oak
19	23	2.75	Conifer
20	18	2.84	Oak
21	19	3.09	Oak
22	7	3.13	Conifer
23	22	3.36	Conifer

The ordered ratios used in conjunction with annotated aerial photos of ground conditions and with the display of the clusters on the interactive monitor were used by wildlife and remote sensing specialists to label the clusters. The labeled ISOCLAS clusters were then grouped into five major vegetation associations for the Booneville area.

The ISOCLAS clusters were then used to provide the statistical data necessary to classify the remaining study area on the Landsat digital data. The program CALSCAN (the maximum likelihood classific developed by the Purdue University Laboratory for the Application of Remote Sensing modified to run on the University of California's CDC 7600 computer) was given the ISOCLAS data relating to the major vegetation associations. Each Landsat pixel was assigned to one of the ISOCLAS clusters. To eliminate pixels which did not closely fit any of the ISOCLAS clusters, a decision model was introduced to "threshold" out these areas. The remaining classification therefore, showed only those areas which were similar to the original ISOCLAS clusters spectrally and therefore in vegetation association information.

To make the final classified output more interpretable to wildlife specialists, each vegetation association was assigned a specific color (see Figure 2).

Figure 2.--The areal extent of the major vegetation associations within the Mendocino study area. Key: White - Bare Soil; Green - Grassland; Yellow - Oak/Grass; Red - Oak; Light Blue - Conifer; Black - Mask

In addition, major urban/agricultural areas within the county which are not appropriate turkey habitat were masked out of the display.

Postprocessing

Two criterea have been established for the interpretation of the vegetation association map for turkey habitat: (1) the proper mix of vegetation associations; and (2) a sufficient areal extent of these mixes to support wild turkey populations. Experience of past releases in California and other states indicates that a minimum area of 2,000 hectares (5,000 acreas) of contiguous suitable habitat is needed. Good turkey habitat in Mendocino County is represented primarily by the oak and oak/grassland associations. Turkeys are also known to use the edges of the conifer and grassland associations when these areas adjoin the oak and oak/grassland areas.

To identify potential turkey habitat throughout the study area, use is being made of the vegetation association map and the two potential habitat criterea of proper vegetation mix and areal extent of habitat.

RESULTS AND DISCUSSION

Two major results to date are the definition of the proper vegetation mix and the generation of the vegetation association map for the Mendocino County study area.

The Booneville training site encompased 2,300 hectares (5,670 acres). Grassland, oak/grassland and oak (the primary components of turkey habitat) comprised 70 percent of the total area (Table 3).

Table 3.--Major vegetation association mix by percent for the three sites within the study area.

Major vegetation association	Booneville	Yorkville	Hopland
Bare soil	11	3	3
Grassland	16	18	16
Oak/Grassland	12	21	18
Oak	35	34	36
Conifer	3	6	13
Other	22	19	14

These preferred vegetation associations covered 73 percent of the 2,040 hectare (5,039 acre) Yorkville test site and 63 percent of the 3,950 hectare (9,757 acre) Hopland test site. Each area was covered by approximately 35 percent of the pure oak association. These data are not sufficient for establishing statistical ranges for each vegetation association percent classification. However, they do provide general parameters to serve as guidelines in finding areas of similar habitat composition within the Mendocino County study area.

Areas that have been identified as potential habitat will be field checked to determine their suitability for the release of turkeys. Such elements as available water, topography, present and proposed land use, land ownership, and proximity to other potential or already stocked turkey sites will be used in further determining the final selection of release sites.

RECOMMENDATIONS

Based on the results of this preliminary study, four areas were identified for continued investigation both with remote sensing and ancillary data:

1. Identify natural vegetation terrain, and cultural barriers which effectively prevent the range expansion of existing wild turkey populations.
2. Evaluate the past turkey release sites that have failed to determine the limiting factor(s) for that particular area.
3. Expand the number of test sites so that valid statistical descriptions of major vegetation association mix can be applied within Mendocino County.
4. Refine the spectral classes used to evaluate the Landsat digital data for the final major vegetation association classification.

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ACKNOWLEDGEMENTS

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A Method of Horizontal Habitat Quantification for Use in Open Canopy Communities [1]

Jeffrey K. Keller[2], Douglas Heimbuch[3], and Milo Richmond[2]

Abstract.--Efforts to relate faunal diversity patterns to horizontal structural complexity of habitat have suffered mainly from lack of a method that adequately describes the two-dimensional pattern of horizontal habitat structure. In this paper we detail a method of horizontal habitat measurement, using a computer based scanning algorithm, that permits the simultaneous quantification of a number of variables. These may then be combined in a multivariate analysis to test their relationship to patterns of faunal diversity and distribution.

INTRODUCTION

Many recent studies dealing with a variety of taxa, including birds, lizards, rodents, insects, stream fishes, and marine invertebrates, indicate that increasing species diversity, measured by either richness or an index combining both richness and equitability (reviewed by Peet 1974), is correlated with increasing structural complexity of the physical environment (MacArthur and MacArthur 1961; Pianka 1966, 1967; Karr 1968; Recher 1969; Rosenzweig and Winakur 1969; Sanders 1969; Cody 1970, 1975; Karr and Roth 1971; Murdoch et al. 1972; Brown 1973; McCloskey 1976; Gorman and Karr 1978; Stinson 1978). The earliest studies in this area (MacArthur and MacArthur 1961; MacArthur et al. 1962) dealt with avifaunal responses to the vertical structure of vegetation. Robert MacArthur and his co-workers found that the number of layers of vegetation present combined with the evenness of foliage distribution among layers, a measure termed foliage height diversity (FHD), was an excellent predictor of bird species diversity (BSD). MacArthur also suggested that "there is a large collection of species" whose presence in a habitat is associated with a particular foliage profile or "patch type" (MacArthur et al. 1962). He pointed out that this did not necessarily mean that a given species used only its patch type in choosing its habitat, merely that the patch type is "closely associated" with whatever the bird relies upon to make its choice (e.g. food abundance, suitable nest site). Several later studies, the first by James (1971), using multivariate analysis of the vegetation structure of individual species territories have supported MacArthur's hypothesis that many species have a patch type (habitat specialist) or range of patch types (habitat generalist) with which they are associated.

Following this line of reasoning MacArthur et al. (1962) argued that there should be a horizontal as well as a vertical component to diversity and suggested that one community might support more species than another of comparable vertical diversity because of "a greater internal variation in vegetation profile (that is, a greater variety of different kinds of patches)". Subsequent studies (Karr and Roth 1971; Willson 1974) have supported this contention by demonstrating that although vertical complexity is a good predictor of BSD across communities, as when going from grassland to shrubland to forest, it is a poor predictor of BSD when comparing avifaunal samples from within a given community type (e.g. Galli et al. 1976). Willson and Moriarty (1976) contended that the inability of vertical foliage profiles to predict BSD among samples from the same community type is due to

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the fact that FHD and other measures of vertical foliage structure, such as percent vegetation cover (Karr 1968), neglect details of foliage distribution in space (horizontal complexity) that may well be critical to the distribution of birds.

