Technology of Radiotracking for Various Birds and Mammals[1]

Paul L. Hegdal[2] and Thomas A. Gatz[3]

Abstract.--A tracking system utilizing a beacon transmitter, numbered tracking stations, and mobile tracking units was devised for determining location and mortality of large numbers of radio-equipped animals. Our field study on 104 birds and mammals representing 17 species showed the system to be readily adaptable and highly efficient.

Most radiotelemetry systems are designed for relatively small numbers of animals that are intensively monitored. Some investigators use fixed receiving stations whereas others use mobile receiving stations and aircraft to monitor the activities and location of instrumented animals. To assess the effects of a rodenticide treatment on other wildlife species, we needed a system that would accommodate a relatively large number of animals in the same general area and work well in the steep foothills of the Sierra Nevada Mountains in southern California. The purpose of this paper is to describe a relatively simple field radio-tracking system that uses a beacon transmitter, numbered tracking stations, and radio-equipped vehicles.

Radio transmitters used in this study were designed and built by the Bioelectronics Unit, Section of Supporting Sciences, Denver Wildlife Research Center. We attached transmitters to 104 birds and mammals of 17 species. Transmitter size and attachment method varied depending on the species (Table 1). All transmitters were on the 12 U.S. Fish and Wildlife Service assigned frequencies between 164.4 and 164.7 MHz.

Because we would be instrumenting several animals on each of 12 available channels (frequencies), we specified that transmitters be built at 6 pulse rates for each channel. We thereby obtained 72 unique combinations of channel and pulse rate. We arbitrarily selected 20 bpm (beats per minute) as the slowest feasible pulse rate to work with in the field. Each succeeding pulse rate was 1.4 times faster than the next lower rate. Pulse rates and their codes were as follows: A-20, B-28, C-40, D-55, E-75, and F-110. Animals were coded by the channel and pulse rate of the transmitter. For example, animal 9D was on channel 9 with a D or 55 bpm pulse rate. In several instances, we put the same channel and pulse rate combination on more than one animal; however, these animals were trapped in different parts of the study area, were different species, and usually were animals with relatively small home ranges such as California quail (Lophortyx californicus) and striped skunks (Mephitis mephitis).

As did Anderson and de Moor (1971), we placed a beacon transmitter on a high hilltop near the center of the study area (Fig. 1). This transmitter emitted a strong CW (continuous wave) signal, and was designed to be on for 2 min and then off for 2 min throughout the study period. Since this signal also was on one of the 12 channels, the off period allowed reception of animal transmitters on the same channel without interference from the beacon.

---

[1]Paper presented at the PECORA IV Symposium on Application of Remote Sensing Data to Wildlife Management, Sioux Falls, South Dakota, October 10-12, 1978. Funds supporting this work were provided by the Environmental Protection Agency under Interagency Agreement EPA-IAG-D7- 0449.

[2]Wildlife Biologist, U.S. Fish and Wildlife Service, Denver Wildlife Research Center, Denver, Colorado.

[3]Wildlife Biologist, U.S. Bureau of Reclamation, Bismark, North Dakota.

Table 1. Transmitter weight and attachment method used on various birds and mammals.

Species	Number instrumented	Attachment method	Transmitter weight (grams)
Golden eagle (*Aquila chrysaetos*)	1	Harness	18
Red-tailed hawk (*Buteo jamaicensis*)	6	"	18
Turkey vulture (*Cathartes aura*)	5	"	18
Great horned owl (*Bubo virginianus*)	4	"	18
Barn owl (*Tyto alba*)	2	"	18
Screech owl (*Otus asio*)	1	Glued-on[1]	7
Common raven (*Corvus corax*)	3	Harness	18
Common crow (*Corvus brachyrhynchos*)	1	"	18
California quail (*Lophortyx californicus*)	9	Glued-on[1]	7
Mourning dove (*Zenaida macroura*)	31	"	7
Bobcat (*Lynx rufus*)	10	Collar[2]	250
Coyote (*Canis latrans*)	6	"	250
Badger (*Taxidea taxus*)	9	"	250
Raccoon (*Procyon lotor*)	4	"	250
Gray fox (*Urocyon cinereoargenteus*)	2	Collar	35
Striped skunk (*Mephitis mephitis*)	9	"	35
Opossum (*Didelphis marsupialis*)	1	"	35

[1] A manuscript on this attachment method is in preparation.
[2] These were mortality transmitters and changed to a much faster pulse rate if the transmitter remained motionless for 3 hours.

Radio-tracking stations were established along roads throughout the study area and marked with numbered rock cairns (Figs. 1 and 2). These stations were usually on high points, away from interference (such as power-lines and fence lines) and preferably on a line-of-sight to the beacon transmitter. The tracking stations were plotted on a composite aerial photograph that was used as the base map for plotting all radio locations.

Radio-tracking vehicles were equipped with roof-mounted dual yagi antennas (Fig. 2) which could be rotated from inside the vehicle; radio bearings were indicated on a 20-cm (8-in) 360° compass rose by a pointer attached to the antenna mast. The pointer was aligned to the null of the antenna. The compass rose was aligned with 0° forward and was not adjustable. Coaxial cables from each of the yagi booms were attached to a null-peak switch box (built by AVM Instrument Company, Champaign, Illinois)[4] which allowed switching from in phase (for maximum signal strength) to out of phase (for precise bearings) operation. We used Model LA-12 receivers (built by AVM Instrument Company) for all radio-tracking. Those used in radio-tracking vehicles were powered from the vehicle's 12-volt system. Hand-held yagi and loop antennas were employed for portable field use. Yagi and whip antennas were used on aircraft during aerial tracking.

We used transceivers in each radio-tracking vehicle for voice communication, which enabled us to coordinate radio-tracking efforts and obtain simultaneous or nearly simultaneous bearings from two or more vehicles. Tracking vehicles usually operated in pairs.

Hutton et al. (1976) described a method of orienting vehicles at a tracking station; however, our beacon transmitter eliminated the need to orient the vehicle in any particular direction. At a tracking station we simply recorded the bearing to the beacon and the bearing to the animal's transmitter (along with date, time, and station number). These bearings were later converted to the angle at the tracking station between the animal's and beacon transmitters which, with two or more bearings, allowed accurate plotting of the animal's location.

We attempted to locate each animal daily and determine if mortality had occurred.

[4]Reference to trade names does not imply Government endorsement.

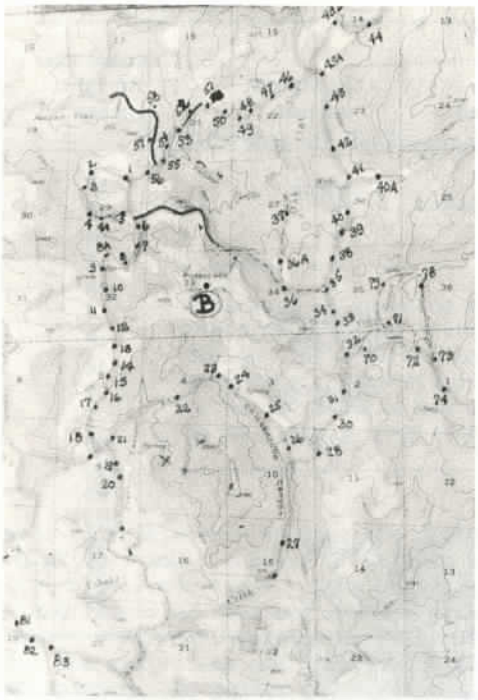


Figure 1.--Location of the tracking stations in relation to the beacon transmitter.

Figure 2.--A radio-tracking vehicle at one of the tracking stations. Note the numbered rock cairn. The beacon transmitter is on top of the pointed hill in the background.

The death of animals equipped with mortality transmitters could be determined by an increase in the transmitter's pulse rate. Mortality of other radio-equipped animals could be determined by lack of movement, varying signal strength of the transmitter, or by using hand-held tracking equipment to find and observe or flush the animal. As have other investigators, we experienced the usual problems of some "lost" or malfunctioning transmitters. However, we found this system to be quick and efficient for monitoring a large number of instrumented animals. No time had to be spent orienting vehicles at any tracking station. Additional tracking stations were established as needed when animals moved outside the area covered by existing stations. Any location could be used for tracking provided we could receive the beacon and plot the location on the map or aerial photo.

Although we did not use a central base station to record and plot bearings immediately after they were taken, this system would readily accommodate such an effort.

LITERATURE CITED

Anderson, Fred, and Phillip de Moor. 1971. A system for radio-tracking monkeys in dense brush and forest. J. Wildl. Manage. 35(4):636-643.

Hutton, T. A., R. E. Hatfield, and C. C. Watt. 1976. A method for orienting a mobile radiotracking unit. J. Wildl. Manage. 40(1):192-193.

The Use of Large Scale Color Infrared Photography for Stream Habitat Inventory [1]

Paul Cuplin[2]

Abstract.--A method of stream habitat inventory using photo interpretation of large scale color infrared photography is described. The supporting methods of ground truth, targeting for aerial photographic identification and photo scale, film format exposure for water penetration of clear water, lens filters, and description of acceptable weather and sunlight conditions for optimum film exposure are identified.

INTRODUCTION

Stream inventories must often be completed in a restricted time period with a limited staff to meet environmental statement deadlines or bureau planning priorities. To accelerate stream habitat inventory a method of large scale color infrared photography (CIR) with water penetration and interpretation of five components of stream habitat are used to categorize existing stream habitat. Existing aerial photography available in bureau field offices is not large enough scale to allow for interpretation of stream habitat conditions.

Ground truth sampling of a stream prior to aerial photography is required for verification of photo interpretation. Photographic scale and location are verified by targets placed at ground truth sites.

The aerial photography will provide a resource data base than can be used to determine existing conditions and to monitor stream habitat responses to land management.

FIELD INVENTORY PRIOR TO AERIAL PHOTOGRAPHY

Each stream that is selected for photographic coverage is sampled in the field and two identifying targets placed on the stream bank.

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

[2]Fisheries Biologist, Bureau of Land Management, Denver Service Center, Denver, Colorado.

The ground truth stream sampling unit is (one tenth mile) 528 feet. The stream habitat inventory profile (see Figure 1.) is used for ground truth and photo interpretation.

TARGETS

Two targets of white fools cap paper 2 feet by ten feet are placed in a pattern that can be identified in the aerial photograph.

The targets not only aid in identifying the stream but will serve to aid in scale determination. The ground truth site is located on a topographic map prior to photo interpretation.

ACQUISITION OF LARGE SCALE COLOR INFRARED STREAM PHOTOGRAPHY

It is recommended that a reliable aerial mapping firm provide the photographs that are required. The specifications for achieving the high quality photograph that will allow you to analyze stream habitat conditions are very specific and outlined in detail in the text. An example specification detail sheet is presented in Figure 2. Obtain current specifications for color infrared photography contracting from Bureau of Land Management, Denver Service Center, Office of Special Mapping prior to contracting for stream photography.

PHOTOGRAPHIC FORMAT

Photograph size or format must be large enough to identify location of the photograph by

Figure 1.

STREAM HABITAT INVENTORY PROFILE
(This form to be used for field inventory or photo interpretation)

Stream ________________ Date ________ Surveyor(s) ________ State ________ Dist. ________

Planning Unit ________________ Site No. ______ Length of Stream Surveyed ________________

Field Survey ________________ Aerial Photograph ________________ (Check one)

Stream Cover (% Shade)	80%+	4	50 - 80%	3	40 - 60%	2	40% or less	1
Stream Bank Condition (% Bare Soil)	5% or less	4	6 - 15%	3	16 - 25%	2	25% or more	1
Stream Bank Stability (% Bank Damage)	0 - 10%	4	20% or less	3	40% or less	2	41% or more	1
Stream Channel Stability (% Channel Movement)	5% or less	4	6 - 10%	3	11 - 15%	2	16% or more	1
Sedimentation of Streambed (% Silt)			10% or less	3	11 - 25%	2	26% or more	1
Column Totals		[ ]		[ ]		[ ]		[ ]

Stream Condition Rating for Length of Stream Evaluated - (Enter total score in appropriate space) Excellent 17 ____ Good 14-16 ____ Fair 10-13 ____ Poor 5- 9 ____

SUMMARY (Last page of inventory for each stream)

Field Inventory Total Number Stream Sites ____
Stream Condition Rating No. Miles: Excellent ____ Good ____ Fair ____ Poor ____

Photo Interpretation Total Number Stream Miles Inventoried ____
Stream Condition Rating No. Miles: Excellent ____ Good ____ Fair ____ Poor ____

Figure 1. (cont.)

A. HIGH STREAM COVER (JUNE - SEPTEMBER; 11:00 am - 5:00 pm, MDT)	RATING
80% +	4
60 - 80%	3
40 - 60%	2
LESS THAN 40%	1

B. STREAM BANK CONDITION

NO NEGLIGIBLE USE/DAMAGE; VEGETATION 1/ WELL-ROOTED; SOD INTACT; VERY LITTLE, IF ANY EROSION FROM VEGETATION AREAS, LESS THAN 5% BARE SOIL SHOWING.	4
SOME USE/DAMAGE; VEGETATION GENERALLY WELL-ROOTED; SOD MOSTLY INTACT; SOIL SHOWING IN PLACES (6% to 15% BARE SOIL SHOWING OVERALL); SOME SURFACE EROSION EVIDENT.	3
USE OR DAMAGE CLOSE TO SOD; VEGETATION SHALLOW-ROOTED; MODERATED SURFACE EROSION (16% TO 25% BARE SOIL SHOWING OVERALL).	2
HEAVY TO SEVERE USE/DAMAGE: VEGETATION GENERALLY CROPPED TO SOD; CONSIDERABLE SOIL SHOWING (OVER 25%) WITH SOD DAMAGE SERIOUS; ACTIVE SURFACE EROSION A SERIOUS PROBLEM.	1

1/ PRIMARILY GRASSES, SEDGES AND FORBS.

C. STREAM BANK STABILITY

BANK STABLE AND UNDAMAGED - PARTIAL OR NO EVIDENCE OF BANK DAMAGE; 90-100 PERCENT OF BANK AREA FREE FROM USE/DAMAGE. LITTLE OR NO UNNATURAL BANK EROSION OR SLOUGHING PRESENT.	4
BANK DAMAGE 20 PERCENT OR LESS - BANKS 80 TO 90 PERCENT FREE FROM USE/DAMAGE. SOME EROSION AND SLOUGHING BUT FULLY RECOVERABLE AFTER A SEASON OF REST.	3
BANK DAMAGE 40 PERCENT OR LESS - BANKS HAVING RECEIVED 20 TO 40 PERCENT DAMAGE FROM USE/DAMAGE. MODERATE TO HEAVY BANK EROSION AND SLOUGHING DURING SEASON(S) OF USE, AND WHICH CONTINUES DURING NO USE PERIOD(S). CONDITIONS WILL NOT ALLOW NATURAL STABILITY RECOVERY OF BANKS TO A LEVEL GREATER THAN 60 PERCENT STABILITY.	2
BANK DAMAGE EXCESSIVE - BANKS EXHIBITING GREATER THAN 40 PERCENT DAMAGE. SEVERE BANK DAMAGE AND ACCELERATED EROSION AND SLOUGHING IS PRESENT OVER VIRTUALLY THE ENTIRE BANK SURVEYED. NO EVIDENCE OF BANK RECOVERY VISIBLE, AND EROSION IS CONSISTENT.	1

D. STREAM CHANNEL STABILITY

NO NEGLIGIBLE LATERAL CHANNEL MOVEMENT AND BANK EROSION (CUTTING) (5%), SCOUR, OR CHANGING CHANNELS.	4
SOME LATERAL CHANNEL MOVEMENT AND BANK EROSION (5 TO 10%), MINOR CHANNEL SCOUR OR CHANGING CHANNELS WITHIN STREAM BED.	3
FREQUENT LATERAL CHANNEL MOVEMENT (10 TO 15%); MODERATE CHANNEL SCOUR OR CHANNEL CHANGE WITHIN STREAM BED.	2
MORE THAN 20% LATERAL CHANNEL MOVEMENT AND BANK CUTTING, CHANGING CHANNELS AND SEVERE SCOUR EVIDENT, AND SOURCE OF EXTREME SEDIMENTATION.	1

E. SEDIMENTATION OF STREAM BED - PERCENT OF FINE SEDIMENTS (PARTICLES SAND SIZE AND SMALLER) COVERING STREAM BOTTOM (WETTED PARAMETER) MATERIALS.

LESS THAN 10%	3
10 - 25%	2
MORE THAN 25%	1

comparison with U.S.G.S. 7 ½ min. topographic map (1:24,000). 5" x 5" is the smallest acceptable format for a resource data base and for rapid photo interpretation. This format is often only available from the defense department. Aerial mapping companies may only have 9" x 9" format available.

The smaller formats of 35 mm and 70 mm have utility if you are doing your own aerial photography however, location identification, handling of film and ease of photo interpretation is much more time consuming as compared to the 5" x 5" or larger photographs.

Figure 2.

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF LAND MANAGEMENT SPECIFICATION DETAIL SHEET	Solicitation Number

Project Name and/or Number

LOCATION				
State	District	Symbol	Square Miles	Linear Mile

DATES PHOTOGRAPHY MAY BE TAKEN		AERIAL CAMERA	
Starting	Completion	Focal Length	Lens Type

Time of day photographs may be exposed:

FLIGHT ALTITUDE		TYPE		
Above mean sea level		Film to be used	Photographic prints	Number of each prir
Above mean terrain				
Scale of photography				
Flight direction				

INDEX

☐ Photo Index	☐ Spot Index	Type of material	Number Required
Index Scale:			

PHOTOGRAPHY SPACING REQUIREMENTS

☐ B/H W/H decimal ratio	CHECK METHOD USED			☐ Percentage overlap
	Min.	Av.	Max.	
Base height ratio along lines of flight (endlap)				Endlap (overlap in line of flight)
Width height ratio between flight lines (sidelap)				Sidelap (overlap between adjacent flight lines)

FILM

Color infrared Kodak film 2443 is recommended. The definition of detail on the ground is enhanced in CIR as compared to black and white or color photography.