Although several efforts to relate horizontal habitat complexity to BSD have been attempted (Wiens 1974; Roth 1976; Martin 1976) with varying degrees of success, none of these has made use of the information from any available remote sensing technique. At the same time, traditional methods of habitat analysis using aerial imagery have been concerned mainly with 1) the proportion of different habitat (community) types present (e.g. Graber and Graber 1976) or 2) the quantification of "edge" (e.g. Schuerholz 1974; Patton 1975). The first method does not consider intra-community variation and information from the second technique rarely has been compared to the distributional pattern of a particular species or the species diversity of a taxon in the community. Wildlife biologists since Leopold (1933) have proclaimed the value of edge and the interspersion of coverts; yet, we have little experimental corroboration of what is actually being accomplished when we create an edge or habitat mosaic (Taylor 1977). Quantification of "edge" or any other habitat variable is of little use to wildlife biologists unless faunal correlations for such measures can be found which will confirm or deny their apparent value to wildlife.

Most previous attempts at quantifying horizontal heterogeneity have either dealt with 1) a single variable or structural component in two dimensions, such as nearest neighbor analysis (e.g. Roth 1976) or 2) multiple structural components in a single dimension, such as the analysis of transition probabilities along a transect (e.g. Martin 1976). These approaches present several problems in quantifying horizontal habitat heterogeneity. Firstly, they limit either the number of variables or the dimensions in which variables are considered; this is true for the majority of currently available techniques (reviewed by Pielou 1977). Secondly, the statistics derived from both approaches are based on samples and therefore a large portion of the available structural information often is not utilized in analyzing the horizontal variability of a site. This problem can be overcome by the use of aerial photographs which offer the potential to utilize more of the structural information available on a given site than can be obtained by ground surveys alone since they make possible analysis of virtually all portions of any site which are visible in a photograph. Lastly, the data obtained from the aforementioned techniques are often reduced to a single statistic (e.g. mean, standard deviation, or coefficient of variation). We believe that no single statistic can adequately describe the horizontal structural variation of a community and suggest that an effort be made not to preclude the correlation of <u>any</u> possible combination of the structural variables being measured with some measure of faunal diversity and/or distribution. By starting with an expanded data set reduction can be accomplished at any later stage of the analysis, should this prove desirable or necessary. Expanding an initially reduced data set is rarely possible.

Thus, in considering the problem of quantifying the horizontal heterogeneity of habitat, we perceive the need for a method that will allow the enumeration of the spatial arrangement (pattern) and interrelationships of multiple structural components within a given area. In this paper we propose a method of horizontal habitat quantification, using aerial photography, that in open canopy communities may elucidate which patterns of horizontal configuration correlate with increasing avifaunal diversity and the presence of particular species.

METHODS

Data Collection

Birds were chosen as the dependent variable for this study because they are 1) numerous, conspicuous and therefore easy to census (Recher 1971), and 2) because more is known of their relationship to habitat structure than for any other group (Whittaker 1977). Avian populations were surveyed on 18 clear-cut and old field "habitat islands" during May, June, and July 1977 and 1978 using a modified form of the spot-map method (Kendeigh 1944; Robbins 1970). These same areas, which ranged in size from 1.5 ha to 32 ha, were photographed in stereo with 70 mm black and white film from an elevation of approximately 1100 m on 22 May 1977 (late spring).[4] Stereo enlargements were printed at a scale of 1:5000; because of the need for small scale imagery in analyzing intra-community heterogeneity, one photo of each plot was enlarged to 1:2000 for use as a base map. Ground truth measurements were used to correct for scale errors while reproducing the 1:2000 enlargements.

A classification system is being developed to categorize various structural components

[4]The size of the plots used in the study will be considered as a separate variable in the final multivariate analysis.

within the old field and cut-over areas. Initially these components will be as finely subdivided (i.e. deciduous trees, coniferous trees, fruit trees; pole timber, saplings, etc.) as the resolution of the photos allows. If, during later analysis, it appears that fine subdivisions do not explain larger portions of the variation in avian habitat utilization, categories will be combined which contain structurally similar vegetation types. Identification of habitat components will be accomplished by superimposing a grid composed of hexagonal cells over the 1:2000 imagery and classifying each cell as to component type (Fig. 2). Cells will be numbered on a cartesian coordinate system so that each cell can be located in two-dimensional space in relation to every other cell. The habitat component type of each cell and its corresponding location on the cartesian coordinate system constitute the data set. A cell size of .25 cm^2 (100 m^2 on the ground) was chosen as being the smallest workable cell size for this scale which still has some biological relevance for this particular analysis. One hundred m^2 approximates the canopy of a moderately sized tree; therefore, each cell classifies individual structural elements which can be perceived by birds. We recognize that a fixed grid size results in a statistic that will be a relative measure of horizontal heterogeneity. This, however, does not diminish the value of the technique if the grid size is biologically relevant to the organism or taxon being considered.

Variables to Consider

In order to devise a method that could extract information contained in the grid of positionally identified structural components it was first necessary to compile a list of the variables that might influence the diversity of breeding birds within a given community type. We do not suggest that this is a complete list of variables applicable to all correlations of faunal diversity with horizontal heterogeneity, only that these variables were the ones considered most relevant for this analysis. By categorizing the hierarchy of possible structural component interactions within study plots, the variables could be divided into two classes: 1) those variables that describe attributes of cell clusters of the same component type (Cluster variables) and 2) those variables dealing with the number and arrangement of clusters within the plot (Plot variables).

A) Cluster Variables and Definitions

1) Cluster Size = the number of contiguous cells of one component type (e.g. 1,2, 3,...n). The number of cells in a cluster also represents its area.

2) Cluster Linear Edge = the number of cell sides of a given cluster that are adjacent to cells of a different component type. The total edge length of a given cluster may also be called its perimeter.

3) Cluster Shape Index = perimeter/$\sqrt{\text{area}}$.

B) Plot Variables and Definitions

1) Number of clusters of each component type.

2) Distance Between Clusters of the same type = the distance between the two closest cells in any two clusters of the same type. This is measured by using the Pythagorean Theorem to calculate the distance between any two points on the grid of cartesian coordinates.

3) Angle Between any Two Clusters of the same type = either the angle between a baseline passing through one cluster center and the line from that center to center of any other cluster or a similarly computed angle between the two closest cells of any two clusters. Again, this calculation is possible because the location of all cells in two-dimensional space is known.

4) Size Difference between adjacent clusters (i.e. clusters of different component types) = either the difference in the number of cells composing adjacent clusters or the ratio of one cluster size to the size of those adjacent to it.

5) Size Difference between clusters of the same type, measured as above.

6) Continuous Edge Length of adjacent components = the length of unbroken edge (measured as number of cell sides) between two adjacent component types.

7) Number of Different Component types adjacent to a given cluster.

8) Plot Edge Index = the sum of all continuous edges/$\sqrt{\text{plot}}$ area.