The film manufacturers instructions state that unprocessed Kodak aerochrome Infrared Film 2443 and finished transparencies should be stored in a cool, dry place. Unexposed film should be kept in a refrigerator (at 55°F or lower) in its original sealed package. If film must be stored for long periods, the sealed film should be stored at 0 to -10°F. Exposed film should be processed as soon as possible after exposure to avoid changes in the latent image.

EXPOSURE FOR WATER PENETRATION

Color infrared film correctly exposed, produces a dark magenta image from clear streams. Water penetration is achieved by overexposing color infrared film ½ f stop. The three layered color infrared film reacts to overexposure by allowing penetration of the green layer resulting in recording of streambottom characteristics below the stream water surface. A Wratten 12 filter is used with color infrared film.

Water penetration cannot be achieved during stream flooding with muddy or turbid water, nor can streams with year round turbidity or glacial flour be penetrated.

Ektachrome X film can be used to penetrate the water of large streams where only algae caused turbidity is present. This technique does not allow for good definition of riparian vegetation. A Wratten 3 filter with 2 f stop overexposure is used for water penetration with Ektachrome X film (Lockwood and Perry).

PHOTOGRAPHIC SCALE

A scale of 1:1000 is required for photo interpretation of the five habitat components identified in stream habitat inventory profile, i.e. stream cover, stream bank condition, stream bank stability, stream channel stability and sedimentation of streambed - the latter component can only be determined by a much greater magnification of the photo transparency than the other four components.

Smaller photographic scale will allow for the identification of some of the components of stream habitat.

PHOTOGRAPH ENDLAP

Photograph overlap of 58% is needed for stereo interpretation of the components of the stream and adjacent area.

TIME OF DAY

Aerial photographs should be taken from 11 am to 1 pm for maximum sun azimuth in the contiguous 48 states. This will minimize shadow of tall trees and steep terrain.

TIME OF YEAR

Photographs should be taken from June 1 to August 31 for maximum infrared or peak of green from vegetation in the lower 48 contiguous states. Exceptions would be the Southwestern United States where peak of green will occur in March or April, in Alaska peak of green will be later July through September.

CLOUD COVER

Photographs should not be taken if cloud cover is greater than 15 percent of any type of clouds.

PHOTO INTERPRETATION

Locate and interpret first the ground truth site in the aerial photographs. Once this has been completed compare photo interpretation with the ground truth rating, using stream habitat inventory profile Figure 1. Use the verification form Figure 3 to compare ground truth and photo interpretation. If ground truth and photo interpretation agree continue on with the photo interpretation.

If they are not within a 5 percent agreement, go back to the ground truth site with aerial photos and recheck the ground truth.

Continue to interpret aerial photographs until a change in stream habitat conditions is apparent. Log on the stream habitat inventory profile form Figure 1 the last frame number then begin a new form and continue again until a change in habitat classification is noted.

Figure 3.

STREAM HABITAT INVENTORY PROFILE
GROUND TRUTH (G.T.)/PHOTO INTERPRETATION (P.I.)
VERIFICATION

State________ District________ Planning Unit________

Stream Name________________ No. Feet G.T.________

Location of G.T.________________

G.T. Target Pattern________________

Photograph Frame Number(s) P.I.________________

Comments________________

	Shade	Stream Bank Condition	Stream Bank Stability	Stream Channel Stability	Sedimentation of Streambed	Total Score
G.T.	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1	3 2 1	____
P.I.	4 3 2 1	4 3 2 1	4 3 2 1	4 3 2 1	3 2 1	____

Difference between scores in percent of potential ____

Example - Scores of 12 (63%) and 11 (58%) difference 5%.

Score	% of Potential		Score	% of Potential	
19	100	Excellent	13	68	Fair
18	85	Excellent	12	63	Fair
17	89	Excellent	11	58	Fair
			10	53	Fair
16	84	Good	9	47	Poor
15	79	Good	8	42	Poor
14	74	Good	7	37	Poor
			6	32	Poor
			5	26	Poor

EQUIPMENT FOR PHOTO INTERPRETATION

A light table with 20X stereoscope is used for rapid analysis of photographs. The transparencies are examined on the three hundred foot roll of film.

FILM STORAGE

Film is identified and stored in rolls approximately 300 feet in length.

SUMMARY

The speed of stream habitat analysis using 5" x 5" format CIR transparencies is approximately ten miles per hour. Correlation between ground truth and photo interpretation is extremely high and reproducible results can be obtained by any trained technician.

ACKNOWLEDGEMENTS

Thanks are extended to Richard Kerr, Wildlife Staff Leader, Denver Service Center, Bureau of Land Management, who encouraged the development of remote sensing techniques for streams and to Fred Batson, Wally Crisco, Lanny Wilson, Carl Armour, Mark Hilliard and Art Oakley who each contributed to the development of this stream habitat inventory system.

SELECTED REFERENCES

Anon, 1970. Photointerpretation for land managers. Kodak Publication M-76, Rochester, NY 14650

Anon, 1972. The use of remote sensing to obtain data for describing the large river, Civil Engineering Dept. Colorado State University, Ft. Collins, Colorado

Cuplin, P., C. Armour, R. Corning, D. Duff and A. Oakley, 1978. Fisheries and Aquatic Habitat Inventory and Analysis Techniques, Draft Technical Note, BLM, Denver Service Center, Denver, Colorado 80225

Cuplin, Paul, 1978. Remote sensing streams. Integrated Inventories of Renewable Natural Resources, pp. 257-259:Proceedings of the Workshop, Tucson, Arizona, Jan. 8-12, 1978. General Technical Report RM-55. Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colorado

Draeger, William C., Andrew S. Benson and Leon A. Johnson, 1974. Usefulness of Remote Sensing Techniques for the Environmental Monitoring of the Sacramento-San Joaquin Delta. Prepared for Dept. of Water Resources, The Resources Agency of California, Center for Remote Sensing Research School of Forestry and Conservation. University of California, Berkeley.

Draeger, William C., 1976. Monitoring irrigated land acreage using landsat imagery: an application example. U.S.G.S. Open-file report No. 76-630, Sioux Falls, SD

Greentree, Wallace J., and Robert C. Aldrich, 1976. Evaluating stream trout habitat on large-scale aerial color photographs. USDA Forest Serv. Res. Paper PSW-123, 21 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, California

Hayes, Frank, 1976. Application of color infrared 70 mm photography for assessing grazing impacts on stream-meadow ecosystems. Univ. of Idaho College of Forestry, Wildlife and Range Sciences Station Note. No. 25

Lockwood, Harold E., Lincoln Perry, Gerard E. Saver, Noel T. Lamar 1974. Water Depth Penetration film test. pp. 1303-1314, Photogrammetric Engineering

Meyer, Merle P., 1973. Operating Manual - Montana 35 mm Aerial Photography System (1st Revision), Univ. of Minn. College of Forestry, St. Paul, Minn.

Meyer, Merle P., and Bruce H. Gerbig, 1974. Remote Sensing Applications to Forest and Range Resource Surveys and Land Use Classification on the Malto District (BLM), Montana. Univ. of Minn., College of Forestry St. Paul, Minnesota.

Miller, Thomas B., Robert C. Heller, Joseph J. Ulliman, Frederic D. Johnson, 1976. Evaluating riparian habitats from aerial color photography, Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow, Idaho.

Specht, M. R., D. Needler, N. L. Fritz, 1973. New Color Film for Water-Penetration Photography, Photogrammetric Engineering, pp. 359-369.

Identification of Ross' Goose Colonies from Landsat Imagery[1]

Richard H. Kerbes[2]

Abstract. --Sites of actual and potential colonies of Ross' geese in the central Canadian Arctic had a distinctive signature on Landsat Band 6 imagery, thus facilitating an inventory of the nesting birds in 1976.

INTRODUCTION

The Ross' goose *(Anser rossii)* has been considered the rarest of North American geese. Most nest in colonies scattered within an area approximately 325 km by 175 km south of Queen Maud Gulf in the central Canadian Arctic. Due to the management need for an accurate census of the population, I undertook an inventory of the nesting Ross' geese in 1976. I used a modification of large format aerial photography previously designed for lesser snow geese *(Anser caerulescens caerulescens)*, (Kerbes 1975). In planning the inventory my first problem was to identify all potential colony sites. Visual aerial surveys conducted from 1965 to 1967 had located 37 colonies (Ryder 1969), but it was unknown if any colonies had been missed or if new colonies had developed since then.

Ryder reported that at all colonies the Ross' geese were nesting on suitable islands in shallow lakes which he estimated to be 0.6 to 2.0 metres deep. The geese select islands in shallow lakes because shallow lakes become covered with melt water much earlier in spring than deep lakes. The arctic fox *(Alopex lagopus)*, which is one of the chief predators of the nesting birds and their eggs, will not cross open water in order to reach the islands (Ryder 1969).

Would those key features of a Ross' goose colony - islands and shallow water - show up on Landsat imagery?

EXAMINATION OF LANDSAT IMAGERY

Initially, I located the 37 known colonies on scale 1:1,000,000 prints of Landsat 1 and 2 (Band 6). Almost all colonies stood out distinctly on imagery from late May to early July, when surface melt water was dark on the shallow lakes, contrasting with the white snow and ice cover of the deep lakes. Also, on imagery from late July to early September, many of the shallow lakes appeared light due to turbidity, while the deep lakes, now clear of ice and snow, appeared dark.

To identify potential colony lakes, I first located lakes with islands on scale 1:250,000 topographic maps (islands were often too small to show up on Landsat). Those lakes then were examined on Landsat imagery and those which appeared shallow were classified as potential colonies. The number of lakes which needed to be checked during my aerial survey was thereby reduced to a small fraction of the many thousands of lakes in the survey region.

GROUND TRUTH

During the aerial photographic survey of the colonies, 15 to 22 June, 1976, I visually estimated the depths of lakes from the photo aircraft, flying approximately 300 metres above ground level. I assessed the known colonies, over 100 potential colony lakes, plus several hundred other lakes.

Almost all lakes proved to be shallow or deep as expected in the classification from Landsat. I discovered five new colonies, all on lakes previously classified as potential colonies.

CONCLUSION

Ross' geese nest on islands in shallow lakes in the central Canadian Arctic. The appearance of shallow lakes is distinct from that of deep lakes on Landsat Band 6 imagery, especially in the spring when the shallow lakes become covered with melt water sooner than the deep lakes. An aerial visual survey in 1976 confirmed that Landsat imagery can be used to identify actual and potential colonies of

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

[2]Wildlife Biologist, Canadian Wildlife Service, Saskatoon, Saskatchewan S7N 0X4 Canada.

Ross' geese.

REFERENCES

Kerbes, R.H. 1975. The nesting population of lesser snow geese in the eastern Canadian Arctic: A photographic inventory of June 1973. Can. Wildl. Serv. Rep. Ser. No. 35. Ottawa. 47p.

Ryder, J.P. 1969. Nesting colonies of Ross' Goose. The Auk 86:282-292.

Radio-Telemetry Techniques for the Investigation of the Behavior and Demography of Wild Turkeys[1]

William F. Porter[2]
Donald B. Siniff[3]
David A. Hamilton[4]

Abstract.--The movement, habitat-use, activity patterns, mortality and range expansion rates of two populations of wild turkeys (Meleagris gallopavo) were studied via radio-telemetry. A total of 215 turkeys were radio-tagged. Telemetry techniques employed provided good estimates of the demographic, as well as the behavioral, parameters. The techniques are presented along with examples of data that were obtained.

INTRODUCTION

Essential to the management of any wildlife species is a thorough understanding of its behavior and demography. The behavioral characteristics of an organism, such as movements and patterns of habitat-use, are key elements in the design of habitat management. Demographic information, such as natality and mortality rates, is of obvious importance to the regulation of harvest. Further, it is increasingly clear that sound management programs must be based on regionally specific data.

Statistical estimates of the various behavioral and demographic parameters are desirable. However precision with these kinds of data has proven difficult to obtain for most wildlife species.

[1]This paper was taken, in part, from the senior author's Ph.D. dissertation. The research was supported by: the National Institutes of Health Training Grant 5 T01 GM01779, the Minnesota Department of Natural Resources, the Minnesota State Archery Association, the Minnesota Big Game Club, and the National Wild Turkey Federation and its Minnesota State Chapter.
[2]Present address: Assistant Professor of Wildlife Biology, College of Environmental Science and Forestry, SUNY, Syracuse, NY 13210.
[3]Professor, Department of Ecology and Behavioral Biology, University of Minnesota, Minneapolis, MN 55455.
[4]Present address: Research Assistant, Cooperative Wildlife Research Unit, University of Missouri, Columbia, MO 65201.

A new approach to gathering data from wildlife populations has emerged with the development of radio-telemetry. Although initially used to acquire behavioral data, radio-telemetry has more recently been incorporated in demographic studies (Williams et al 1968, Dumke and Pils 1973, Glidden and Austin 1975, Porter 1978). Reported here are some of the techniques used to study both the behavior and demography of the wild turkey in southeastern Minnesota.

THE PROBLEM

Wild turkeys were transplanted into southeastern Minnesota during the 1960's and early 1970's from native populations in other states. By 1973 two populations were established. Southern Minnesota constitutes the northern boundary of the known native range for the species. Almost no information was available concerning the turkey in this region but it was thought that intensive management would be necessary to prevent severe fluctuations in population size.

To obtain the information necessary for such management, a four year study was conducted. Six classes of data were desired: 1) movements, 2) habitat-use, 3) activity patterns, 4) natality, 5) mortality and 6) population range expansion.

THE TECHNIQUES

An 18 month pilot project was undertaken to develop radio-telemetry techniques for the study of wild turkeys in this region. A total of 35 turkeys were radio-tagged during this initial effort and telemetry data were acquired through a nine month field season. The pilot project was followed by a two-year, intensive study in which 180 birds were radio-tagged.

All work was done in two 300 km^2 study areas which encompassed the ranges of the turkey populations. Terrain in these areas is unusually rugged for the Midwest and is similar to the Allegheny Plateau region of northern Pennsylvania. The vegetation pattern in the area is a patchwork of agriculture crops (Zea maize - Medicago sativa) and hardwood forests (Quercus - Ulmus).

Acquisition of movement and habitat-use data required a telemetry system that could provide accurate location fixes in the rugged terrain under a variety of seasonal weather conditions. The transmitter unit developed produced a pulsed signal near 164 MHz and was powered by one 2.8 volt organic lithium battery. Circuitry and battery components were encased in Scotch-Caste #5. The transmitter antenna was a 35.56 cm whip made of 1.7 mm plastic-coated aircraft cable. The transmitter was designed to remain operational down to temperatures of -30°C.

Transmitter packages were cylindrical (3.0 X 9.0 cm). They were harnessed to the bird's back with 19 strand Teflon-coated wire sheathed in PVC tubing that was looped around the breast and under each wing (Fig. 1). The entire package was covered with black Scotch #33 electrical tape to reduce its visibility. Weight of the complete package was approximately 110 g.

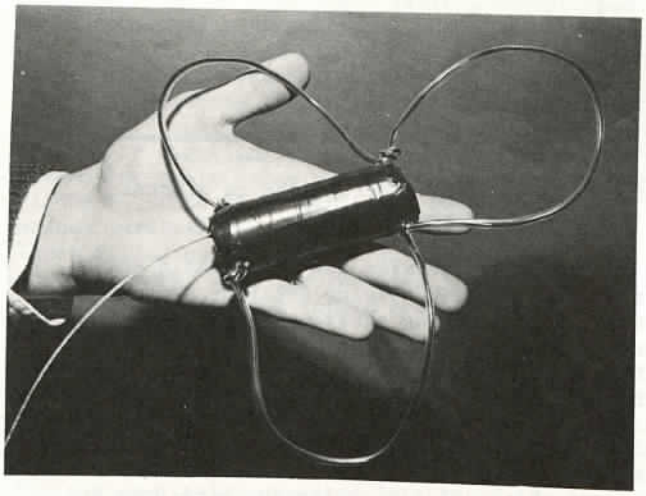


Figure 1.--Transmitter package and harness.

The receiving system used four-element, yagi antennas and crystal controlled, double conversion, super-heterodyne receivers. The system allowed reception of a signal to a maximum of 8 km ground-to-ground. Transmitters operated 9 ± 1.1 ($\bar{x} \pm$ SE) months with fewer than one percent failing to provide at least one month's data[1].

All location fixes of radio-tagged birds were obtained via triangulation from two telemetry recording positions (TRP). Several criteria were developed to enhance triangulation accuracy (after Heezen and Tester 1967). First, for each location fix, bearings were recorded simulataneously from two TRP's. Second, an attempt was made to record bearings from TRP's that were within 3 km of the general location of the bird. Finally, only those triangulations in which the crossing angle was between 60 and 120 degrees were used to obtain location data.

These criteria and the mobility of the turkey required a flexible telemetry system. Hundreds of TRPs were established in the study area. This precluded the use of antenna towers common to wildlife telemetry research work. Further the need for simultaneous, accurate bearings from two TRPs made the use of vehicle-mounted and hand-held antennas undesirable. The system that was developed involved the use of antennas mounted on aluminum tripods. Antennas were mounted with photographic "Pro Zip Grips" (Burleigh/Brooks, Inc.) which allowed easy attachment and removal of the antennas from the tripods (Fig. 2). Directional bearings were obtained using Brunton Pocket Transits laid along the axis of the antenna. The tripods reduced bearing errors to ± 2 degrees and the system allowed location of radio-tagged birds to within 50 meters of their actual location more than 90 percent of the time (Porter 1976).

Preliminary work showed that one location every 2 days would provide a reasonable estimate of an individual's home range and its diurnal habitat-use patterns. These locations were obtained for 15 to 20 radio-tagged birds each month during the second, more intensive phase of the project. Home ranges were delineated for each individual following the Modified Minimum Area Method (Harvey and Barbour 1965).

Habitat-use patterns were quantified as the proportion of diurnal location fixes occurring in each habitat type. More than 10,000

[1]All transmitters and receivers were dedesigned and constructed at the Bioelectronics Laboratory, Cedar Creek Natural History Area, Bethel, Minnesota 55005.

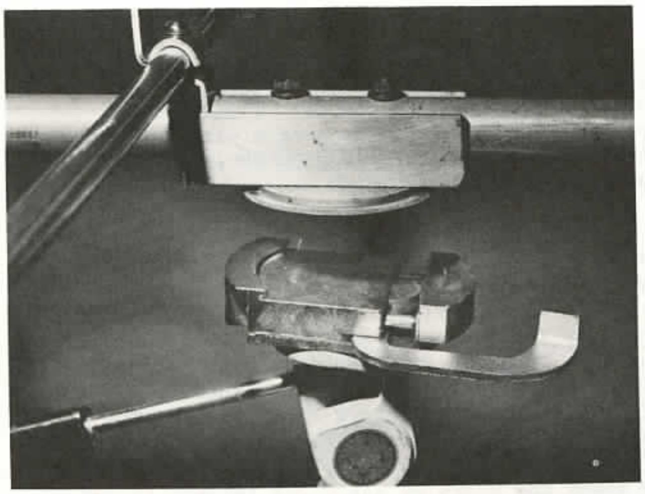


Figure 2. Antenna and tripod showing "Zip Grip" mounting bracket.

Figure 3. Monthly fluctuations in home range size.

location records were pooled by sex-age class for this analysis. Figure 4 illustrates the use pattern for basic topographic and vegetation features that was shown by females during the winter months.

In addition to the radio-tagged turkeys that were located intensively, another 35-40 radio-tagged birds were monitored daily for activity. Variation in signal strength during a 30 second observation period was used as an indication that the bird was active. Approximately 50,000 activity records provided a general diurnal activity pattern (Fig. 5).

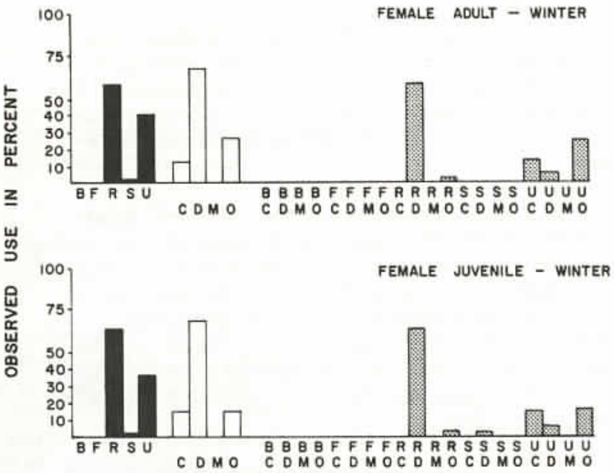


Figure 4. Winter use of five topographic and four vegetation habitat classes and their combinations by females.

Filled bars: B-Bench, F-Floodplain, R-Ravine, S-Slope, U-Upland
Open bars: C-Coniferous, D-Deciduous, M-Mixed (C & D), O-Open
Stipled bars: combinations of topographic and vegetation classes

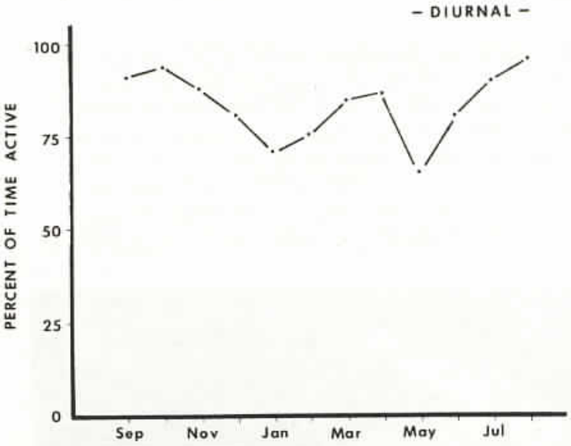


Figure 5. Monthly fluctuations in diurnal activity patterns.

Activity patterns for individuals also proved valuable in gaining natality and mortality data. In the spring activity patterns of females were used to estimate the onset of incubation. (Subsequent evaluation of this technique showed that the onset of incubation could be determined within $\pm$ 2 days). Data showed that females could be approached and located visually during the last week of incubation with less than a 5 percent chance of disturbing the bird from the nest. Later, when activity and movement data showed the female had left the nest permanently, the nest was examined. This provided information on nest success rates, egg fertility rates and number of young hatched per female.

Throughout the year birds that were observed to be inactive during an inordinate amount of time were located visually. When the cause for inactivity was mortality, an effort was made to determine the cause of death. In cases of mortality, the carcasses were usually located within 24 hours of death. Where the cause of death was predation, the class of predator (i.e., mammalian or avian) could be determined in nearly 70 percent of the cases.

With a sample size of 215 radio-tagged birds, it was possible to generate good estimates of natality and survival parameters. Natality parameters were estimated in a straight forward manner from nest data. Survival analyses were more complex. Ideally, seasonal and annual survival should be estimated by following a sample cohort in which all the individuals were tagged simultaneously. However, a tagging season of three months for turkeys and periodic tag losses made this procedure inefficient. Instead, seasonal and annual survival rates were estimated from monthly analyses. Monthly mortality rates were calculated as follows:

$$q_m = \frac{N_d}{N_a} = \frac{\text{Number of tagged birds alive on the first day of the month and dying during the month}}{\text{Number of tagged birds alive on the first day of the month}}$$

Thus monthly survival was equal to:

$$l_m = 1.0 - q_m$$

Birds on which radio-tags malfunctioned were excluded from the analysis. Table 1 exemplifies monthly mortality rates.

Seasonal and annual survival rates were generated assuming hypothetical cohorts of 1000 individuals and modeling them through a series of monthly mortality rates. This is illustrated for adult males and females in Figure 6. Data were sufficient to estimate annual survival for each of several age classes. These estimates, along with age-specific natality data, were incorporated in a population model to project future growth of the turkey populations.

The final parameter examined was the rate of range expansion for the populations. It was estimated that the potential turkey range in this region included a minimum of 30,000 km^2. State conservation agencies interested in facilitating the expansion of turkey populations required information concerning 1) the natural rate of expandsion and 2) the effectiveness of expansion survey techniques (not involving telemetry). The large sample of radio-tagged birds provided a means of gaining this information.

Table 1. Monthly mortality rates for males and females, 6 months' data are pooled for all radio-marked birds 1975-1978 and for all age classes.

	Males			Females		
	N_a	N_d	q_m	N_a	N_d	q_m
Jan	35	1	0.029	41	3	0.073
Feb	47	2	0.043	91	15	0.165
Mar	42	5	0.119	91	15	0.165
Apr	47	3	0.064	89	3	0.034
May	31	2	0.064	29	3	0.103
Jun	29	0	0	24	2	0.083
Jul	27	1	0.037	20	0	0
Aug	25	0	0	19	0	0
Sep	23	0	0	19	1	0.053
Oct	24	0	0	16	0	0
Nov	29	2	0.069	16	0	0
Dec	29	0	0	15	0	0

N_a = Number of birds marked and alive on the first day of the month.

N_d = Number of birds marked and alive on the first day of the month and dying during the month.

q_m = Monthly mortality rate. (N_d/N_a)

Figure 6. Monthly losses for males and females assuming initial cohorts of 1000 individuals. M = Males, F = Females.

By the spring of 1978 telemetry data showed turkey populations had expanded to fill more than 2000 km^2 (Fig. 7). Telemetry data showed that survey techniques underestimated the range expansion of the populations by about 10 percent.

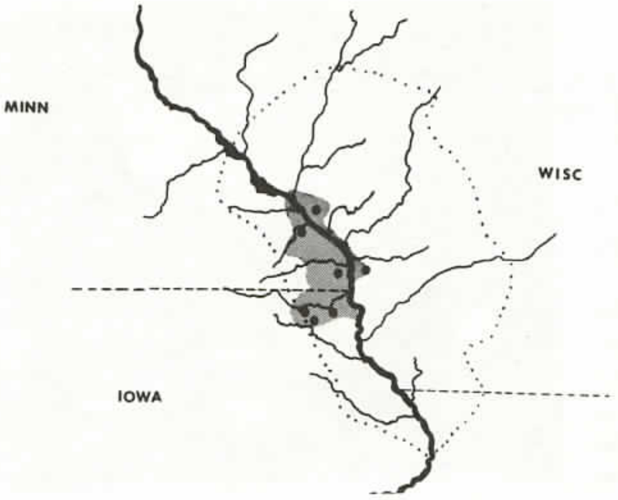


Figure 7. Map shows current distribution of the turkey population (hatched area). Dots show original transplant release sites; dashed line encompasses anticipated distribution of this population.

Obtaining this information required an investiment of approximately $48,000. Most of the field work was completed by one graduate student and varying numbers of student interns and part-time technicians. Direct benefits to wildlife management programming were numerous. First, behavioral and demographic data demonstrated that intensive habitat management was not essential to the persistence of the wild turkey in this region. Further, the data showed that reproduction was sufficient to allow more liberal harvest regulations. Finally, the data enabled the formulation of criteria necessary to evaluate potential turkey habitat throughout the Upper Midwest.

This was a relatively short-term, intensive research effort. The simultaneous study of both behavioral and demographic parameters using radio-telemetry proved most effective in gaining an understanding of the biology of the wild turkey in this region. Already this knowledge is enhancing the integration of this species with regional wildlife management programs.

LITERATURE CITED

Dumke, R. T. and C. M. Pils. 1973. Mortality of radio-tagged pheasants on the Waterloo Wildlife Area. Wisconsin Department of Natural Resources Technical Bulletin 72, 52 pp.

Glidden, D. E. and L. W. Austin. 1975. Natality and mortality of turkey poults in southwestern New York. pp. 55-60. In L. K. Halls (Ed.) Proceedings of the third National wild turkey symposium. The Texas Chapter of the Wildlife Society. 255 pp.

Harvey, M. J. and R. W. Barbour. 1965. Home range of Microtus ochrogaster as determined by a modified minimum area method. J. of Mammal. 46(2): 398-402.

Heezen, K. L. and J. R. Tester. 1967. Evalu- of radio-tracking by triangulation with specific reference to deer movements. J. Wildl. Manage. 31(1):124-141.

Porter, W. F. 1976. Habitat utilization by wild turkeys in southeastern Minnesota. (unpubl.) M.S. Thesis. University of Minnesota, Minneapolis. 94 pp.

Porter, W. F. 1978. The ecology and behavior of the wild turkey (Meleagris gallopavo) in southeastern Minnesota. (unpubl.) Ph.D. Dissertation. University of Minnesota, Minneapolis. 124 pp.

Williams, L. E., D. H. Austin, N. F. Eichholz, T. E. Peoples and R. W. Phillips. 1968. A study of nesting turkeys in southern Florida. Proceedings of the Annual Conference of the SE Association Game and Fish Commissioners. 22:16-30.

Applications of Satellite Imagery to Management of Arctic Nesting Geese

Henry M. Reeves
Office of Migratory Bird Management
U.S. Fish and Wildlife Service
Washington, D.C.

Abstract.--Cooperative efforts to monitor the extent and rate of snow disappearance from Arctic goose nesting areas have been undertaken annually since 1975 by the U.S. Fish and Wildlife Service and the Canadian Wildlife Service. Retrospective assessments for 1973 and 1974 are also reported upon. Two types of satellite imagery are operationally used: (1) Multi-Spectral Scanner (MSS) imagery from LANDSAT; and (2) Very High Resolution Radiometer (VHRR) imagery from National Environmental Satellite Service spacecraft. Advantages and disadvantages of products from each sensor are discussed. Gross assessments of habitat conditions during the nesting periods for 1973 through 1978 and production prospects are discussed, along with age ratios of geese harvested or observed in the United States in following winters. With few exceptions, the predictions projected from satellite imagery were later corroborated by other data. Prospects for further improvement of this effective and economical management tool for Arctic nesting geese are discussed.

INTRODUCTION

This paper reports upon the usage of satellite imagery to monitor habitat conditions confronting Arctic nesting geese, and indirectly, to provide insight into their probable production during years of abnormal weather conditions. These annual assessments are undertaken cooperatively by the U.S. Fish and Wildlife Service and the Canadian Wildlife Service. The two federal agencies have primarily responsibilities for the management of migratory bird resources in their respective countries as the result of a migratory bird treaty signed in 1916.

Most of North America's geese nest in the Arctic. 1/ Among these are most races and management populations of the abundant and widely distributed Canada goose (Branta canadensis); snow geese (Anser caerulescens), including the dark morph of the "lesser" subspecies; Ross' geese (Anser rossii); most white-fronted geese (Anser albifrons); brant (Branta bernicla); and emperor geese (Philacte canagica). Besides having important cultural and aesthetic values, these geese provide many recreational opportunities and much food to North Americans, sportsmen and natives alike. During the 1976-77 hunting seasons, U.S. hunters harvested 1.69 million geese, while 0.52 million were taken in Canada. Well over three-fourths of these birds originated from Arctic nesting areas.

North American geese are managed chiefly through the establishment of annual hunting regulations related to population objectives and probable fall flights, and intensive land use on Federal and State waterfowl areas. These areas, along with supplemental private and public lands, fulfill the needs of geese during most of the migration and wintering periods. No substantial management other than regulation of subsistence use appears feasible in the Arctic.

Arctic nesting geese possess a number of physiological and behavioral attributes which enable them to endure the harsh environment, and in most summers, produce young. Geese exhibit strong tendencies to return annually to precise nesting and wintering locales. Several species, notably snow geese, Ross' geese, brant, and small races of Canada geese,

1 As used here, Arctic describes the area beyond the northern limit of tree growth.

tend to nest in colonies of varying nest densities. To illustrate, Kerbes (1975) reported that snow geese at Tha-anne River, N.W.T., had densities of 2,909 nests per sq. km. Densities for 16 surveyed colonies in 1973 averaged 127 nests per sq. km. Arctic nesting geese have become physiologically adapted through evolution so that during most years the adult component is able to locate nesting sites, construct nests, deposit and incubate eggs, and rear young to flight stage before return of adverse weather. In addition, adults undergo the annual molt, when for a period of several weeks they are flightless. The long Arctic days of midsummer and an abundance of foods facilitate these accelerated life processes.

Experience has demonstrated that delayed snow and ice disappearance some years from nesting areas may result in retarded and/or markedly reduced goose production. Indeed, in extreme situations, virtually no reproduction may occur. Unusually adverse weather and habitat conditions may result in failure of geese to even attempt to nest. In this event, partially developed embryos are resorbed, no doubt as a mechanism to ensure survival of the adult females.

Among the important studies on relationships between weather conditions and goose reproduction are those for cackling geese (B. c. minima) and white-fronted geese on the Yukon-Kuskokwim Delta, Alaska (Mickelson 1975); white-fronted geese (Dzubin et al 1964); Canada geese in northwestern Ontario (Raveling and Lumsden 1977); brant on Southampton Island, N.W.T. (Barry 1962) and at the mouth of the MacKenzie River, N.W.T. (Gillham in Einarsen 1965;43); lesser snow geese (Anser c. caerulescens) in the Canadian Arctic (Cooch 1958, 1961; Finney and Cooke 1978) and on Wrangel Island, U.S.S.R. (Uspenski 1965); Ross' geese at Perry River, N.W.T. (Ryder 1967, 1970); Emperor geese in Alaska (Eisenhauer and Kirkpatrick 1977); and geese nesting on the Anderson River Delta, N.W.T. (Barry 1967). In addition, a wealth of information on these geese appears in several recent books (Bellrose 1976; Johnsgard 1975; and Palmer 1976).

Our past inability to detect years of production failure of some Arctic breeding geese prior to the establishment of annual hunting regulations has occasionally led to overharvests and population declines so great that hunting had to be curtailed to allow the population to rebuild. Brant of the Atlantic Flyway best illustrate this situation. Atlantic Flyway brant nest on Southampton Island and other remote areas of the Canadian Arctic. In several recent years they have been notably unproductive. Field observations on the Atlantic Coast wintering areas in 1971 enabled biologists to determine that the population had an age ratio of only 0.06 immature per adult. During the following winter only 13 immatures were observed among 15,664 brant, for an age ratio of only 0.0008 immature per adult. These two unproductive years, unexpectedly high harvests in the 1972-73 season, plus natural losses, caused the population to crash from 151,000 brant in January of 1971 to 40,700 in January 1973. As a consequence, no brant hunting was allowed in the Atlantic Flyway during 1973 and 1974. A restricted season was allowed in 1975 following substantial population recovery. Unfortunately, recurring production failure during 1976, followed by severe winter losses during 1976-77 and 1977-78 depressed the population to a record low of about 35,500 spring migrants. No hunting of these geese has been allowed in the United States since the 1975 season.

Administrative and legal requirements necessitate establishing the annual hunting regulations in Canada in early July, and in the United States by mid-August. These tight, inflexible schedules severely limit the time within which waterfowl managers can gather, evaluate, and distribute information on the current status and reproductive success of North America's waterfowl resources. Furthermore, the wide distribution and inaccessibility of most goose nesting grounds in the Arctic, and weather hindrances to travel, preclude annual on-site investigations--even if adequate funds were available.

Our initial experience indicated that satellite imagery provided goose resource managers with an economical new tool helpful in grossly assessing habitat conditions confronted by Arctic nesting geese and their probable production many years (Reeves, Cooch, and Munro 1975). This paper reports upon our progress to date, problems which have arisen, and possible solutions to some of these. In this respect, it summarizes and updates information given in the above paper.