Habitat Data Compilation

Once the habitat variables of interest were defined, we concluded that the most expedient method of compiling the vast amount of data that would be generated was by computer analysis of the study plots. A program is being completed that will allow storage of the location and component type of each grid cell for any study plot. The program then calls for a systematic scan of the plot which will identify the location and size of clusters of a given component type and the length and composition of their associated edges. A second program will analyze inter-cluster distances and angles. Following is a generalized outline of the scanning program logic illustrated in Fig. 1:

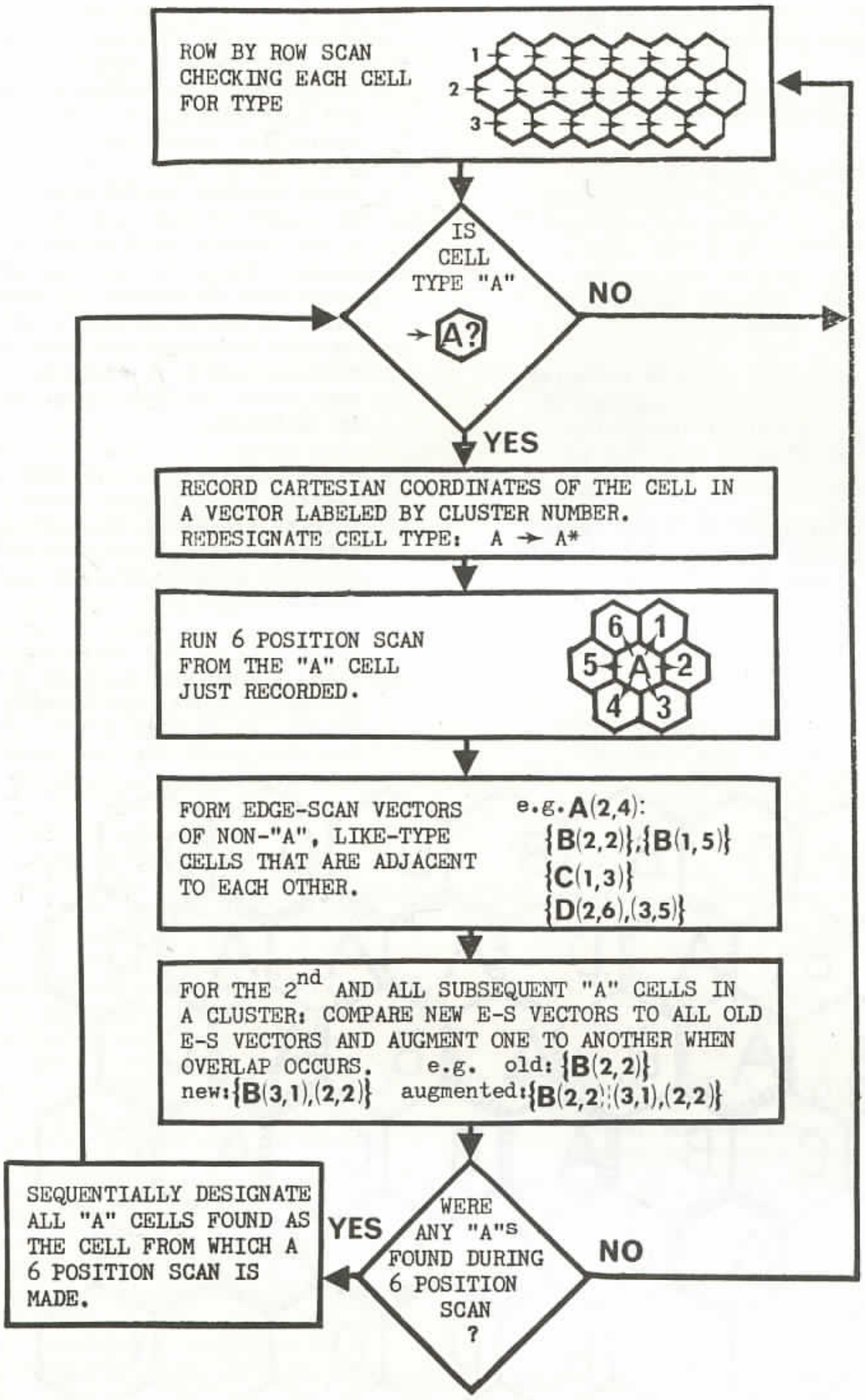

Fig. 1. Flow diagram of a Scanning Algorithm for Quantification of Horizontal Heterogeneity. All examples cited refer to the hypothetical habitat component arrangement illustrated in Fig. 2.

SCANNING ALGORITHM FOR QUANTIFICATION OF HORIZONTAL HETEROGENEITY

All examples refer to the hypothetical habitat component arrangement in Fig. 2.

1) The overall pattern of scanning is to move along the rows and down the columns, scanning from left to right for cells of a particular component type (T), until the farthest right cell of the bottom row is encountered. Data is then output and the program is ended.

2) When a cell of type T (A in this example) is encountered its cartesian coordinates are recorded and the cell's designation is then changed so that it will not be recorded again.

3) Scan the 6 cells adjacent to T and record the label[5] and position of any non-T cells (e.g. B[1,5]). Place the label and type of all the non-T cells which are both adjacent to each other and of the same type in the same vector called Edge Scan (ES) (e.g. D[2,6], [3,5]).

[5]The label is a cataloguing device which locates the cell's position in the rows and columns of a computer storage space.

4) Where there is more than one cell in a given cluster of type T (e.g. A[2,4], A[3,3]), compare each new non-T ES vector which is formed during the second and each subsequent 6 position scan, within the same cluster, with all existing ES vectors of the same type. Where overlap exists augment the new ES vector to the existing one (see Fig. 1 for example of augmentation procedure). Where there is no overlap an additional ES vector is created and added to those already extant. In this way the length of all continuous edges between type T clusters and any adjacent non-T clusters (e.g. AB, AC, AD) is recorded.

5) a) If any of the cells adjacent to the first T (e.g. A[2,4]) were also of type T (e.g. A[3,3] is adjacent to A[2,4]), return to step 2 and scan all subsequent type T's in the order in which they are encountered.

b) If none of the cells adjacent to the first T were also of type T (e.g. A[5, 3] has no other type A cells adjacent to it), go to step 1 and continue the row scan until the next type T cell is encountered.