I am indebted to F. G. Cooch and H. Boyd, Canadian Wildlife Service, and G. Jonkel, U.S. Fish and Wildlife Service, all of whom participated in assessing Arctic goose habitat and production prospects. G. K. Brakhage and A. D. Marmelstein helpfully reviewed the paper. Also, I wish to acknowledge the independent efforts of Heyland (1975) in applying similar techniques to study greater snow goose production on Bylot Island in the eastern Canadian Arctic.

METHODS AND MATERIALS

Satellite Imagery Products

Our work has focused upon imagery from the Multi-Spectral Scanner (MSS) of LANDSAT and the lesser known Very High Resolution Radiometer (VHRR) sensor of the Improved TIROS Operational Satellites. Data acquired from the former sensing system is administered by the U.S. Geological Survey in cooperation with the National Aeronautical and Space Administration (NASA) while the latter system, generally used for weather forecasting, is directed by the National Environmental Satellite Service (NESS) of the National Oceanic and Atmospheric Administration (NOAA). LANDSAT imagery of Arctic Canada was supplied on microfiche by Integrated Satellite Information Services, Ltd., Prince Albert, Sask., on a subscription basis. VHRR imagery was viewed at the NESS's office in Suitland, Md., and key images obtained for future study and reference.

Products from these two sensing systems enabled us to view and evaluate the rate of ice and snow disappearance from key goose production areas on both macro and micro scales. Each MSS image encompasses an area of about 25,900 sq. km. (100 sq. miles), with a subsatellite resolution of 91.4 to 121.9 m. In contrast, each VHRR image depicts an area of approximately 2.59 million sq. km. (1,000,000 sq. miles), with a resolution of 0.81 km. Costs of products from the two systems are comparable. Unfortunately, MSS imagery for Alaska is not yet available on a schedule satisfactory for our use. In addition to affording imagery of differing scale and resolution, the two systems have independent orbiting schedules. Consequently, when imagery from one system is not available or usable, satisfactory output may be available from the other system.

The recycle rate of LANDSAT over the same geographical location north of about 70° N. latitude is about 18 days whereas the NESS satellite passes over the same general earth location twice daily (once during daylight). These recycle rates are only approximate because of the convergence of orbital tracks towards the poles and resultant overlap of imagery. Also, the availability of output from both LANDSAT 2 and 3 shortens the effective recycle rate.

Advantages of VHRR imagery over MSS imagery include: (1) more frequent coverage of any given geographical location; (2) much larger field of view; and (3) more ready availability of output. All factors are extremely important because clouds and coastal fogs typically occlude much of the Arctic during the crucial late May and June period. On the other hand, MSS imagery permits more precise assessments to be made of those areas for which satisfactory coverage is available.

Our work with satellite imagery commenced in 1975 with restrospective assessments of VHRR imagery for 1973 and 1974. These experimental evaluations included imagery in early, mid-, and late June for scattered Arctic locations. Biological data from scattered on-site investigations in past years indicated that nesting areas had to be available (free of snow and ice) to geese by about mid-June if they were to reproduce successfully. From 1975 to date we have viewed LANDSAT imagery of Canada during June on a nearly current (7-10 days after overflight) basis, and VHRR imagery in late June.

In addition to use of satellite products, we are also assembling and evaluating data from other sources to determine whether they support or contradict production estimates projected from knowledge of habitat conditions deduced from satellite imagery. These other sources include harvest data (magnitude, species, age composition, and geographical distribution), field observations (age composition by species and geographical locations), banding information (distributions of bandings and recoveries), and winter surveys (goose numbers by species and locations). Most of this supplemental information is available in published and unpublished reports.

Primary attention has centered on snow geese (including greater snow goose, *A. c. atlantica*) because of their extensive breeding range (western Greenland and Baffin Island west to Wrangel Island, U.S.S.R.); overall abundance (second only to Canada geese and trending upwards); harvest importance (in the U.S., second only to Canada geese); distinct plumage differences between immatures and older cohorts; and comparatively better information and understanding of breeding biology, abundance, distribution, and harvest.

RESULTS

Generalized evaluations of habitat conditions and probable goose production based on satellite imagery, plus comparisons with post-predictive information were summarized by years. Age ratio information for both the white and dark morphs of lesser snow goose harvested in the three westerly flyways is summarized in Table 1. Because of closed seasons prior to 1975, and small samples with which to calculate age ratios during subsequent years, no age ratios are available for greater snow geese harvested in the Atlantic Flyway. Age ratios of geese observed in the field in late December are also given for the Gulf Coast (where both Central and Mississippi Flyway snow geese winter), and for greater snow geese wintering along the Atlantic Coast. Although field observation data were also available for Pacific Flyway wintering snow geese, the relatively small effort put into the survey there, plus differences in annual coverage made year-to-year comparisons questionable.

Age Ratios

A review of the age ratios in Table 1 indicates that: (1) within the same year, and type (harvest, observed) of age ratio data, considerable differences existed among flyways within the same year; (2) age ratios varied markedly from year to year within the same flyway; (3) age ratios of white and dark morph lesser snow geese in the two interior flyways the same year were usually similar; and (4) age ratios ascertained from harvest surveys were always higher than those based on field observations.

Several factors account for the age ratio differences noted in the two surveys. Because immature geese are normally more vulnerable to hunting mortality than adults, the age ratios from harvest surveys were biased upwards from the actual ratios in the populations at the time of harvest. Other possible explanations include selective shooting of one age over the other by some hunters, the different time periods to which the age ratios relate (harvest survey reflects the total seasonal harvest whereas field observations are usually made after most of the harvest has occurred), and probable sampling differences by time and place. Furthermore, most geese do not breed until their second or later spring. Finney and Cooke (1978) reported that some lesser snow geese at La Perouse Bay, Manitoba, did not nest until at least 4 years of age. Thus, the population of the non-productive yearlings and older non-breeding birds--which are indistinguishable from breeding adults--influence the calculation of age ratios in both the harvest and field surveys. In the breeding season following a good production year, a large part of the population consists of non-breeding yearlings. Conversely, a low proportion of this cohort occurs in the year following a poor nesting year. Consequently, both types of age ratios should be viewed as indices rather than actual measurements of the past summer's production. Dzubin et al (1975) cautioned against the use of uncorrected age ratios in the harvest as a parameter on which to weight population productivity.

Annual Assessments

1973

Prospects.--Retrospective satellite imagery, limited to VHRR output, strongly suggested that excellent habitat conditions prevailed for nesting snow geese prior to mid-June. The important Hudson Bay lowlands and the Arctic coast of mainland Canada were snowfree before 3 June. Prior to 14 June, Banks Island, the major nesting area for Pacific Flyway snow geese, was totally free of snow. Snow disappearance was somewhat retarded east of Hudson Bay but fragmentary imagery indicated that snow

Table 1.--Age ratios of snow geese (white and dark morphs) from U.S. harvest surveys, and field observations, 1973-77.

Year	Age ratios (weighted) in harvest 1/					Age ratios observed in field 1/	
	Pacific Flyway	Central Flyway		Mississippi Flyway		Gulf	Atlantic
	White	White	Dark	White	Dark	Coast 2/	Flyway 3/
1973	1.60	1.54	1.74	1.37	2.33	0.61	0.70
1974	0.08	0.70	0.51	0.74	0.74	0.21	0.02
1975	2.60	1.42	1.57	0.99	1.02	0.81	0.39
1976	1.66	0.62	0.52	0.51	0.63	0.29	0.11
1977	0.62	1.32	1.39	1.41	1.34		0.31

1 Files, Office of Migratory Bird Management, U.S. Fish and Wildlife Service, Washington, D.C.

2 Includes white and dark morphs.

3 Greater snow geese.

geese returning to the huge colony sites on Baffin Island found conditions satisfactory for nesting. All in all, conditions in 1973 appeared to be very favorable for snow geese throughout the North American Arctic, and excellent production seemed likely.

Evaluation.--Age ratio data from geese harvested in the Pacific, Central, and Mississippi Flyways generally exceeded 1.5 immatures per adult. Field observations of Atlantic Flyway greater snow geese indicate that they likewise were very productive.

1974

Prospects.--Although much of the Canadian mainland west of Hudson Bay was bare by mid-June, snow disappearance was unduly delayed on offshore islands. On 17 June Banks and Victoria Islands were still under snow cover, as was the key Bowman Bay, Cape Dominion, and Koukdjuak River areas of Baffin Island where many geese, especially dark morphs, destined for the Mississippi and eastern Central Flyway, breed. Wrangel Island, U.S.S.R., was still largely snow-covered on 15 June. We concluded that the combination of little or no production from some important areas, combined with fair to normal production from others, would lead to overall below average production of snow geese destined for the two interior flyways. Inasmuch as production prospects for both Banks and Wrangel Islands were bleak, poor production was envisioned for Pacific Flyway snow geese. Little if any production was anticipated for greater snow geese of the Atlantic Flyway.

Evaluation.--Age ratios in the harvest of Central and Mississippi Flyway snow geese indicated that they were only half to a third those of 1974. Production of dark morph birds, many of which normally nest on Baffin Island, was somewhat poorer than of white morph snow geese which tend to nest farther west and south. Very low age ratios of lesser snow geese in the Pacific Flyway (0.08:1, from harvest survey) and greater snow geese of the Atlantic Flyway (0.02:1 from field observations) substantiated the expectations from satellite imagery.

1975

Prospects.--By early June, ice and snow melt was well under way over much of the Arctic including most islands of the Canadian Archipelago. Some lowlands on Ellesmere and Axel Heiberg Islands used by greater snow geese were snowfree on 3 June. The Southampton Island lowlands and southern Bylot Island were bare by 5 June. All key areas in the Hudson-James Bay area were available to nesting geese approximately two weeks earlier than normal. Snow had vanished from the important Great Plain of the Koukdjuak, Baffin Island, prior to 15 June. Thaw progressed rapidly during June over most of the Canadian Arctic. Exceptions to the early breakup were limited to portions of the extreme western Arctic, notably the North Slope of Alaska and Wrangel Island, U.S.S.R. Prospects for goose production were excellent over most of Arctic North America. Exceptions to this assessment were limited to Northern Alaska, where few snow geese nest, and Wrangel Island.

Evaluation.--High age ratios were found in snow goose harvests in the Pacific, Central, and Mississippi Flyways. These generally exceeded 1 immature:1 adult. Field observations along the Gulf Coast corroborated the prediction of good production by these snow geese. Greater snow geese produced successfully but perhaps not as well as in 1973.

1976

Prospects.--Satellite imagery indicated that nesting areas were snowfree by mid-June south of a line north of Banks Island, and extending southeasterly across northeastern Victoria Island, northeastern Keewatin, south of Southampton Island, and easterly across the extreme northern tip of the Ungava Peninsula. In contrast, heavy snow cover generally persisted north of the line. The Banks Island lowlands were exposed as early as 2 June, as were the James-Hudson Bay lowlands. Low elevations on Wrangel Island were snowfree by 12 June. Favorable breeding conditions prevailed in Alaska, Banks Island, most of Victoria Island, the Canadian mainland except for the extreme northeastern Keewatin, N.W.T., the Hudson and James Bay lowlands, and the Ungava Peninsula. Little bare ground was noted on Bylot Island by 16 June although more northerly nesting areas of greater snow geese were available then. Snow persisted on Bylot until after 24 June. Good to excellent production was expected from nesting areas situated south of the line described above. Little to poor production was anticipated for geese which nest north of the line. Production prospects for snow geese were generally better in the western Arctic than eastward.

Evaluation.--Good production (1.66 immatures:1 adult) were noted in Pacific Flyway snow geese. Below average ratios occurred in snow geese harvested in the Central and Mississippi Flyways, and in samples of geese observed along the Gulf Coast. Observations of greater snow geese wintering in the Atlantic Flyway indicated that they had experienced poor production in 1976.

1977

Prospects.--Snow disappearance in western and southern Arctic areas was somewhat earlier than usual. Mainland Canada except the northern District of Keewatin and northern Ungava Peninsula were snowfree by mid-June. Banks Island was mostly clear by 4 June, and 80 percent snowfree by 7 June. A notable feature in 1977 was the rapid retreat of the snowline in the eastern Canadian Arctic during the period 13-20 June. By the later date it had advanced beyond Hudson Bay and southern Baffin Island, apparently freeing these areas for nesting. Although the Bylot Island nesting grounds of greater snow geese were still snow covered on 17 June, more northerly areas had cleared earlier in June. The Wrangel Island nesting grounds were still under snow by mid-June. Good production was anticipated for lesser and below average for greater snow geese.

Evaluation.--The age ratio of harvested snow geese in the Pacific Flyway (0.62:1) was considerably lower than age ratios of Central (1.32:1) and Mississippi Flyway (1.41:1) white morph snow geese. This discrepancy initially appears to conflict with production predictions. However, it should be noted that Pacific Flyway snows had excellent production in 1976, thus the 1977 population contained a large proportion of non-productive subadults. On the other hand, most of the Central and Mississippi snow geese returning north in 1977 were capable of breeding. Another possibility is that the snowstorm which swept over Banks Island in late June affected nesting success.

1978

Prospects.--The lower western Hudson Bay lowlands were snowfree by 9 June. However, snow melt over much of Arctic Canada was at least two weeks late. Persistent cloud cover over the eastern Arctic precluded the recording of useful imagery during the crucial ten-day period from mid-June onward. However, limited imagery in very late June indicated that cloud cover had retarded normal snow disappearance. Bylot Island was under snow cover until late June. Snow covered Banks Island until late June although the nesting area on Wrangel Island was snowfree before mid-June. It appeared that snow goose production in the eastern Arctic during 1978 would be poor, and similarly unfavorable prospects applied to lesser snow geese nesting on Banks Island. Some production seemed possible on Wrangel Island. All in all, overall snow goose production prospects in 1978 were bleak.

Evaluation.--Age ratio information from harvest surveys and field observations will not be available until the spring of 1979. A brief communication from E. V. Syroetchkovski, a Soviet biologist working on Wrangel Island, indicated that snow geese nesting there did experience good production.

PROBLEMS AND SOLUTIONS

Problem areas and potential improvements may be divided into those relating to satellite imagery and those relating to goose biology and management.

Satellite imagery needs include:

1. More ready availability of LANDSAT imagery for Alaska and Wrangel Island. These are operational problems which could be resolved with greater resources allocated to the EROS Program.

2. Means for securing usable imagery when ground locations are occluded by clouds and fog during the crucial late May - June breeding period. SEASAT's radar sensors have the capability for providing such imagery. We anxiously look forward to evaluating its output for our applications.

3. Supplemental means of assessing habitat conditions. One supplemental data source not yet examined by us involves the thermal sensors of SEASAT and other satellite sensors. Records of earth surface temperatures could provide clues to the phenology of spring in the Arctic, and recurrence of sub-freezing temperatures during the egg laying, incubation, and gosling growth periods.

4. Monitoring habitat conditions after hatching to determine whether late snowstorms and low temperatures result in significant gosling mortality. On several occasions we have detected snowfall after initial snow disappearance. In some instances, existing forms of imagery may permit biologists to identify the effects of these late storms. In other cases, new or supplemental imagery may be required.

The use of satellite imagery as we have employed it to date can be evaluated only to the extent that reliable information is available from other sources. Obviously, the best source would be independent on-site evaluations of habitat conditions and production being simultaneously deduced from satellite imagery. Considering the costs, logistics, and other problems associated in representively conducting such ground studies, other data sources must be resorted to. These include:

(1) Banding studies, particularly to determine migration and harvest patterns from varous breeding areas, and to ascertain differential vulnerability of various age cohorts to hunting.

(2) Periodic aerial surveys of nesting colonies such as was undertaken by Kerbes (1975) for lesser snow goose colonies in the eastern Arctic. Such information allows the viewer of satellite imagery to better estimate the effects of unusual habitat conditions in terms of magnitude of production affected.

(3) Population surveys on the wintering grounds and at key staging areas along migration routes.

(4) Field observations to determine age structure of the population, before advent of hunting, and at the conclusion of hunting season. The former provides age structure information most closely related to actual production; the latter furnishes the best information on age composition of geese returning northward to breed.

(5) Age ratio information from national waterfowl harvest surveys in the United States and Canada. Improvements in the design and randomization of these surveys--especially in the United States--would provide data superior to that now being gathered. Managers and researchers familiar with each of these data sources recognize their inherent strengths and weakness.

It seems premature to conclude which single, or combination of data sources provides the best standard against which satellite deduced habitat conditions and probable goose production can be compared. Only continued experience and improved methodology will provide an answer to this question, and simultaneously establish more clearly the worth of satellite technology in the management of Arctic nesting geese.

LITERATURE CITED

Barry, T. W. 1962. Effect of late seasons on Atlantic brant reproduction. J. Wildl. Mgmt. 26(1):19-26.

_____. 1967. The geese of the Anderson River Delta, N.W.T. Ph.D. Thesis. Univ. of Alberta, Edmonton, Alberta. 212 p.

Bellrose, F. C. 1976. Ducks, geese & swans of North America. Stackpole Books, Harrisburg, Pa. 543 p.

Boyd, H. 1976. Estimates of total numbers in the Hudson Bay population of lesser snow geese, 1964-1973. Prog. Notes No. 63. Can. Wildl. Serv. 7 p.

Cooch, F. G. 1958. The breeding biology and management of the blue goose (Chen c. caerulescens). Ph.D. Thesis. Cornell Univ., Ithaca, N.Y. 235 p.

_____. 1961. Ecological aspects of the blue-snow goose complex. Auk 78(1):72-89.

Dzubin, A., compiler. 1974. Snow and blue goose distribution in the Mississippi and Central flyways: a compendium of results of band recovery analyses. Can. Wildl. Serv., Saskatoon, Sask. 566 p.

_____. H. Boyd, and W. J. D. Stephen. 1973. Blue and snow goose distribution in the Mississippi and Central flyways, a preliminary report. Vol. 1. Can. Wildl. Serv., Ottawa, Ontario. 81 p.