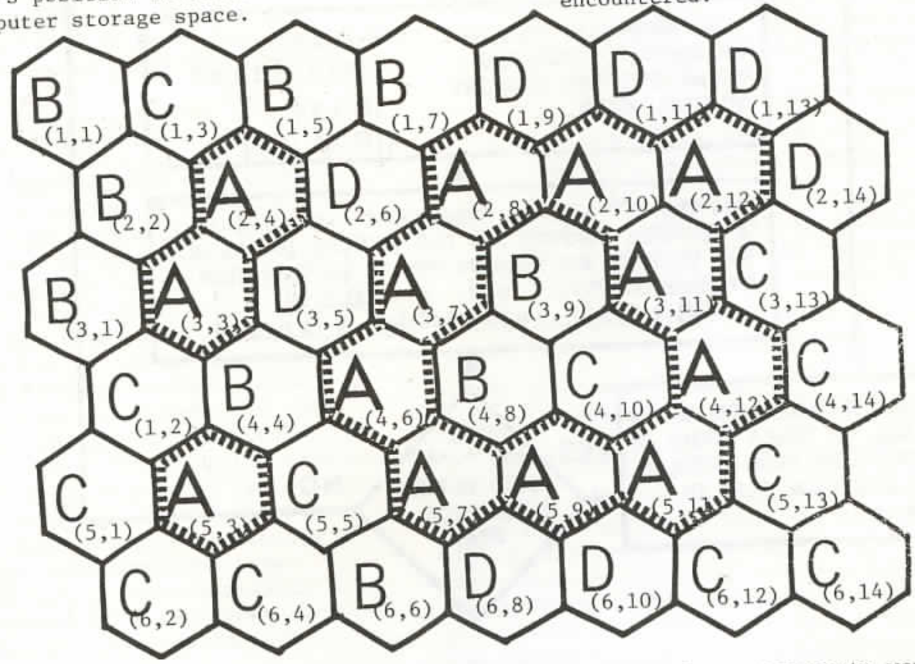

Fig. 2. Hypothetical Habitat Component Arrangement. If the four components were imagined as being structural elements in an old field, A might represent low shrubs, B deciduous saplings, C open growth white pines, and D herbaceous vegetation.

Thus, for the above example using Fig. 2, there would be 3 type A clusters of size A_1 = 2, A_2 = 10, A_3 = 1 with, for example, A_1 having 3 continuous edges with AB of lengths 1 unit (i.e. B[1,5]), 1 unit (i.e. B[4,4], and 3 units (i.e. B[2,2], [2,2], [3,1]).

Output

Data gathered from the horizontal habitat scan will be output in the form of frequency histograms. Appropriate frequency classes for the variables being considered have not yet been chosen. The histograms and/or their associated parameters may then be combined in a multivariate analysis of their relationship to species diversity (BSD for this study) or some species distributional patterns. This method of quantification will enable researchers to test a wide range of hypotheses concerning the relationships of faunal distribution and diversity to habitat complexity. Should such studies reveal actual patterns of diversity and distribution associated with variables quantifiable with this technique, it would be of great value to wildlife managers in the manipulation of habitat for both the maintainance of species diversity and the maintainance of dwindling populations of desirable species.

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Use of Landsat Imagery for Estimating Food Available to Refuging Lesser Snow Geese [1]

Erwin E. Klaas[2], William H. Anderson[3] and Robert B. Frederick[4]

Abstract.--Landsat imagery, acquired for four dates during September to November 1976, was used to estimate and monitor the amount of food available to lesser snow geese (Anser caerulescens) using the DeSoto National Wildlife Refuge, Iowa and Nebraska.

Geese concentrating on DeSoto refuge fly 50 miles or more to feed in harvested fields along the Missouri River. Previous studies established the relationship between available food (mainly corn-harvest waste) and the total area of harvested, unharvested, and plowed fields within the feeding range of the geese. Sequential Landsat false-color composite images were analyzed using a sampling procedure to estimate total acreage for each of three field-cover categories as a function of distance from the refuge. Data on the amount of harvest waste estimated on the ground were combined with field-cover data (derived from Landsat) to estimate the total amount of available food.

INTRODUCTION

The term "refuging" refers to the rhythmical movement of groups of animals from, and their return to, a fixed central place or core (Hamilton and Watt 1970). In refuging systems, many individuals disperse radially from the core to some well-defined limit. The area between the core and this dispersal limit, the "arena", is where resource (usually food) acquisition takes place. We have found this interpretation of refuging to be a useful concept in the analysis of the socioeconomic systems of migrating waterfowl. A fuller understanding of these systems and energy use strategies of refuging populations should greatly improve capabilities for managing the resources needed to maintain optimal population levels, affect the distribution of birds in a refuging system, and control such undesirable effects as crop depredations, disease, and disruption of traditional migration patterns.

We recently began intensive field studies of fall migrating lesser snow geese (Anser caerulescens) with the ultimate purpose of determining and quantifying the different components of energy input and expenditure by members of a refuging population. Knowledge of abundance and density of food per unit area through time is one of the most crucial and basic variables needed in such an analysis. The purpose of this paper is to describe a technique in which we used remote sensing to estimate the amount of food available within the arena of a refuging population of snow geese during fall migration in 1976.

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

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STUDY AREA

The core of the refuging goose population is an oxbow lake on the Missouri River about 20 miles north of Omaha, Nebraska (fig. 1). The lake and surrounding area are managed by the U.S. Fish and Wildlife Service as the DeSoto National Wildlife Refuge. Geese usually begin arriving each year in late September. Peak population numbers of 100,000 or more geese are usually reached in early to mid-November. By mid-December most of the geese have migrated from the area because ice forms on the lake and snow covers their food. A few hundred geese occasionally remain throughout the winter.

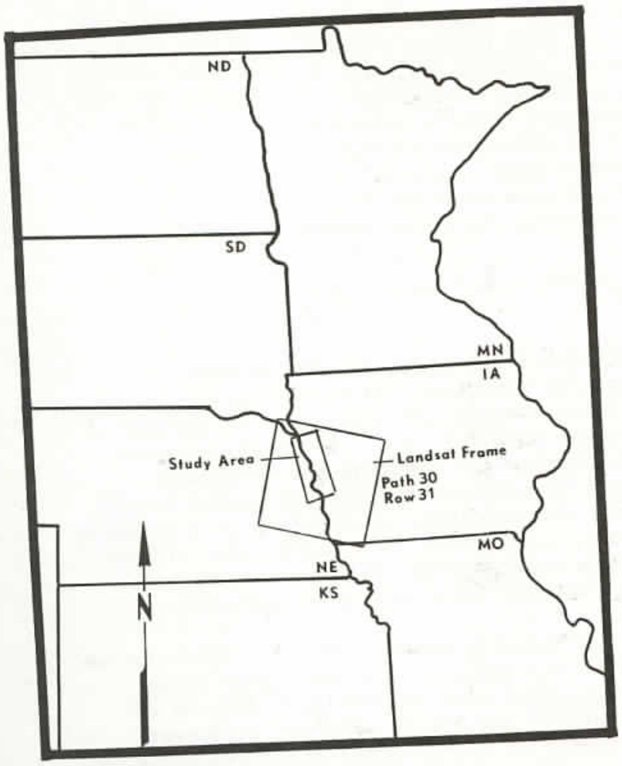

Figure 1. Study area location.

Geese are attracted to the lake for three reasons: (1) it is the largest quiet body of water within several hundred square miles which they can use for drinking, bathing, loafing and protection from predators, (2) food is abundant in the area surrounding the lake, and (3) they find protection from hunters. Agricultural crops, principally corn, constitute their food. An estimated 45.5 percent of all land in the feeding area (arena) is planted in corn (Harmon and Duncan 1978), including about 1,400 acres on the Refuge.

FORAGING BEHAVIOR OF GEESE

Field observations indicated that the dispersal limits of most foraging geese coincided well with the flat alluvial flood plain of the Missouri River between Omaha, Nebraska, and Sioux City, Iowa. The flood plain is wider north of the Refuge and geese usually fly in that direction to feed. We observed color-marked individuals from the Refuge feeding in fields 35 miles to the north, and geese, presumably from the Refuge, were seen feeding 50 to 60 miles to the north. Geese moving southward to feed were never observed going beyond the Omaha metropolitan area (15 miles); however, it was difficult to follow their movements in that direction. Small flocks of geese were occasionally observed flying over hilly land that borders the flood plain on the east and west or following along valleys of small tributary rivers that lead into the Missouri River. However, we believe the number of geese that feed outside the main flood plain is small.

Geese in the study area have been observed to feed almost exclusively on corn left in fields by mechanical pickers. Although they are known to occasionally graze on winter wheat, wheat constitutes an insignificant proportion (less than 3 percent) of the crop area in the valley. Geese have not been observed feeding on soybeans or standing corn in the valley.

Harvest-loss corn sampled in seven fields soon after harvesting in 1976, was estimated to average 206 lbs. per acre (weight corrected to 15.5 percent moisture content). After plowing, the amount of exposed grain on the ground was reduced by 92 percent to a mean of 16.5 lbs. per acre. Although geese appeared to prefer to feed in untilled fields, we occasionally saw large flocks feeding in tilled (plowed or disced) cornfields. Since harvesting and tilling both occur during the fall, the amount of available food changes during the refuging period.

REMOTE SENSING

Cloud-free, false-color composite Landsat images of the study area were obtained for four dates in 1976: September 7 (Landsat identification No. 8259416184502); October 13 (No. 8263016173502); October 31 (No. 8264816165502); and November 18 (No. 8266616161502).

Enlarged color prints of the study area were obtained from the EROS Data Center, Sioux Falls, South Dakota (fig. 2). We determined

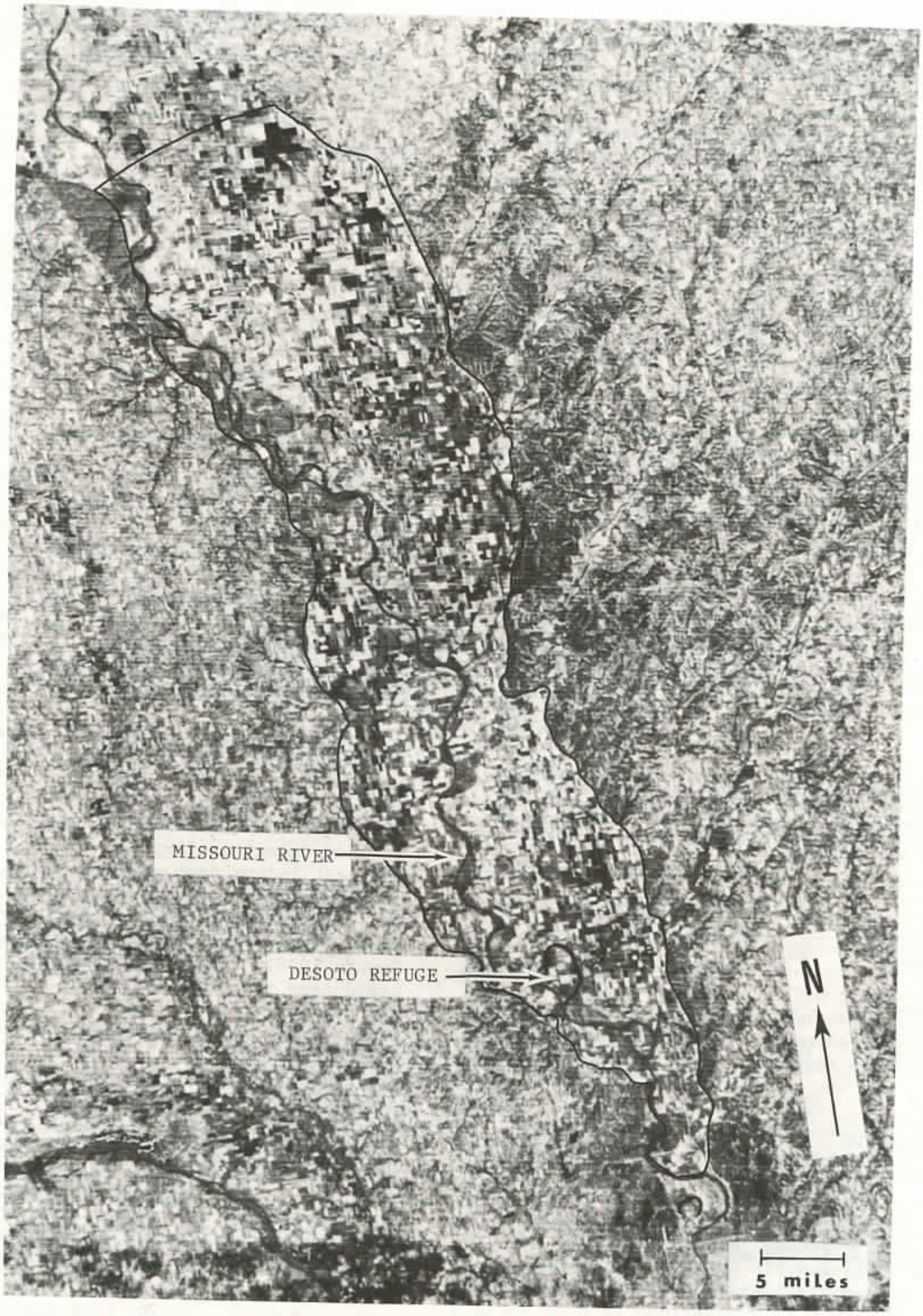

Figure 2.--Black and white reproduction of Landsat false-color composite image for October 13, 1976. Study area is outlined in black. Tilled fields are black and harvested untilled fields are white in this photo.

the nominal scale of these images to be 1:248,863 by comparing distances between features on the photos with those on a 1:250,000-scale U.S. Geological Survey topographic map.

Land-cover categories were identified with the aid of a vegetative cover map of DeSoto Refuge, which included several thousand acres of agricultural land. For example, tilled cropland appeared dark green or black and had a smooth texture, on all dates. Harvested cropland was light yellow or tan, and often had a mottled appearance. Forests and grassland were deep red, had a rough texture, and were irregularly shaped. Water appeared black and had a smooth texture. (Additional annotations are shown on figure 2.)

A transparent overlay was prepared that delineated the flood plain boundary. The area within the flood plain was then partitioned into a series of concentric zones, each 5 miles wide (ground distance) radiating outward from the Refuge.

A dot grid was used to estimate area of each category of cropland within each 5-mile zone, by placing the grid sequentially and tallying each dot according to cover category (table 1). The procedure was repeated for each date of imagery.