_____, H. Boyd, and W. J. D. Stephen. 1975. Blue and snow goose distribution in the Mississippi and Central Flyways, 1951-71. Prog. Notes No. 54. Can. Wildl. Serv. 34 p.

_____, H. W. Miller, and G. V. Schildman. 1964. White-fronts. Pages 135-143 in J. P. Linduska, ed. Waterfowl tomorrow. U.S. Government Printing Office, Washington, D.C.

Einarsen, A. S. 1965. Black brant, sea goose of the Pacific Coast. Univ. of Washington Press, Seattle. 142 p.

Eisenhauer, D. I., and C. M. Kirkpatrick. 1977. Ecology of the Emperor goose in Alaska. Wildlife Monogr. 57. 62 p.

Finney, G., and F. Cooke. 1978. Reproductive habits in the snow goose: the influence of female age. Condor 80(2):147-158.

Heyland, J. D. 1975. Monitoring nesting success of greater snow geese by means of satellite imagery. Pages 243-254 in Proceedings of Third Canadian Symposium on remote sensing, Edmonton, Alberta.

Johnsgard, P. A. 1975. Waterfowl of North America. Indiana Univ. Press, Bloomington and London. 575 p.

Kerbes, R. H. 1975. The nesting population of lesser snow geese in the eastern Canadian Arctic. Can. Wildl. Serv. Rep. Ser. 35. 47 p.

Mickelson, P. G. 1975. Breeding biology of cackling geese and associated species on the Yukon-Kuskokwim Delta, Alaska. Wildl. Monogr. 45. 35 p.

Ogilvie, M. A. 1978. Wild geese. Buteo Books, Vermillion, South Dakota. 350 p.

Palmer, R. S., ed. 1976. Waterfowl (first part), Vol. 2 of Handbook of North American Birds. 521 p. Yale Univ. Press, New Haven and London.

Raveling, D. G., and H. G. Lumsden. 1977. Nesting ecology of Canada geese in the Hudson Bay lowlands of Ontario: evolution and population regulation. Fish and Wildl. Res. Rep. No. 98. Ontario Ministry of Natural Resources. 77 p.

Reeves, H. M., F. G. Cooch, and R. E. Munro. 1976. Monitoring Arctic habitat and goose production by satellite imagery. J. Wildl. Mgmt. 40(3):532-541.

Ryder, J. P. 1967. The breeding biology of Ross' goose in the Perry River region, Northwest Territories. Can. Wildl. Serv. Rep. Ser. 3. 56 p.

_____. 1970. A possible factor in the evolution of clutch size in Ross' goose. Wilson Bull. 82(1):5-13.

Uspenski, S. M. 1965. The geese of Wrangel Island. Wildfowl 16: 126-129.

Wetland Inventory and Condition Evaluation Techniques [1]

Norman E.G. Roller
John E. Colwell[2]

Abstract.--Two techniques for obtaining quantitative wetland inventory information from remote sensing data are discussed. The first technique discussed is a "digital" photointerpretation procedure for detecting changes in wetlands and identifying their causes. The second technique described is a computer model that evaluates waterfowl habitat and assigns to it a numerical habitat quality rating, based on the relative abundance and arrangement of water and surrounding vegetation types that provide food and cover.

INTRODUCTION

In the face of increasing competition for undeveloped land, the Federal and state governments have recognized the need to provide wetlands with the protection and environmentally sound management they deserve. Before the programs designed to carry out this policy can be effectively implemented, however, a great deal of baseline inventory data about wetlands must be collected or updated. Remote sensing is potentially one of the most valuable tools available for accomplishing this task because it provides a practical way of (1) collecting the large volumes of data required and (2) reducing it to information, in a period of time short enough for the information to still be relevant to decision making.

The basis of the cost-effectiveness of remote sensing lies in the fact that its special advantages substantially reduce the amount of field work required to conduct a wetlands inventory (Roller, 1977). Reducing the proportion of total inventory effort taken up by field work is beneficial because field work is typically the most expensive and time consuming activity associated with an inventory of natural resources. Reducing the amount of field work required in connection with a wetlands inventory is of particular value, however, because wetlands are some of the most difficult environments in which to do survey work. The obvious reasons that wetlands are hard to work in are (1) their poor trafficability, (2) their general lack of topography which prevents obtaining any overview of an area, and (3) large amounts of dense and frequently tall vegetation. An additional factor which compounds the difficulty of the inventory task is that many types of wetlands are floristically very dynamic, so that actually several surveys must be carried out (either seasonally or annually) to obtain an accurate portrait of their vegetative composition.

CHANGE DETECTION

Determining the factors responsible for changes in or losses of wetlands is difficult without knowledge of historical conditions. ERIM has found that a "digital" technique for evaluating change in wetland conditions based on the comparison of current and historical aerial photography is a very useful and low-cost way to obtain the quantitative data needed to evaluate trends in habitat quality, as well as the impact of various land use and management practices on wetlands.

The change detection technique described is based on vegetation cover type information derived from aerial photography and "digitized" by overlaying a grid on air photos and labelling

---

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

[2] Research Associate and Associate Research Scientist, respectively, Environmental Research Institute of Michigan, P.O. Box 8618, Ann Arbor, Michigan 48107

the vegetation observed in each cell with a code. Placement of the grid on the aerial photos is determined by the placement of a similar grid on a geometrically correct basemap. This insures knowing the exact location of each grid cell. This step is also necessary to insure that cellular information for two different dates extracted from different sets of air photos will be equivalent.

Adequate photo interpretation can usually be done with equipment as simple as a light box and a 8 or 10 X magnifier, and thus could be done without large capital outlays. Recording the cell identifications is speeded up by using two persons, one to classify the data and one to code it.* The coded data can be stored in tabular form or in a computer data base. Identification of changes in cover types between dates is then accomplished by comparing the classifications of each cell for each date. For more information on the practical aspects of using this technique see Istvan and Bondy (1977).

An example of the application of this technique is provided by a brief description of how it was used in the preparation of an environmental impact statement for St. John's Marsh, Michigan.

The State of Michigan has long wished to acquire a 1260 hectare area known as St. John's Marsh, located on Lake St. Clair at the mouth of the St. Clair River, for the purpose of preserving it as a state wildlife refuge. The area is unique in that it is the last large block of privately owned marsh remaining along the southeastern Michigan shoreline. Biologists consider it important for its role in fish propagation. Furthermore, the marsh is located along a major waterfowl flyway that is used by canvasbacks (Aythya valisineria) and other diving ducks. This makes the marsh important from a conservation and recreation standpoint.

Public acquisition of St. John's Marsh would eliminate the threat of a continuing loss of marshland to residential development and the accompanying pollution that has been observed in recent years. However, the achievement of this goal will require the estimated expenditure of over $4 million in public funds. To obtain these funds the Michigan Department of Natural Resources (DNR) has had to prepare an environmental impact assessment of the proposed purchase, including an estimate of what the consequences will be if the marsh is not acquired.

To determine the consequences of continued private ownership of the marsh, the change detection procedure described above was used to document the changes that occurred in the marsh over the past 36 years. Black and white, 1:20,000 ASCS and DNR air photos for the years 1938 and 1974 served as the data source (see Figure 1). The results of this study showed that a total of 33% (127 ha.) of the permanent wetlands in the area have been lost (53% to residential construction, 25% to shoreline erosion, another 14% to canalization, 7% to dredge spoil dumping, and 1% to marina construction). (Roller, 1976). The list of recent applications for permits to dredge and fill sites for additional residential dwellings confirms that this trend will continue.

The summary statistics for the change detection analysis (Table 1) revealed yet another interesting fact: in spite of the destruction of some wetlands by development, more wetlands currently exist in the area than were present in 1938.

Table 1.--Change detection summary for St. John's Marsh, St. Clair County, Michigan (in ha/%).

Land Use or Cover Type	Situation in 1938	Situation in 1974	Change
Urban/Built-up	127/6	321/14	+194/+8
Recreational	59/3	6/1	-53/-3
Agricultural	824/36	431/19	-392/-17
Idle/Pasture	594/26	236/10	-357/-16
Forested	245/11	365/16	+120/+5
Waterways	21/1	109/5	+88/+4
Wetlands	388/17	789/35	+401/+18
TOTAL	2257/100	2257/100	---

The explanation for these seemingly contradictory latter results is that the Great Lakes were at the peak of a high water cycle in 1974. The effect of this cycle is to create a zone of transient wetlands that encroach upon and retreat from the shoreline, in concert with the lake level. This zone is unsuitable for residential development, but it has considerable ecological value if left in its natural state.

ERIM was able to identify this zone for the Michigan DNR by the following analysis. The year 1938 is the record low water level

*More sophisticated procedures are also possible with more expensive equipment.

1938

1974

FIGURE 1. LOSS OF WETLANDS IN SOUTHEASTERN MICHIGAN CAUSED BY RESIDENTIAL CONSTRUCTION AND CANALIZATION OVER 36 YEARS.

year for the Great Lakes. Thus, areas that were wetlands as observed in the 1938 photography can be considered permanent wetlands, i.e., wetlands regardless of lake level. The year 1974 is close to the record high water level year of 1976 for the Great Lakes, and the location of wetlands as shown on the 1974 photography documents their maximum extent. To then define the zone of transient wetlands, we mapped all those cells that were wetland in 1974, but not in 1938. Cells which were wetlands at both dates were classified as permanent wetlands. Figure 2 shows the distribution of permanent and transient wetlands in St. John's Marsh and the areas lost to development.

Based on these findings and other data, the DNR has already denied a permit to begin construction of additional residential housing in an effort to protect the marsh until the funds to purchase it can be allocated.

WATERFOWL HABITAT QUALITY MODELING

Waterfowl habitat quality is a function of both water conditions and the terrain characteristics of the surrounding landscape. We have attempted to quantify these relationships and develop a formal model which uses cover type information as input, and provides an objective, numerical evaluation of habitat quality as output. The advantages of such a model, which combines remote sensing and computer technology to generate habitat quality ratings, is that it makes possible the rapid,objective inventory of large areas.

The model has been developed for the U.S. Fish and Wildlife Service using Landsat data over areas with both good and poor habitat quality in North Dakota.

Model Description

The habitat quality model actually consists of two submodels, one that evaluates water conditions of the habitat and another which evalues its vegetation cover. These two submodels will be discussed in turn, and then the manner in which they are integrated will be indicated.

Water Conditions Submodel

The water conditions submodel has been designed to take into account the following factors which are important to waterfowl: pond numbers (PNF), pond area (PAF), and pond size class distribution (PSF). In practice each of these parameters is calculated by computer for each habitat unit from remote sensing data in digital format. The results of these calculations are then evaluated by the model and a factor value assigned. For example, the literature suggests that 10 or more ponds per section is optimal for mallard ducks in North Dakota. Based on the number of ponds actually found in a section, a value is then assigned to the section for the PNF or pond number variable in the model.

Integrated Pond Factor (IPF).--A factor indicating the relative integrated quality of all pond conditions (on a scale from 0 to 1) was calculated from the individual water factors by use of the relationship

$$IPF = PNF\ (.67\ PAF + .33\ PSF)$$

The pond number factor was made multiplicative to indicate that the number of ponds is the most important factor in the submodel, and that without ponds the water quality rating goes to zero (as do all the individual factors). Of the remaining two factors PAF was considered twice as important as PSF. The weighting coefficients allow the term in parentheses to achieve a value of 1.0 if both PAF and PSF are valued 1.0.

Terrain Factors Submodel

The presence of water bodies is only a partial indicator of waterfowl habitat quality. Other terrain features are also important. For example, the presence of upland cover has long been known to be essential to good waterfowl habitat. In addition, the spatial arrangement of the various components of habitat, which affects their interspersion and juxtaposition, is known to be important. In this section we describe how such terrain information is incorporated into our model for evaluating waterfowl habitat quality. For this discussion we have chosen to greatly simplify and generalize upon habitat relations in order that the concept we are illustrating not be lost.

The terrain factors submodel evaluates the presence of cover types and their spatial arrangement. Although the factors could have been considered separately, we incorporate presence and spatial arrangement into a single factor represented by the amount of edge between desirable terrain types.

The individual components (scene classes) considered in our North Dakota duck habitat model were:

1) OW = open water
2) WL = wetland vegetation
3) COV = upland cover (hay, grasses and pasture)

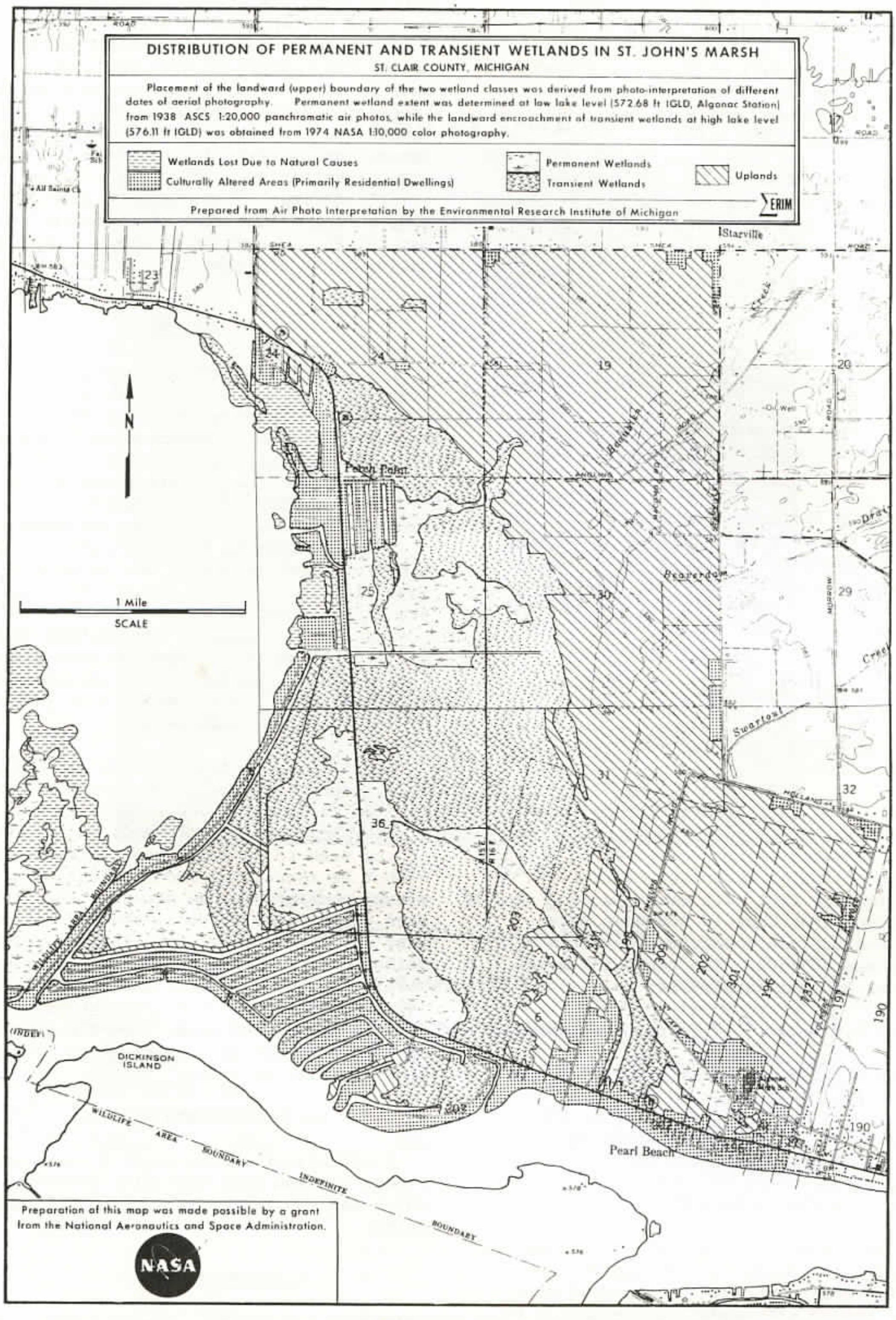

DISTRIBUTION OF PERMANENT AND TRANSIENT WETLANDS IN ST. JOHN'S MARSH
ST. CLAIR COUNTY, MICHIGAN
Placement of the landward (upper) boundary of the two wetland classes was derived from photo-interpretation of different dates of aerial photography. Permanent wetland extent was determined at low lake level (572.68 ft IGLD, Algonac Station) from 1938 ASCS 1:20,000 panchromatic air photos, while the landward encroachment of transient wetlands at high lake level (576.11 ft IGLD) was obtained from 1974 NASA 1:10,000 color photography.
Wetlands Lost Due to Natural Causes
Culturally Altered Areas (Primarily Residential Dwellings)
Permanent Wetlands
Transient Wetlands
Uplands
Prepared from Air Photo Interpretation by the Environmental Research Institute of Michigan
ERIM
Starville
Perch Point
Pearl Beach
DICKINSON ISLAND
1 Mile
SCALE
N
Preparation of this map was made possible by a grant from the National Aeronautics and Space Administration.
NASA

FIGURE 2.

4) AG = upland areas providing some cover during part of the year and possibly some food in the fall (small grains, row crops)
5) OTHER = upland areas providing no particular value to waterfowl (e.g., bare soil)

The edges considered, and their assumed relative importance, based partially on literature review and on an analysis of good and poor quality habitat, are:

1) OW/WL 1.0
2) WL/COV 0.8
3) OW/COV 0.7
4) OW/AG 0.5
5) WL/AG 0.3
6) COV/AG 0.2

It is assumed that edges including OTHER have no value since there is no advantage to waterfowl in crossing such a boundary.

The terrain factor submodel was computed as the sum of the weighted proportions of all the edges considered, normalized to the average amount of useful edge in sections considered to be good habitat. Specifically, the terrain factor submodel form is:

$$TF = \frac{1.0\ OW/WL + .8\ WL/COV + .7\ OW/COV + .5\ OW/AG + .3\ WL/AG + .2\ COV/AG}{\text{Average Total Edge of Good Habitat/Habitat Unit}}$$

Integration of Water Condition and Terrain Factors Submodels

The output of the terrain factors submodel was subsequently additively combined with the results of the water factors submodel to obtain an integrated value of waterfowl habitat quality. Since we feel that water is an essential ingredient that is somewhat more important than terrain conditions we weighted the two factors 60%/40%. The resulting model for waterfowl habitat quality is:

$$WHQ = [.6\ \text{Water} + .4\ \text{Terrain}] \times 100$$

$$= 60\ [PNF(.67\ PAF + .33\ PSF)] + 40\ [TF]$$

Using sections of habitat identified by FWS as examples of good, intermediate and poor habitat to calibrate the model, the final output of the main model was scaled to generate ratings from 0 to 100.

Since we are evaluating habitat quality on a per unit area basis in relation to the activity of breeding ducks, the physical size of the unit should correspond approximately to the pair's home range. For some waterfowl, (e.g., mallards) home range is approximately 1 mi^2 in extent, resembling a section. Furthermore, the study area is gridded into sections on topographic maps. We, therefore, found it convenient and reasonable to demonstrate the concept of waterfowl habitat quality by generating ratings on a section-by-section basis. Although this procedure imposes an artificial grid system on the natural characteristics of the study area, it also characterizes habitat on the basis of readily definable land ownership and management units, a significant advantage. Ultimately, some averaging of the section-by-section ratings over a larger unit of area may prove desirable.

RESULTS

The above model was implemented over a study area in North Dakota for the U.S. Fish and Wildlife Service, Northern Prairie Research Station. Habitat quality ratings were generated for 3 townships, a total of 108 sections. The results produced for one of the townships is shown in Figure 3. This area is particularly interesting because it contains a large block of agricultural land in the upper right, and an area of natural prairie in the lower left. The prairie area is, of course, better duck habitat, and in general the ratings indicate this, being overall higher in this region. It also shows, however, that considerable variability in habitat quality is indicated in the prairie region as well.

The habitat quality ratings in this study were generated using categorized Landsat data as input. For other applications, where greater spatial resolution is required because of the need to consider scene classes that cannot be identified from Landsat data, aerial photography can serve as the data base. When photography is used, the information must be digitized before using the model. A method can be used like the one described earlier in this paper to generate digital input for the model from photography. It is important to remember that the model can be used with any type of map base data as long as it is in digital format.

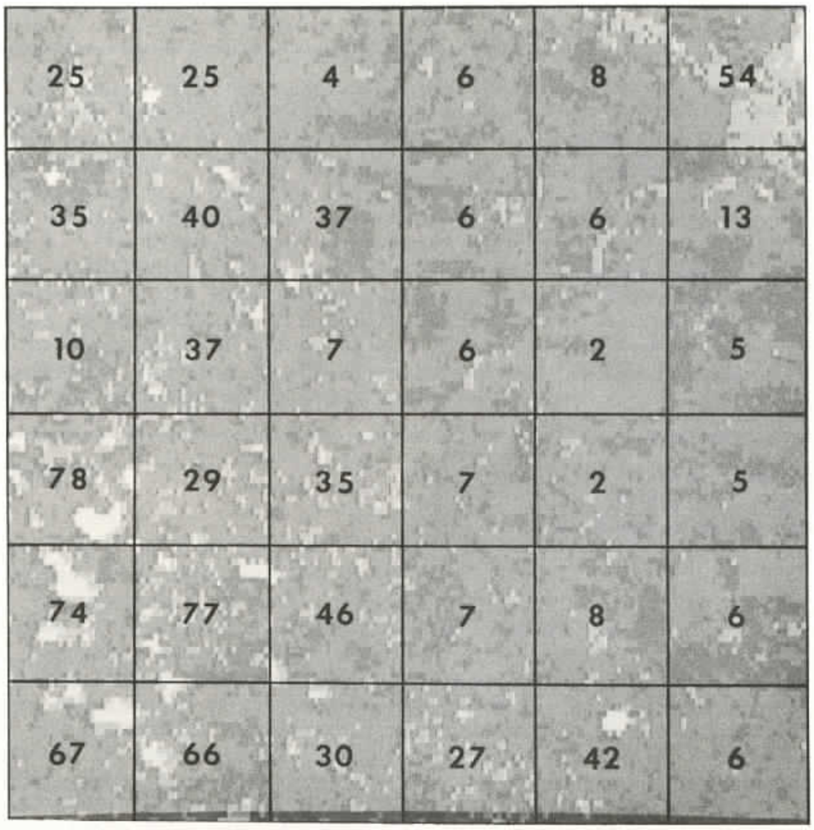
CONCLUSION

A variety of remote sensing techniques and remote sensing data analysis techniques exist which can contribute to wetland information needs.

LITERATURE CITED

Roller, N.E.G., 1977. Remote sensing of wetlands, ERIM Report 193400-14-T. Environmental Research Institute of Michigan, Ann Arbor, Michigan, 156 p.

WATERFOWL HABITAT QUALITY RATINGS



T 144N, R67W
Stutsman Co., North Dakota
Condition: Transitional Habitat

LEGEND

- **Blue-** Open Water
- **Magenta -** Wetlands
- **Light Green -** Cover
- **Dark Green -** Agriculture
- **Yellow -** Other

RATING SYSTEM

0 Poor Habitat

↕

100 Good Habitat

SECTION NO.'s

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

FIGURE 3. WATERFOWL HABITAT RATINGS

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

Roller, N.E.G., 1976. Changes in the wetlands and land-use patterns of St. John's Marsh, St. Clair County, Michigan. ERIM Report 193400-11-T, Environmental Research Institute of Michigan, Ann Arbor, Michigan, 7 p.

Assessment of Humpback Whale (Megaptera novaeangliae) Stocks Using Vertical Photographs [1]

Gerald P. Scott and Howard E. Winn[2]

Abstract.--Vertical photographic sampling was conducted to test the utility of different films and scales and to determine the depth of discrimination of M. novaeangliae for stock assessment. Of the films and scales tested, FE3432 (Kodak) taken at a scale of 1:21,000 proved to be optimal. Depth of discrimination at 1:17,000 was found to be in excess of 20 m. The distribution of humpback pods was found not to differ significantly from that expected from a random distribution model. Pod size averaged 1.91 (s = 1.66) individuals, leading to an estimate of 0.311 ±0.069 (95% C.I.) whales/km^2 for the upper half of Silver Bank. In conclusion, vertical photographic sampling was found to be a rapid, cost-effective method for humpback whale stock assessment.

INTRODUCTION

Sighting data gathered from a variety of platforms and using different techniques have been used to estimate the abundance of cetacean stocks. In the case of protected species such as the humpback, Megaptera novaeangliae, sighting and, to a limited degree, acoustic data (after Winn, Edel, and Taruski 1975) are all that is available for estimating the present stock size. Although in some special cases like the California gray whale (Eschrichtius robustus) where land-based counts can be made (Rice 1961, Rice and Wolman 1971), the general approach to estimating stock abundance of protected and noncommercial species has been the use of shipboard and aerial procedures.

Recently, aerial surveys have become common in marine mammal sampling programs mainly because aerial procedures are more cost-effective than comparable shipboard operations (see Leatherwood, Gilbert, and Chapman 1978 for a short review). However, vertical photography has received only limited usage for sampling marine mammal populations. Heyland (1974) has used vertical photos to census a herd of beluga whales (Delphinapterus leucas) at Cunningham Inlet, N.W.T. And Dohl (1975) studied the utility of vertical photos for delphinid herd identification and census in the Pacific.

The use of vertical photographs for sampling cetacean stocks offers several advantages over aerial-visual methods including: 1) providing a permanent record of each encounter, 2) allowing for accurate calculations of the total area sampled, and 3) offering a base from which other analyses may be conducted such as length-frequency, morphometric, and behavioral measures (Heyland 1974). The intent of this study was to develop a useful sampling procedure for humpback whale stocks in the western north Atlantic using vertical photographs.

In the western north Atlantic, humpbacks annually migrate to the Caribbean to mate and calve during the winter months. While in the Caribbean these animals are found on specific breeding banks, generally between the 10 and 100 fathom marks (Townsend 1935, Winn et al. 1975). Winn et al. (1975) made a series of shipboard censuses for humpbacks throughout the Caribbean and found 754 of an estimated total of 1018 animals to inhabit Silver Bank at the end of the Bahamian archipelago (fig. 1).

The western north Atlantic population of humpbacks is characterized by their long (up to 5 m in a 15 m animal), white pectoral flippers which tend to make them highly visible underwater. Aerial sampling takes advantage of this fact and allows for the censusing of animals both above and below the surface. Aerial surveys were made over Silver and Navidad Banks

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

[2]Graduate School of Oceanography, University of Rhode Island, Kingston, RI 02881.

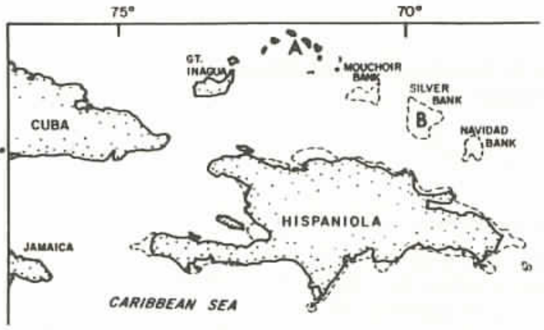


Figure 1.--The study area. The sampling survey was conducted from a land-base of South Caicos, Turks and Caicos Islands (A). Silver Bank (B) was found by Winn et al.(1975) to have the highest concentration of humpbacks in the West Indies and was the target for aerial sampling. The test survey was conducted from Puerto Plata, Dominican Republic (along the north coast of Hispaniola).

using various film types and photographic scale combinations.

MATERIALS AND METHODS

Two sampling surveys and one test survey were conducted over Silver and Navidad Banks, West Indies (fig. 1). The sampling flights were made from a land-base of South Caicos on February 26 and 27, 1976, between 0730 and 1230, local time. The test flight initiated from Puerto Plata, Dominican Republic, on 1 March, 1978, and was conducted from 1430 to 1545.

Aerial Platforms

Two specially modified aircraft were used for these flights. One, a twin engine Piper Apache, was used as the sampling survey platform; the other, a Cessna 337-G Skymaster, was the test survey platform. Both aircraft, owned and operated by Aero-Marine Surveys of New London, Conn., were fitted with twin Hasselblad MK-70 cameras for vertical imagery. In the Piper, the cameras were mounted behind the pilot's seat on a stable platform that could be leveled using a manually operated spirit leveling system. This insured that each frame was exposed in a plane parallel to the average ocean surface (fig. 2). In the Skymaster, the cameras were mounted under the starboard front seat. This configuration did not permit the operator to level the camera system in-flight. A third camera (Hasselblad 500EL) was used to record flight data used for photogeometric calculations from a panel placed behind the rear observation seats. This camera was synchronized with the vertical cluster. The data recorded included altitude, heading, speed, real and elapsed time, and frame number.

Each vertical camera was equipped with a calibrated 61 mm Biogon lens and Reseau grid and a standard size 70 mm magazine. Approximately 100 frames per camera could be exposed before the film required changing. The cameras were fired simultaneously and at a constant interval for the sampling surveys, but manually for the test survey.

Films and Scales

Four film types were used in the surveys (all Kodak). These were: 1) 2420, Plus-X, black and white negative film; 2) FE3432, minus red, color transparency film (water penetrating film); 3) 2445, color negative film; and 4) MS 2448, color positive film. Only two film types were used in the 1978 test survey vertical cameras: FE3432 and MS2448. The data camera in the test survey used Plus-X film. Additionally, MS2448 was used only in the test survey.

In the 1976 sampling survey, films were exposed at altitudes of 3050, 1275, and 550 m (scales of approximately 1:50,000, 1:21,000, and 1:9,000). The 1978 test survey was flown at an altitude of 1040 m (an approximate scale of 1:17,000). All flights were made at a standard speed of 120 knots.

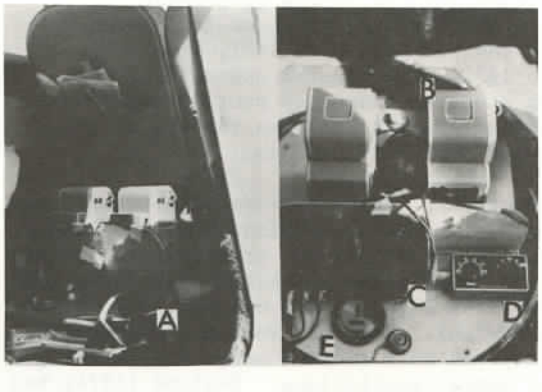


Figure 2.-- The vertical camera cluster. For the sampling survey, the cameras were mounted on a stable platform directly behind the pilot's seat (A). The MK-70 cameras (B) were equipped with standard magazines (4.6 m film rolls). The view screen (C) allowed the operator to observe the photographic field. The attached intervalometer (D) was used for automatic exposures and the cluster was leveled with the spirit level system (E).

Sampling Survey

The sampling survey was conducted over Silver Bank. Multiple tracks were flown at each altitude (fig. 3) and different combinations of film types were used to test their relative resolving power at different scales. Two sampling schemes were used in the survey. Photographs were generated automatically and the intervalometer was used to produce either overlapping or non-over-lapping photos. Overlapping photos resulted in a strip sample running the length of the transect across the bank. Non-overlapping photos resulted in quadrat samples systematically taken along the track line. Strip sampling was conducted only at 1275 m.

Test Survey

The test survey was completed on Navidad Bank by lowering an "artificial flipper" constructed of dacron sail material bound to a 1.2 x 3.6 m PVC pipe frame (fig.4) from shipboard to controlled depths of 2.5, 10, 20, 25, and 30 m. The aircraft made two overhead photographic passes for each depth. Lowering of the flipper was achieved by allowing the negatively buoyant apparatus to descend to the above depths, suspended by lengths of 0.8 cm diameter nylon lines equal to the control depths and buoyed to the surface with 0.6 m ball floats. Snorkel divers attended the flipper and added lengths of premeasured line to adjust the depth. The shipboard platform for the test survey operations was the R/V Westward, a 38 m (125 ft) staysail schooner operated by the Sea Education Association (SEA) of Woods Hole, Mass. The photographic overflights were made at an altitude of 1040 m (1:17,000).

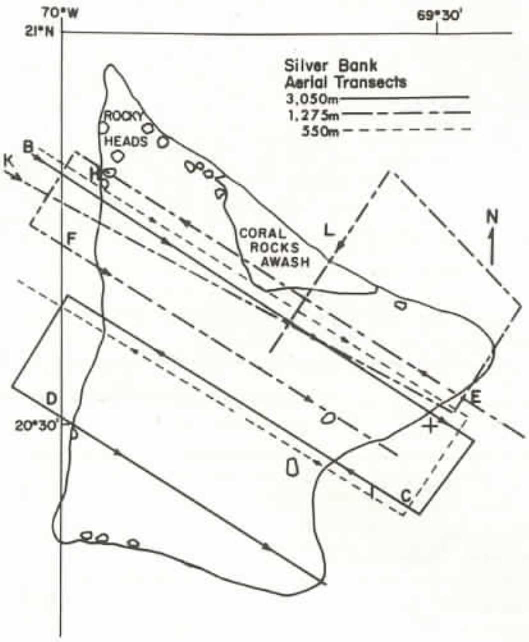


Figure 3.--Sampling survey aerial tracks over Silver Bank. Transects K and L were flown on 27 February, all other transects were flown on 26 February, 1976.

Figure 4.--The "artificial flipper" used to determine the depth of discrimination for humpback whales. Here the 3.6 x 1.2 m flipper is being lowered over the side of the R/V Westward prior to the tests.

Film Analysis

The films were analyzed using a light box and variable power 7-30X Bausch and Lomb stereoscope apparatus as depicted in figure 5, a modification of the apparatus suggested by Heyland (1974). A 10X magnification was used for examination of the frames. At this magnification, four passes were required to examine the entire frame. Higher magnifications were used to closely examine actual and questionable whales. Each film roll was independently analyzed for individual whales and pods (groups) of individuals three times. Results of the analyses were then compared and inconsistencies were resolved. Comparisons were then made between simultaneously exposed film types.

Estimation of Abundance

Individuals and groups (pods) data from the 1275 m transects were first fitted to the negative exponential (clumped) and Poisson (random) distribution models. The fits were tested with the chi-square and variance-to-mean ratio test (Elliott 1971). A random pair-

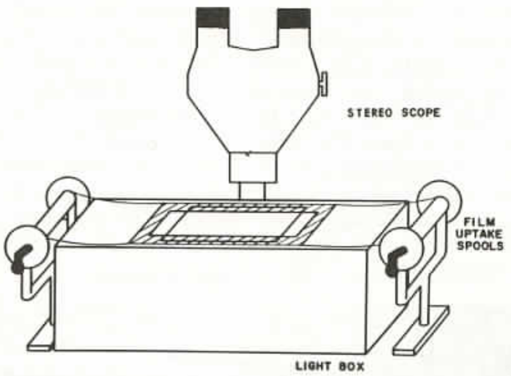


Figure 5.--The film analysis apparatus. A Bausch and Lomb zoom stereoscope, light box and film reels were used to examine the vertical photographs.

ing of quadrats test due to Goodall (1974) was also used to examine the groups data for pattern. Mean group size was determined by pooling the available data. In this paper, a group (or pod) is defined as any single individual in a frame or any combination of individuals in close proximity to each other.

Pod number, pod density, total number, and total density of individual whales estimates were made as follows (after Seber, 1973). Define:

G = total number of pods,
A = stock area,
$D_g = G/A$, the average pod density,
pA= area sampled,
and n_g= number of pods observed.