Table 1.--Percentages of land in different use categories in the Missouri River flood plain between Omaha, Nebraska, and Sioux City, Iowa, on four dates in 1976, as determined by interpretation of Landsat imagery. Estimnted percentages of cropland in corn (shown in parentheses) is taken from 1974 land use data given by Harmon and Duncan (1978)

Land use category	Date			
	Sep. 7	Oct. 13	Oct. 31	Nov. 18
Tilled cropland	6.5 (4.3)	23.1 (15.3)	64.2 (42.6)	72.6 (48.1)
Harvested cropland	0.6 (0.4)	21.7 (14.4)	16.7 (11.1)	9.4 (6.2)
Unharvested cropland	81.9 (41.9)	42.2 (21.6)	4.9 (2.5)	3.7 (1.9)
All cropland	88.9 (45.5)	87.0 (44.5)	85.7 (43.8)	85.6 (43.8)
Forests and grassland	4.6	7.0	8.9	7.3
Water	2.4	2.0	1.7	2.3
Other[1/]	4.3	4.3	4.1	5.2

[1]Includes 3.0 percent for roads (data from Iowa Department of Transportation.

Acreage estimates given in table 2 for each zone were calculated from the mean dot-count for each category on each of the four dates.

Table 2.--Estimated acreages in 11 five-mile-wide zones within the study area that are each successively greater distances from DeSoto National Wildlife Refuge.. Acreages determined from the mean of four dot counts made for each zone on overlay. Dot density = 25 per sq. in., or 395 acres per dot at image scale

Distance from Refuge (miles)	Acres
0-5	45,714
5-10	74,545
10-15	55,983
15-20	41,074
20-25	40,876
25-30	43,345
30-35	46,208
35-40	44,826
40-45	50,256
45-50	50,355
50-55	41,567
Total	534,748

Adjustments and Computations

Primary and secondary roads were not visible on the images because of the relatively coarse resolution of the Landsat system. The Policy Analysis Section, Iowa Department of Transportation, estimates that roads cover approximately 3 percent of the state's land area. Consequently, we adjusted each percentage estimate for cropland to account for roads by multiplying by 0.97 and adding 3 percent to the "other" category.

Although wheat and alfalfa were distinguishable from other crops, corn and soybeans could not be reliably separated. Therefore, overall percentages for the various cropland categories were adjusted proportionately by an independent estimate of cornland acreage. The best independent estimate of the ratio of corn acreage to other crops in the study area was found in 1974 land use data for Iowa Soil Association Areas 21 and 22 (Harmon and Duncan 1978). These Soil Association Areas are unique to the Missouri River flood plain and constitute more than two-thirds of all soils in the flood plain. It is unlikely that the proportion of cornland changed greatly between 1974 and 1976 in our study area (Gerald A. Miller, Agronomy Department, Iowa State University, personal communication). Assuming that corn and soybeans were the only crops harvested and tilled during the fall, corn made up 65.4 percent of the acreage of these two crops. Corn then made up 51.2 percent of all cropland and 45.5 percent of all land in the study area, according to 1974 estimates.

After adjusting cropland percentages to obtain separate estimates for cornland for each zone. we calculated acreages for tilled

Table 3. Estimated numbers of acres of tilled (T) and harvested untilled (H) cornland on four dates in 1976, by increasing distances from DeSoto National Wildlife Refuge

Distance from Refuge (miles)	Date			
	Sep. 7	Oct. 13	Oct. 31	Nov. 18
0-5				
T	3,385	7,294	16,094	19,530
H	522	5,784	5,531	3,551
5-10				
T	3,996	8,631	31,559	32,581
H	0	12,186	8,468	7,441
10-15				
T	3,322	6,802	22,811	25,772
H	256	12,348	5,704	4,003
15-20				
T	2,543	7,066	13,463	18,222
H	0	5,234	8,568	4,362
20-25				
T	2,062	9,108	20,546	22,988
H	773	5,564	2,757	1,534
25-30				
T	1,280	7,473	19,195	23,544
H	257	5,230	4,862	2,304
30-35				
T	1,008	6,784	19,994	20,844
H	0	5,576	4,250	2,287
35-40				
T	1,757	6,217	18,383	20,720
H	0	6,964	5,617	2,622
40-45				
T	1,527	5,767	20,794	25,212
H	256	4,764	6,673	2,801
45-50				
T	1,014	9,574	25,722	27,048
H	0	8,040	3,856	1,530
50-55				
T	1,049	7,250	19,182	20,947
H	0	5,252	2,777	757
All Zones				
T	22,921	81,945	227,594	257,432
H	2,030	76,886	59,196	33,177
On Refuge				
T	0	0	0	0
H	0	784	848	1,443

and harvested fields (table 3). The amount of corn potentially available to geese and other wildlife within each zone was then calculated by using sampling estimates for corn on the ground (table 4).

DISCUSSION

The use of field-cover data derived from Landsat imagery and combined with ancillary land-use information was a viable alternative to conventional aerial photography or ground surveys for estimating the amount of food available to refuging lesser snow geese in the Missouri River valley. Because of the large size of the study area and the need for repetitive coverage to document seasonal changes in food, conventional aerial photography would have been costly. Ground surveys would have required much personnel time and vehicle mileage, and instantaneous full coverage of the study area would have been impossible.

Table 4. Amount of corn (thousands of pounds) potentially available to waterfowl in tilled (T) and untilled harvested (H) fields on four dates in 1976 by increasing distances from DeSoto National Wildlife Refuge. Estimated amount of corn = 16.5 lb./acre in tilled fields; and 206 lb./acre in harvested fields

Distance from Refuge (miles)	Date			
	Sep. 7	Oct. 13	Oct. 31	Nov. 18
0-5				
T	56	120	266	322
H	108	1,192	1,139	732
5-10				
T	66	142	521	538
H	0	2,510	1,744	1,533
10-15				
T	55	112	376	425
H	53	2,544	1,175	825
15-20				
T	42	116	222	301
H	0	1,078	1,765	898
20-25				
T	34	150	339	379
H	159	1,146	588	316
25-30				
T	21	123	317	388
H	53	1,077	1,001	475
30-35				
T	17	112	330	344
H	0	1,147	876	471
35-40				
T	29	102	303	342
H	0	1,434	1,157	540
40-45				
T	25	95	343	416
H	53	981	1,375	577
45-50				
T	17	158	424	446
H	0	1,656	794	315
50-55				
T	17	120	316	346
H	0	1,082	572	156
All Zones				
T	378	1,352	3,755	4,248
H	418	15,838	12,194	6,834
On Refuge				
T	0	0	0	0
H	0	162	175	297

Although the resolution of Landsat imagery is less than that of conventional aerial photography (about 260 feet or 1.1 acre per pixel) our estimates of 85.6 to 88.9 percent cropland compared favorably with 1974 (Harmon and Duncan 1978) estimates of 88.9 and 93.5 percent cropland in Soil Association Areas 21 and 22, respectively.

We believe the technique described here could be used in estimating available food resources for other waterfowl, blackbirds, cranes and other refuging species whose foraging areas are large and where their food type can be identified on Landsat photos. Landsat satellites II and III are now functioning and one of the satellites passes over a given area of the Earth's land masses at 9-day intervals. Imagery is available within the limitations imposed by cloud cover, from the EROS Data Center, Sioux Falls, South Dakota.