Estimating:

$$\hat{G} = n_g/p = x_g \cdot L \qquad (1)$$

where x_g is the average number of groups per sampling unit and L is the potential number of sampling units per stock area, A. The variance of G is estimated by:

$$s_{\hat{G}}^2 = L^2 \cdot v/l(1 - l/L) \qquad (2)$$

where l represents the number of samples of equal size made. The value of v is given by:

$$v = \sum_1^t (x_{gi} - x_g)^2/(l - 1) \qquad (3)$$

noting that x_{gi} is the number of groups observed in the ith sampling unit. Confidence intervals were constructed:

$$\hat{G} \pm (t_{l-1}, \alpha/2)s_G \qquad (4)$$

A similar interval about the groups density, D_g, was achieved by dividing equation (4) by A.

Estimation of the number of individuals and individual density follows by multiplication with mean group size, g.

$$\hat{N} = \hat{G} \cdot \hat{g} \qquad (5)$$

Where N is the total number of individual whales with a variance estimate

$$s_{\hat{N}}^2 = s_{\hat{G}}^2 + s_g^2 + 2\text{cov}(\hat{G},\hat{g}) \qquad (6)$$

after Goodman (1960). The covariance term was calculated using the pooled 1275 m data for group size and group number.

Confidence intervals about N were then calculated as in (4) and, similarly, individual density estimates were made.

RESULTS AND DISCUSSION

Films and Scales

Of the three film types tested in the sampling survey, water penetrating film (FE3432) provided the most consistently interpretable images. Whales were seen under the surface a higher percentage of time in water penetrating frames than in either of the two simultaneously run film types (see table 1). In most cases, water penetrating film provided the actual count per frame. A fact which greatly aids image interpretation on this film is that the frames are positive transparencies. Thus, unlike either Plus-X or 2445, images on the film closely approximate those which are seen by the human eye. In all but one case the water penetration film proved superior to the other films used.

Table 1.--Film combinations and interpretation results for the sampling survey at 1275 m (1:21,000)

Track	Film[1]	WHALES Total	UW	%UW
E	FE3432	16	5	31.2
E	2402	14[2]	1	7.7
F	FE3432	7	4	57.1
F	2402	4[2]	0	0
K	FE3432	14	6	42.8
K	2445	10	2	20.0
L	2445	12	2	16.7

[1]Films are: FE3432 (water penetration), 2402 (Plus-X), and 2445 (color negative).
[2]These data include false images interpreted as whales.

The color negative film (2445) had a quality which aided in image interpretation. In these frames, the animals' flippers stood out as purple V's. When there was a great deal of surface glare or water churned by the activities of several animals at the surface, the animals were still identifiable. In one case when color negative was run simultaneously with the water penetration film, three animals were resolved in the color negative frame while only two were seen in the FE3432. One animal, a calf, was hidden in the surface wash and only its purple flippers were visible in the color negative film. However, this feature of type 2445 was found to improve interpretability over FE3432 in only a few special circumstances.

Plus-X film (2402) was found inferior to both water penetration and color negative films. In fact, several times misinterpretation of surface images was made with this film. Water patterns on the surface were sometimes mistaken for animals where, after examining the frames of the simultaneously run film type, there proved to be none. However, Plus-X has the distinct advantage of providing an inexpensive source of enlargements for other analyses (for example, linear measurements on animals for length frequency or morphometric studies).

In the test survey, water penetration and aerial Ektachrome (MS2448) films were directly compared. The water penetrating capabilities of both films was determined with the artificial flipper (discussed later). The aerial Ektachrome was found to equal the water penetrating capabilities of type FE3432. Additionally, the ektachrome is also a positive transparency film and thus, was found to be a suitable substitute for FE3432 (now unavailable). These results concur with those of Dohl (1975) who concluded that ektachrome was equal to, if not better than water penetration film for delphinid stock assessment in the Pacific. Heyland (1972) also found Aero-Ektachrome to be of high quality for censuses of Greater Snow Geese (Anser caerulescens atlantica) flocks along the St. Lawrence River.

Tracks flown at an altitude of 3050 m yielded a photo scale of 1:50,000 and each frame covered 6.75 km^2. However, a 15 m object (the maximum size for humpbacks) has an effective image size of only 3 mm at a 10X magnification. Upon initial analysis, this scale was found too small for accurate interpretation of humpback whales and thus, the 3050 m transects were deleted from further analysis. Photos taken at an altitude of 1275 m (1:21,000) covered approximately 1.08 km^2 per frame. A 15 m animal has an effective image size of 7mm at this scale. In frames taken at this scale, adult animals became clearly visible and, with close examination, calves could be discriminated. At an altitude of 550 m (1:9,000) each frame covered approximately 0.22 km^2 and a 15 m animal has an effective image size of 16 mm. All size animals were plainly visible at this scale.

There is an obvious trade-off between area of coverage and image resolution that one must consider. Of the scales tested in the sampling survey, imagery at 1:21,000 was found to "optimize" the trade-off. According to Greig-Smith (1964), one rule of thumb for selecting sampling unit size states that there should be no more units with zero animals than units with just one individual. At 1:50,000, no animals were observed since whales could not be discriminated from whitecaps or other false images. At 1:21,000, no animals were observed in 101 of 123 frames (approximately 82%) and the maximum count per frame was 10 individuals in a single pod; three pods in a single frame was the maximum observed. At 1:9,000, no whales were seen in 71 of 79 frames (approximately 90%). The maximum number of whales observed per frame was four and no more than one pod/frame was seen at 1:9,000. Clearly, at no scale for which animals could be resolved were there at least 50% of the frames with one or more individuals.

However, at 1:21,000, single frames were found to contain multiple pods. Additionally, each pod observed was compact and in no case was a pod cut through by the edge of the frame. In this case, sampling unit area has no effect on the analysis of the distribution of individual whales (Pielou 1977). Thus, the Greig-Smith rule of thumb may be disregarded. But the size of a sampling unit may have an influence on the analysis of the distribution of whale pods. A contiguous quadrats test is required for pod distribution analysis.

Overlapping photos were found to offer two advantages over nonoverlapping photos: they 1) increased the efficiency of the survey since more area was sampled per unit of flying time and 2) reduced the effects of glare. The amount of overlap can be adjusted so that areas obliterated by glare in one frame are relatively glare-free in the next, thus increasing the effective amount of area covered in the survey procedure.

Test Survey

Positive identification of whales in frames of the vertical photographs was primarily based on the observation of the general outline of the animal. Usually the white flippers were the first indication of an animal's presence on a frame, although observation of a flipper by itself was not sufficient for positive identification. The flippers tend to stand out in the photographs because of their characteristic shape and coloration.

The test survey was flown at an altitude of 1040 m (1:17,000). In the 1978 survey effort, both visual and photographic sampling techniques were employed[3]. Therefore, the survey was flown at 1040 m to better accommodate the visual sampling. Analysis of the test survey photos demonstrated that the humpback flipper model could be plainly discriminated at depths of 2.5, 10, and 20 m at a scale of 1:17,000. At a depth of 25 m, the model no longer had the distinctive appearance of a flipper, but was visible as an amorphous white mass below the surface. The actual maximum depth of discrimination for the model lies between the 20 and 25 m depth levels. Discrimination of the flipper model at a photographic scale of 1:21,000 was not tested. However, if loss of depth discrimination with respect to scale is assumed to be a linear function, then the actual maximum depth of discrimination at 1:21,000 must lie between 16 and 20 m.

It is not known to what depths humpbacks usually dive or how the population as a whole is distributed throughout the water column. However, SCUBA observations of animals on Silver and Navidad Banks show that although some animals dive to the bottom, in general they tend to remain in the upper half of the water column (R. Edel personal communication)[4]. The maximum charted depth for Silver Bank is 43.9 m. However, the area of the bank over which the 1275 m transects were restricted averages only 27 m in depth. It is likely that few animals were missed because they were beyond the depth of discrimination in the 1275 m transects.

Estimation of Abundance

Silver Bank was determined to have a total area of 2903 km^2 by Winn et al. (1975). The 1275 m transects were restricted in coverage to the northern half of the bank (area, A, of 1544 km^2) and thus stratified. The distribution of individual whales and whale pods is presented in figure 6. For the purposes of the analyses of spatial pattern and estimation of variances, tracks K and L were partitioned into 63 sampling units, equal in size to those in tracks E and F. A frequency table using the pooled individuals data was constructed and the data were then fit to the Poisson (random) and negative binomial (clumped) distribution models. Results of these tests are presented in table 2. The distribution of whales in the sample was found to be in close agreement with the clumped model ($\chi^2 = 0.939$, 1 d.f.). Because individual whales were found to occur in

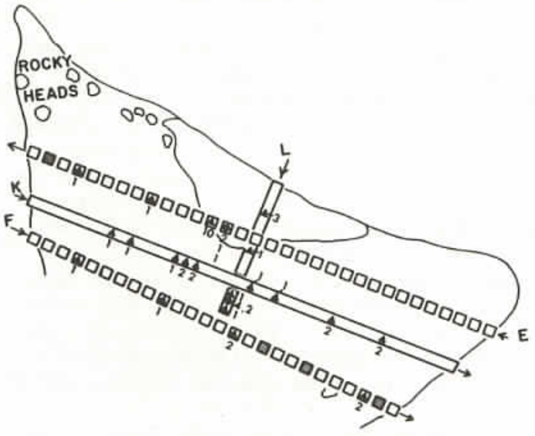


Figure 6.--The distribution of individual whales and whale pods in the 1275 m transects. Closed triangles represent a single pod; circles, two pods; and hexagons, three pods per frame. The number of individual whales per pod is listed. Stippled areas represent areas obliterated by cloud cover and not included in the analyses.

distinct groups or pods, the pooled whale pod data were then tested against the random (Poisson) distribution.

A large sample approximate test for the agreement with the Poisson was first conducted (after Elliott 1971). The average number of pods per sampling unit, x_g, was found to equal 0.2032, with a variance estimate, s^2_{xg}, of 0.2270. The index of dispersion, given as the ratio of variance to mean was 1.117. The computed value for d ($\sim N(0,1)$) of 0.99 was found to support the hypothesis that humpback whale pods were randomly distributed over the bank at an α of 0.05. However, since the analysis of true pattern is sometimes masked by the size of the sampling unit (see Pielou 1977, for example), a contiguous quadrat type test (Goodall 1974) was performed.

The test offered by Goodall (1974) requires one to randomly pair sampling units from a contiguous series (either grid or belt) and is an alternative to the more standard Greig-Smith

[3]The test survey was a part of a larger sampling effort sponsored by the Marine Mammal Commission and designed to compare aerial photographic and visual and shipboard visual survey methods for humpback whales.

[4]These observations have yet to be quantified.

Table 2.--Tests for agreement of the individuals data with the Poisson (random) and negative binomial (clumped) distributions[1]

Whales·Frame	Obs.	Pooled	Poisson Exp.	Poisson χ^2	Negative Binomial Exp.	Negative Binomial χ^2
0	101		83.85	3.463	101.14	0.0002
1	12		32.07	13.442	11.44	0.0274
2	6		6.12		4.67	
3	1					
4	1	10		1.307		0.9104
5	0					
6	1					
7	0	4	0.86		5.75	
8	0					
9	0					
10	1					
Totals	123		123	17.330[2]	123	0.9390[3]

[1]All data from the 1275 m tracks were pooled for this analysis, $\hat{n}$ (average number of individuals per frame) equals 0.382 with variance, $s^2_{\bar{n}}$, of 1.456. The negative binomial parameter, $\hat{k}$, was found to equal 0.1456 using the method of maximum likelihood.

[2]The chi-square value of 17.330 with one degree of freedom is significant at an α of 0.001.

[3]The chi-square value of 0.9390 with one degree of freedom is not significant at the α level of 0.05.

(1952) analysis. Since the data showed a high frequency of no pods in sampling units, the test was based on presence or absence of pods rather than their quantity per sampling unit. The null hypothesis states that the probability of the occurrence of one whale pod in a sampling unit is independent of the occurrence of a whale pod in a sampling unit spaced one unit apart (that is, the pods are distributed randomly with respect to one another). The alternative hypothesis in this case (spacing of one sampling unit) is the clumped model. Only tracks K and L were used for this test. The following results wre obtained:

	Observed	Expected
n_0	14	$14.44 = (1 - \theta)^2 N$
n_1	10	$9.12 = 2\theta(1 - \theta)N$
n_2	1	$1.45 = \theta^2 N$

where n_0 is the number of randomly paired units with no pods present, n_1 is the number of paired units in which only one unit has pod(s) present, and n_2 is the number of paired units in which both have pods present. The value of N (25 in this case) is the total number of randomly paired units and θ is estimated by: $(2n_2 + n_1)/N$. The binomial probability of observing one out of 25 random pairs with pods present in both sampling units by chance was determined to be greater than 0.73. The result of this test also supports the hypothesis that the pods of whales tend to be randomly distributed on the bank.

The random distribution of humpback whale pods seems inconsistent with the hypothesis of Winn and Winn (1978) who state that one possible function of the humpback song is that of a spacing mechanism. If this were the case, one would expect to find a regular distribution of pods rather than random. However, the characteristic song of this species is produced only by lone individuals who may be males (Winn and Winn 1978) and the data presented represent a pooling of all group sizes encountered. It is possible that a uniform distribution of lone males is masked by the otherwise random distribution of other pod sizes in the stock. Further analysis of larger samples are required to test the hypothesis.

In essence, the sampling procedures used were systematic in design. Systematic sampling tends to bias variance estimates so that confidence intervals are underestimated. However, since the pods distribution data were found to agree with the random distribution, this sampling procedure inputs no bias (see Freese 1962).

Humpback density was estimated with the pooled 1275 m data in order to improve the estimate of variance. A total of 31 pods of humpbacks were sampled at both 1275 and 550 m. The pods ranged in size from a single individual to a group of 10 whales with an average value of 1.91 (g) and variance (s_g^2) of 2.77. Twenty-five pods of whales were sampled in the 1275 m transects. The total area sampled (pA) was 129 km^2. Pod density, D_g, was estimated at 0.194 ± 0.069 (95% C.I.) whale pods/km^2. The density of individual whales on the bank was estimated at 0.311 ± 0.069 (95% C.I.).

Because sampling was restricted to the upper half of the bank, estimates of the number of whales present can only legitimately be made for that area. Thus, the number of whales on the northern half of Silver Bank was determined to range from 405 - 618.

Winn et al. (1975) estimated the density of humpbacks on Silver Bank at 0.260 whales/km^2 in 1973. In fact, the present estimate is not statistically different from that of Winn et al. (1975) at an α level of 0.05. Although the census method used by Winn et al. (1975) was different (a shipboard procedure) the estimates are reasonably close. It is possible that the level of whales on Silver Bank has been relatively constant over the three years between the sampling surveys, indicating a steady-state level in abundance. However, present estimates for the maximal rate of population increase for this species average 5% per year (ACMRR 1976) which projects the expected density to

0.302 whales/km^2 for 1976. The precision of present estimates will not permit the detection of such a small increase. We would require many more years between surveys to detect an increase. An alternate approach to this problem would require a series of estimates for trend analysis.

Presently, no such series exists. The stock of humpbacks on Silver Bank and other stocks around the world have been studied by a large number of investigators recently. However, censusing techniques have been as varied as have been the investigators. Standardization of technique and comparisons of the various methods are required before estimates made can be directly compared.

The relative cost (in both effort and dollars) of this method as compared to shipboard sampling operations was found to be on the order of one-third to one-quarter. The shipboard estimates of Winn et al. (1975) required a minimum of five days (including transit to and from a land base) to complete three transects on Silver Bank. The aerial sampling method described here required only two days to complete including multiple transects made at different altitudes. In a concentrated effort of one day, one could produce 10 or more strip samples across the bank. The effectiveness of the vertical photographic method compared to the visual shipboard method is unknown since no direct comparisons have been made. However, the present estimate was found not to be statistically different from that of Winn et al. (1975). Therefore, it is not unreasonable to assume that this method is at least as accurate for estimating humpback whale abundance. It must be noted that the utility of this sampling method is restricted to relatively small areas of high whale density such as Silver and Navidad Banks or Cunningham Inlet, N.W.T. (after Heyland 1974). Aerial-visual or shipboard precedures would certainly prove more cost-effective than the photographic strip method in large areas with low whale densities.

CONCLUSIONS AND RECOMMENDATIONS

The vertical photographic sampling method considered "optimal" for the stock of humpback whales on Silver Bank is as follows: strip sampling at a scale of 1:21,000 using water penetration (FE3432) and Plus-X (2402) in the vertical cameras. Because type FE3432 is no longer available aerial Ektachrome was found to be a suitable substitute and should be used. In future efforts using this technique single strips, rather than single frames, should be considered sampling units in order to increase the precision of estimates. Strips of unequal length may be treated using a modified ratio of means estimator of density (after Estes and Gilbert, 1978).

The vertical photographic sampling method is a rapid and cost-effective alternative to shipboard procedures. In addition to the potential as a powerful censusing procedure, this method offers other information which is not available to those on shipboard. The aerial method is relatively instantaneous and thus provides a picture of how animals are distributed around the bank at any one point in time and, therefore, can be used to test hypotheses about movements, social organization and other aspects of humpback biology. The vertical photographs provide permanent records which may be reexamined in the future for other analyses such as length-frequency or morphometric studies. The applicability of this method to other cetacean stocks has not been considered, but there is certainly potential for more expansion, especially for the other world stocks of humpbacks and perhaps cetaceans in general.