In our study, imagery cost about $100 and all manual interpretation tasks required about 8 hours for each of four images. Costs and time would vary with the number of images needed to cover a particular study area.

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Use of Landsat Data for the Wetland Inventory of Alaska

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Abstract.--The National Wetland Inventory is a congressionally mandated programmatic activity of the U.S. Fish and Wildlife Service. The inventory is scheduled for completion by December 31, 1981 but there is no recent statewide air photo coverage for Alaska. If such a data base did exist, the photo-interpretative effort would exceed the fiscal limitations appropriated for the activity. Therefore, viable alternatives were sought and the use of machine processed Landsat data was investigated. A data stratification technique was developed to meet the requirements of the wetland inventory classification system and a decision to utilize Landsat data for the wetland inventory of Alaska was reached in January of 1978.

INTRODUCTION

The first Landsat satellite was launched on July 23, 1972 and would eventually generate a synoptic data base of remote sensing data for the entire state of Alaska. A number of multidisciplinary investigations ensued in order to address the feasibility of applying the Landsat multispectral data to diverse fields of endeavor.

The senior author participated in an investigation of the feasibility of applying Landsat data to wildlife management tasks in Alaska. Conclusions reached from this investigation were that the most promising area of application was vegetation cover type mapping using digital image processing technology (Lent and LaPerriere 1974). Several projects followed this initial investigation and these addressed land-use planning (LaPerriere 1975), moose habitat mapping (LaPerriere 1976), and caribou/reindeer range potentials (Nodler, LaPerriere, and Klein 1978).

The Clean Water Act as amended in 1977 authorized the U.S. Fish and Wildlife Service to conduct a wetland inventory of the United States with completion by December 31, 1981. In the contiguous 48 states, this activity has been implemented through airphoto interpretative techniques. In Alaska, however, this approach is untenable. Alaska's 586,000 square mile landmass represents about one fifth of the landmass of the contiguous 48 states. Unlike the 48 states, however, recent aerial photography does not exist over most of Alaska. Even if aerial photography were immediately available, the photo interpretative effort would require an estimated 40 man years. Finally, most of Alaska is roadless and access for ground truth is extremely expensive.

Therefore, viable alternatives were sought and the use of machine processed Landsat data is being considered. The use of Landsat, however, does present a number of problems. First, the classification system in use for the wetland inventory (Cowardin et al 1977) has five major systems, namely, Marine, Estuarine, Riverine, Lacustrine and Palustrine. While cover types such as emergent wetland or aquatic bed can be determined by spectral signatures, the spectral signature alone is usually insufficient to determine the major system (Morrow and Carter 1978). Second, the inventory activity addresses maps using U.S. Geological Survey (USGS) maps as a map base. Landsat scene centers are primarily a function of orbital characteristics. Finally, the maps normally generated from Landsat analyses are color photographic products which are prohibitively expensive for mass distribution.

METHODS

Data Stratification - A method of data stratification is proposed to deal with the problem of identifying classification results with a particular major system. That is, major system boundaries are manually analyzed and drawn on USGS maps. These boundaries are then digitized and superimposed upon the Landsat data matrix. Subsets of data identified by the boundaries are thus isolated and can be clustered and classified separately.

For spatially contiguous systems such as Marine and Estuarine, this approach is straightforward and relatively simple. The remaining three systems, however, are not spatially contiguous. For example, the Palustrine and Lacustrine systems consist of spatially discontinuous areas interspersed with each other and uplands. Digitization of these system boundaries is impractical.

The Riverine system as defined by Cowardin et al 1977 is also spatially discontiguous. The definition given is "The Riverine System includes all wetlands and deep-water habitats contained within a channel, except: 1) wetlands dominated by trees, shrubs, persistent emergents, non-aquatic mosses or lichens, and 2) habitats with waters containing ocean-derived salts in excess of 0.5%. A channel is, "an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water (Landgein and Iseri 1960:5)" (Cowardin et al 1977:16).

One implication of this definition is that vegetated river islands may be palustrine or upland but are not part of the riverine system. Another implication is that, if the river channel widens into a lake or disperses into swamps or marshes, with inlets and outlets, the riverine system is spatially discontiguous.

It was decided to manually analyze a boundary approximation for the Riverine System by delineating river and stream boundaries as shown on USGS MAPS. By isolating this subset of data, Riverine components can be separated by definition of classes within the subset.

Therefore, in the approach used, the data matrix is stratified to four data subsets, namely Marine, Estuarine, Riverine Approximation, and Other. The "Other" subset contains palustrine, lacustrine, and upland elements which can then be separated by class definition within that subset.

DATA ORGANIZATION

The needs and objectives of the National Wetland Inventory require data organization by USGS base map quads such that acreage tabulations can be generated for each production unit. Carrying this concept a bit further, the township is a more basic land-use management unit widely used in Alaska today. Therefore, it is highly desirable to create a subfile index such that acreage tabulations or other output for a given township could be readily generated.

Consequently, the Landsat data is reformatted to correspond to the USGS base map quads and subfile indices for township are generated. This approach permits acreage tabulations by map quad or township as readily obtained output products.

MACHINE PROCESSING

The first step in processing is geometric correction and mosaicking of the digital data. The mosaic is carried out using control points from USGS 1:63,350 maps and the end result is a new file corresponding to one USGS 1:250,000 quad map. Superimposed on this new file are scene boundaries and strata boundaries.

A random sample containing at least 3% of the data from each subset (strata) is obtained. These data are used to generate clusters for classification of the remaining data in each strata. The clustering algorithm is based on Euclidean distance between cluster centers. When all possible clusters have been formed, clusters are combined using a 3 standard deviation criteria. That is, cluster centers are constrained to a separation of 3 standard deviations in 4 dimensional statistical space.

Cluster centers are then plotted 2 dimensionally in bands 5 and 7 (Fig. 1). The figure is a theoretical model which illustrates the correspondence between relative position on the graph and feature type. An initial interpretation of this graphic output is made and selected cluster classes are combined. Generally speaking, combination is made of classes which are obviously cloud, snow, or bare ground but classes which are vegetated or partially vegetated are retained.

The data in each strata are then classified using the appropriate statsitics data set. The classification algorithm combines parallelipiped and maximum likelihood classification techniques. That is, it first constructs 4 dimensional polygons based on cluster statistics. Each pixel is examined for inclusion into an appropriate polygon. If a pixel falls within more than one polygon, a Bayesian maximum likelihood routine resolves the classification.

Classification results are stored on a new digital tape from which ground truth field products are generated. These field products are line printer maps approximately 1:30,000 scale where each cluster class or grouping is assigned a unique printer symbol.

The laboratory analysis of these products consists of map orientation and site selection for empirical class definition. Sites representing each cluster class are selected and plotted on 1:63,360 USGS maps. After all sites are selected and plotted, the boundaries of the 1:63,360 quads are plotted on aeronautical charts for flight planning purposes. High wing single engine aircraft are used for low level aerial reconnaissance of sites. Depending upon point of flight origin, final destination, and site density, data can generally be obtained over 30 to 50 sites on one 4 hour flight. These data consist of site photography with Polaroid color film and 35 mm color infrared film, and verbal description of the site.

Aerial reconnaissance data are used to select further sites for on the ground visits for classes which require more detailed data for definition.

After empirical definition of cluster classes, a thematic intepretation is applied. Each cluster class is evaluated in terms of the specific application involved. In this case, each class is evaluated in terms of the wetland inventory classification system (Cowardin et al 1977). Within the context of this interpretation, classes judged to have the same relative value, e.g. uplands, are combined. An important point here, however, is that this class synthesis is purely for presentation purposes and preparation of a map product. The class information is retained on the digital tape and remains available for other interpretations such as vegetation type mapping using a different classification system, timber volume analysis, or wildlife habitat analysis.

After the thematic analysis, the computer compatible digital tape is used to produce a lithographic plate where user specified classes or grouping of classes are portrayed as particular colors. The technology in this process involves use of a digital laser printer which produces the plates directly from the tape.

RESULTS

Computer Compatible Tapes

The principal output product of the analysis is the computer compatible tape which may be used in connection with a geobased information management system. Depending upon existing software and hardware peripherals, a variety of output products are possible. The most basic of these are simply acreage tabulations for individual classes or specified groupings of classes. These may be readily obtained for USGS map quads, townships, or readily described subunits thereof down to quarter section. Because of the inherent geometric accuracy limitations of Landsat, it is not advisable to attempt acreage tabulations for areas much smaller than a quarter section.

Another output product which is easily obtained is a line printer map where classes or groupings of classes are assigned a particular symbol. With most line printers, however, a certain amount of aspect ratio distortion is introduced because of the characteristics of the line printer.

Still another potential product is a feature map produced by a graphics plotter such as Calcomp plotter, Gerber plotter or similar device. Software to convert the high resolution cellular data to a polygonal format, however, is required.

Finally, if a CRT is interfaced to the system, the data may be brought up on the display screen and manipulated. Different class combinations may be displayed and, with appropriate software, irregularly shaped geographic areas may be designated and these data subsets may be isolated. After such isolation, a variety of products such as acreage tabulations, line printer maps, or plotter maps may be generated for the subset. Similar cautions as to area size apply, however, and, from a practical standpoint, it does not appear advisable to select areas much smaller than about 100 acres.

MAP PRODUCTS

Color maps may be produced from the computer compatible tapes. This process involves several steps. An existing USGS base map is selected for use. Control points on that base map are selected and used to generate a geometric correction fitting the classified tape matrix to the base map. From the corrected computer compatible tape, three color separations are effected producing three lithographic plates. The base map is digitized using a scanner device and the result is used to produce a fourth lithographic plate for the USGS map data.

The four lithographic plates are then utilized with a four color printing press. The plate containing the USGS map information may be printed in black ink. The other three plates produce the desired color presentation of the classification results.

CONCLUSIONS

Stratification

The stratification scheme developed as an accommodation to the classification system, improved overall classification results. In previous automated analyses carried out without data stratification, certain misclassification of features occurred and these were simply considered "inevitable" or "limitations of the platform". Examples of this include misclassifications of Alpine barrens or mountain shadow as shallow water and some extent of misclassification of recently burned areas as shallow water. Another example might include classification of partially vegetated areas as one feature class whether the areas so classified were pioneer communities on river islands, or partially vegetated tidal flats. In summary, certain feature discriminations could not be made adequately based on spectral signature alone. These discriminations, however, could be made relatively easily by a human interpreter utilizing available USGS map information in analysis of a photographic print of the Landsat scene. Consequently, we decided to expand the stratification concept somewhat to the following strata: Marine, Estuarine, Riverine, Lowland, Alpine, Urban, Suburban/Residential, and Recent Wildfire burn. This stratification will be carried out by a human interpreter visually analyzing a 1:250,000 positive false color transparency of the Landsat scene overlayed on a 1:250,000 USGS base map. The result of this stratification analysis will then be digitized and incorporated as a new subfile of the digital Landsat data matrix.

Another conclusion reached from results of the pilot study is that the most useful and flexible products are the classified computer compatible tapes. These products used in connection with a geobased information management system are the most valuable to land-use planners. Considering the cost of producing color map products, the question arises as to the justification for producing maps for mass distribution when higher resolution, larger scale, more detailed information may be obtained for specific areas from the classified data tapes compatible with the information management system. Consequently, the matter is still under consideration and a map series for public distribution may or may not be produced for Alaska. In any case, classification results will be available to land-use management/planning agencies in Alaska.

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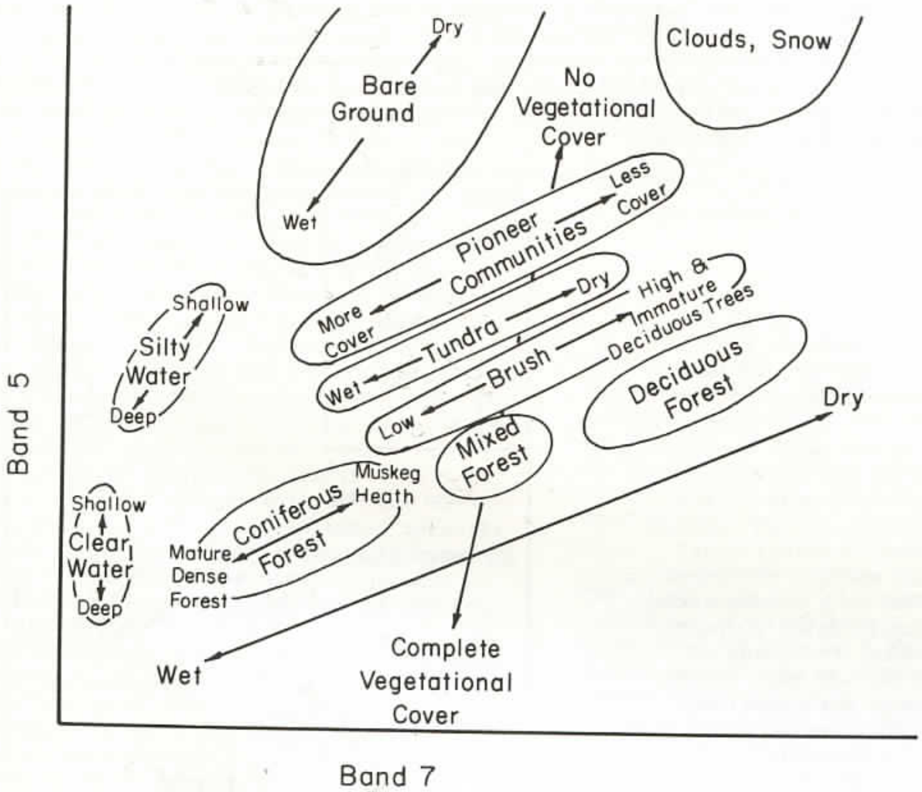
Fig. 1: Theoretical model illustrating relative graphic positions of feature classes.



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