ACKNOWLEDGEMENTS

A large number of persons were involved in this project. Special appreciation is offered to S B Saila, W W Steiner, T J Thompson and N Bray who critically reviewed earlier drafts of the manuscript. M Nigrelli kindly typed the final copy. T Flynn and J McMicken were the pilots for the survey efforts. J H W Hain and the rest of the scientific party of the R/V Westward were instrumental in the test survey effort. The sampling survey field work was funded by the Office of Naval Research through contract number N00014-76-C-0226 and the test survey work by the Marine Mammal Commission through contract number MM7AC029 to H Winn. G Scott received additional support for this work from a National Wildlife Federation fellowship. The work reported herein is part of a dissertation submitted in partial fulfillment of the requirements for the Ph.D. degree in the Department of Oceanography, University of Rhode Island.

REFERENCES CITED

ACMRR. 1976. Scientific committee on large whales report of ad hoc group I. FAO Sci. Consul. Mar. Mam. Doc. ACMRR/MM/SC/2 Suppl. 1:5-8

Dohl, T.P. 1975. Aerial survey techniques. Paper presented at: Conference on the Biology and Conservation of Marine Mammals, Univ. of Calif., Santa Cruz, Dec. 4-7, 1975.

Elliott, J.M. 1971. Some methods for the statistical analysis of samples of benthic invertebrates. Freshwat. Biol. Assn. Sci.

Publ. No. 25.
Estes, J.A. and J.R. Gilbert. 1978. Evaluation of an aerial survey of Pacific walruses (Odobenus rosmarus divergens). J. Fish. Res. Board Can. 35:1130-1140.
Freese, F. 1962. Elementary forest sampling. US Dept. Agriculture, Handbook No. 232.
Goodall, D.W. 1974. A new method for the analysis of spatial pattern by random pairing of quadrats. Vegetatio 29(2):135-146.
Goodman, L.A. 1960. On the exact variance of products. J. Am. Stat. Assoc. 55:709-713.
Greig-Smith, P. 1952. The use of random and contiguous quadrats in the study of the structure of plant communities. Ann. Bot. Lond. N.S. 16:293-316.
Greig-Smith, P. 1964. Quantitative Plant Ecology. 2nd ed. Butterworths, London.
Heyland, J.D. 1972. Vertical aerial photography as an aid in wildlife population studies. Proc. First Cdn. Sym. on Remote Sensing:121-135.
Heyland, J.D. 1974. Aspects of the biology of beluga (Delphinapterus leucas Pallas) interpreted from vertical aerial photographs. Proc. Second Cdn. Sym. on Remote Sensing: 373-390.
Leatherwood, S., J.R. Gilbert, and D.G. Chapman. 1978. An evaluation of some techniques for aerial censuses of bottlenosed dolphins. J. Wildl. Manage. 42(2):239-250.
Pielou, E.C. 1977. Mathematical Ecology. John Wiley & Sons, New York.
Rice, D.W. 1961. Census of the California gray whale 1959/60. Norsk Hvalfangsttidende 50(6): 219-225.
Rice, D.W. and A.A. Wolman. 1971. The life history and ecology of the gray whale (Eschrichtius robustus). Am. Soc. Mammal. Spec. Publ. No. 3, 142pp.
Seber, G.A.F. 1973. The Estimation of Animal Abundance and Related Parameters. Griffin, London.
Townsend, C.H. 1935. The distribution of certain whales as shown by logbook records of American whaleships. Zoologica XIX, No. 1, 50pp.
Winn, H.E. and L.K. Winn. 1978. The song of the humpback whale Megaptera novaeangliae in the West Indies. Mar. Biol. 47:97-114.
Winn, H.E., R.K. Edel, and A.G. Taruski. 1975. Population estimate of the humpback whale (Megaptera novaeangliae) in the West Indies by visual and acoustic techniques. J. Fish. Res. Board Can. 32:499-506.

Aerial Photogrammetry: A Method for Defining Black-Tailed Prairie Dog Colony Dynamics[1]

Howard P. Tietjen, James F. Glahn
and Kathleen A. Fagerstone[2]

Abstract.--Remote sensing by vertical aerial photogrammetry was evaluated as a means for plotting the distribution and size of black-tailed prairie dog (Cynomys ludovicianus) colonies in South Dakota. An analysis of 1:15,840 scale 9 by 9 inch black and white contact prints spanning a 5-year period shows this technique to be useful for plotting colony location and size and may provide the basis for modeling changes in colony dynamics.

Our review of the over 200 references on prairie dogs uncovered only a few studies that dealt with rangeland ecology and prairie dog-rangeland relationships. As with most nongame species, our knowledge of prairie dogs is limited to general distribution, systematics, life history, biology, and control methods. The literature discloses little information on the prairie dogs' impact on rangeland and interactions with other wildlife and domestic species.

Prairie dogs, as competitors with livestock for forage, are no longer considered as serious an economic problem as they once were. However, unless prescribed management techniques are developed, a potential for uncontrolled population expansion and subsequent rangeland deterioration exists on federally administered lands and state and private holdings. We must realistically assume that contemporary land management and conservation decisions may indicate that some degree of prairie dog control is essential. To develop a management program, old theories and practices must be discarded and efforts made to expand our base of knowledge about this colonial species and its influence on rangeland resources.

This paper presents a comprehensive outline of aerial photogrammetric techniques that have practical application for defining the distribution and size of colonies and which may provide the basis for modeling annual changes in colony dynamics.

MATERIALS AND METHODS

Study Area

Our study area is located on a 400 mi^2 section of the east one-half of Buffalo Gap National Grassland in southwestern South Dakota. The boundaries of this 256,000 acre area extend eastward 40 miles from the Cheyenne River to Interior, South Dakota, and northward 10 miles from the Pennington County line up to, and including portions of Badlands National Monument. This tract lies within the bounds of T.3S. and T.4S. and R.11E. through R.18E.

---

[1]Paper presented at the PECORA IV Symposium on Application of Remote Sensing Data to Wildlife Management, Sioux Falls, South Dakota, October 11, 1978.

[2]Authors are, respectively:
Wildlife Biologist, U.S. Fish and Wildlife Service, Denver Wildlife Research Center, Denver, Colorado
Wildlife Biologist, U.S. Fish and Wildlife Service, Denver Wildlife Research Center, Bowling Green, Kentucky
Wildlife Biologist, U.S. Fish and Wildlife Service, Denver Wildlife Research Center, Denver, Colorado

Flight Protocol

Missions to acquire vertical imagery needed to plot prairie dog colonies were made in late September each year (1974 to 1978) using a Cessna Turbostream 310 or turbocharged Cessna 206 STOL-equipped aircraft. A Zeiss RMK A 15/23 high resolution mapping frame camera with a standard high contrast filter was used with Kodak 2402 Plus X film.[3] Aircraft and shutter speeds were calibrated to obtain an end lap of 55-65% and a side lap between 15-45% for stereoscopic coverage. Tip and tilt averaged 2° with a maximum allowable limit of 3°. Missions were flown at an altitude of 7,920 feet above ground level (scale = 1:15,840) under cloudless conditions. Film was exposed and processed to provide high contrast 9 by 9 inch contact prints.

Aerial Photograph Processing

Interpretation and Plotting

All photographs from a single mission underwent a standardized processing sequence as follows: (1) file by flight line number with exposure indices in consecutive order; (2) scan completely each stereo pair using a mirror stereoscope with 1.8x objective lens; (3) determine presence of prairie dog colonies which register on black and white prints as groupings of white dots representing soil mounds (fig. 1) and (4) verify presence of colonies using 3.0x objective lens and outline colonies with a fine tipped pen (4x0 Rapidograph or equivalent) (fig. 2).

All interpretation and colony delineation was limited to the central 7 by 7 inch area of the 9 by 9 inch prints to limit errors related to prismatic distortion.

Transposition to Topographic Maps

The outline of each colony was transferred from the black and white prints to 1:24,000 scale U.S. Geological Survey topographic maps using a variable scale reflecting projector. To prepare prints, we first identified landmarks or control points, preferably survey corners, established road junctions, or other identifiable boundaries common to both the prints and the topographic maps. The control points were marked with a grease pencil on the prints and with a lead pencil on the topographic maps. These points of common reference were used to best advantage when they formed a triangular pattern adjacent to the periphery of the subject colony or colonies. The print image was then projected onto the topographic map and adjusted so that the control points on both registered and the

Figure 1.--Prairie dog soil mounds register as white dots on 1:15,840 scale vertical aerial photographs using Plus X film.

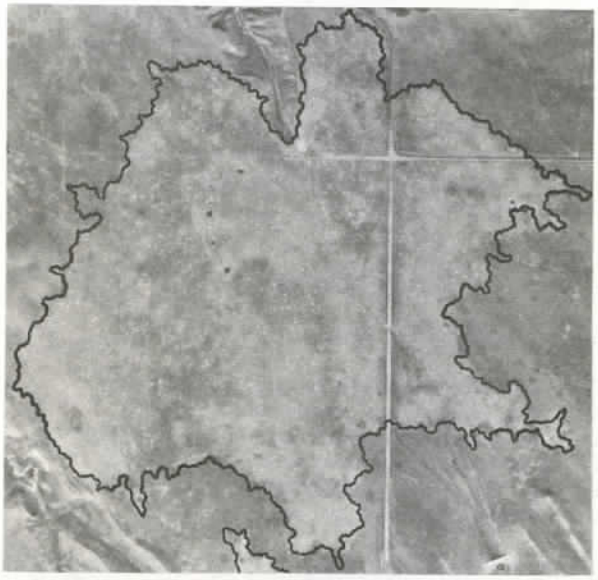


Figure 2.--Black-tailed prairie dog colony on Buffalo Gap National Grassland study area as verified and outlined using a mirror stereoscope and 3x magnification.

[3]Reference to trade names in this publication does not imply endorsement of specific commercial products by the Federal Government.

outline of each colony was traced onto the topographic map using a fine drafting pencil (fig. 3). This process reduced scale variation in the print to one uniform map scale; however, it did not remove image displacement caused by major changes in relief or tip or tilt of the mission aircraft.

Figure 3.--Prairie dog colony as it appears on topographic map after photo transposition process using a variable scale reflecting projector.

Map Processing

Estimation of Colony Area

The acreage occupied by an individual prairie dog colony was measured from the outline on the topographic map using a disc roller planimeter calibrated to 1/10 of an acre (fig. 4). The planimeter was calibrated before each use by checking it

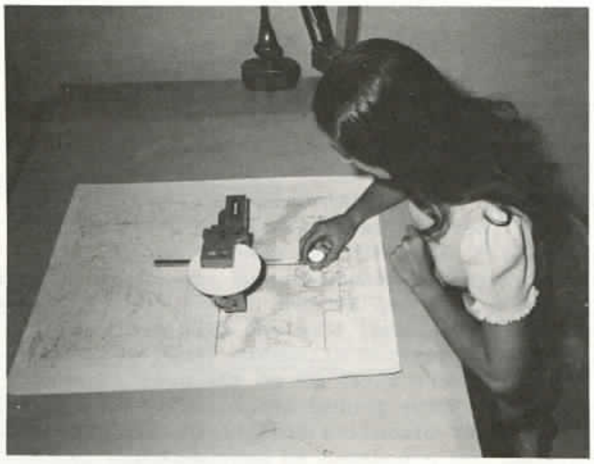


Figure 4.--Disc roller planimeter used to measure area (acreage) of individual prairie dog colonies on topographic maps.

against a known base area (640 acres) on the map. Maps were placed on a clean, flat, and smooth work surface before measurements were taken to minimize errors caused by interference with the planimeter rollers.

Transposition to U.S. Forest Service Map

The final display of annual colony distribution and size was presented on a 1:126,720 scale (1 inch = 10,560 feet) U.S. Forest Service Class A Recreation Map (fig. 5). In this relatively simple process, the outline of each colony on the 1:24,000 topographic maps was scaled down to the correct proportion and outlined to the new scale in a single operation using a bar pantograph.

RESULTS AND CONCLUSIONS

A preliminary analysis of data obtained in ground truth surveys (incomplete as of

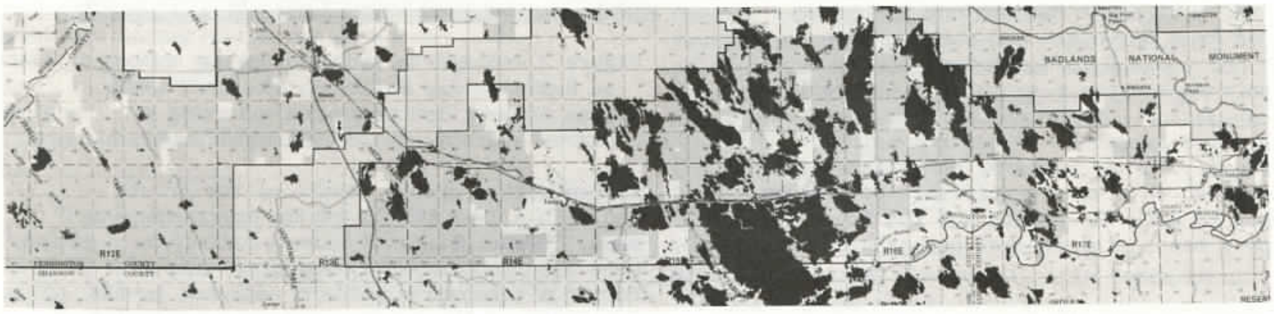


Figure 5.--Display of annual prairie dog colony distribution and size on 256,000 acre study area as it appears on 1:126,720 scale Class A Recreation Map. Colonies (black areas) range in size from 0.1 acre to over 6,400 acres.

this time) indicates that we can: (1) consistently locate colonies throughout the study area and (2) define their acreage with an error term of approximately 3.1% as measured from the maps. At a total cost of approximately 4 cents per acre, including the photo mission, two sets of contact prints and the time and manpower needed for processing, we feel this technique is accurate and economical.

The application of remote sensing techniques to studies of prairie dogs and other fossorial rodents is not new. Driscoll (1969), Lovaas (1973), Cheatheam (1973, 1977), and Bishop and Culbertson (1976) describe similar studies, at least in general terms, for prairie dogs and pocket gophers (Thomomys sp.). However, to our knowledge, this study represents a first attempt to apply data obtained by remote sensing to an assessment of annual changes in prairie dog colony dynamics and to the development of population models, both key elements in the development of management plans for prairie dogs on western rangelands.

LITERATURE CITED

Bishop, Norman G., and James L. Culbertson. 1976. Decline of prairie dog towns in southwestern North Dakota. J. Range Manage. 29(3):217-220.

Cheatheam, Lloyd K. 1973. Censusing prairie dog colonies using aerial photographs. In Proc. Black-Footed Ferret and Prairie Dog Workshop. Rapid City, S. Dak.: p. 78-88.

________________. 1977. Density and distribution of the black-tailed prairie dog in Texas. Texas J. Sci., Vol. XXIX (1 and 2): 33-40.

Driscoll, Richard S. 1969. Aerial color and color infrared photography--some applications and problems for grazing resource inventories. In Proc. Aerial Color Photogr. Workshop (Aerial color photography in the plant sciences). Univ. Fla. Gainesville: p. 140-149.

Lovaas, Alan L. 1973. Prairie dogs and black-footed ferrets in the national parks. In Proc. Black-Footed Ferret and Prairie Dog Workshop. Rapid City, S. Dak: p. 139-148.

Telemetered Heart Rates as Indices of Physiological and Behavioral Status of Deer[1]

Nadine K. Jacobsen[2]

Jerry L. Stuart[3]

Abstract.--Two telemetering systems suitable for real-time data transmission of either the pulse-rate or the electrocardiogram wave-form of an animal are described. The transmitted data are processed into a format suitable for presentation on a strip-chart recorder. Heart rate as influenced by apparent behavioral state is discussed.

INTRODUCTION

Heart rate is an important and accessible means of monitoring ecological interactions occurring between an animal and its environment. Since blood flows through the body in response to metabolic and thermal requirements, heart rate should be associated with differences in the intensities of productivity, thermal balance, and activity of the animal. Thus, knowledge of changes in heart rate may contribute to understanding differences in metabolism of deer which are related to age and season.

The cardiac responses of unrestrained animals can be remotely monitored by a system that telemeters either an analogue of each cardiac cycle (pulse-rate) or continuous record of changes in electrical correlates (wave-form). None of the transmitter designs available met the criteria of use as either an external or internal unit with crystal-controlled transmission, comparatively non-restrictive range, and relatively low cost. We describe two transmitter systems for telemetering cardiac responses, and compare the advantages of each for physiological and behavioral studies of captive black-tailed deer (*Odocoileus hemionus columbianus*.

TELEMETRY SYSTEM

Bioelectrical potentials are sensed by a pair of silver-disc electrodes (Narco Biosystems, Inc.) positioned immediately behind the forelegs of each animal in the horizontal plane of the heart. Electrical contact between the 2-cm hair-free surfaces and the electrodes is maintained by a liberal application of electrode paste (Narco Biosystems, Inc.) to both surfaces, and by adjustment of the Velcro closures on the 4-cm-wide elastic harness. This preparation usually allowed continuous monitoring for 24 hours or more without readjustment of either the harness or electrodes. The deer were accustomed to the instrumenting procedures, and wore the transmitter-harness without apparent discomfort or changes in behavior.

The bioelectrical potentials sensed by the electrodes are amplified and filtered by a 5-50 Hz bandpass filter of the pulse-rate transmitter (Stuart, EKG-1). The resulting peak-detected signal turns on a 10-millisecond one-shot, which controls ON time of the transmitter. After being on for 10 milliseconds, the transmitter turns off and waits for the next heart beat, thus conserving battery energy by being on only once during each QRS complex of the cardiac cycle. The transmitter radiates a 148 MHz pulse from a small loop antenna mounted at the end of the transmitter. The electrical characteristics of the loop are designed to match the electrical impedance of the

---

[1]Paper presented at the PECORA IV Symposium: Application of remote sensing data to wildlife management, Sioux Falls, South Dakota.

[2]Assistant Professor, Department of Wildlife and Fisheries Biology, University of California, Davis, California 95616.

[3]Consultant, Systems Design, J. Stuart Enterprises, P.O. Box 2219, Grass Valley, California 95945.

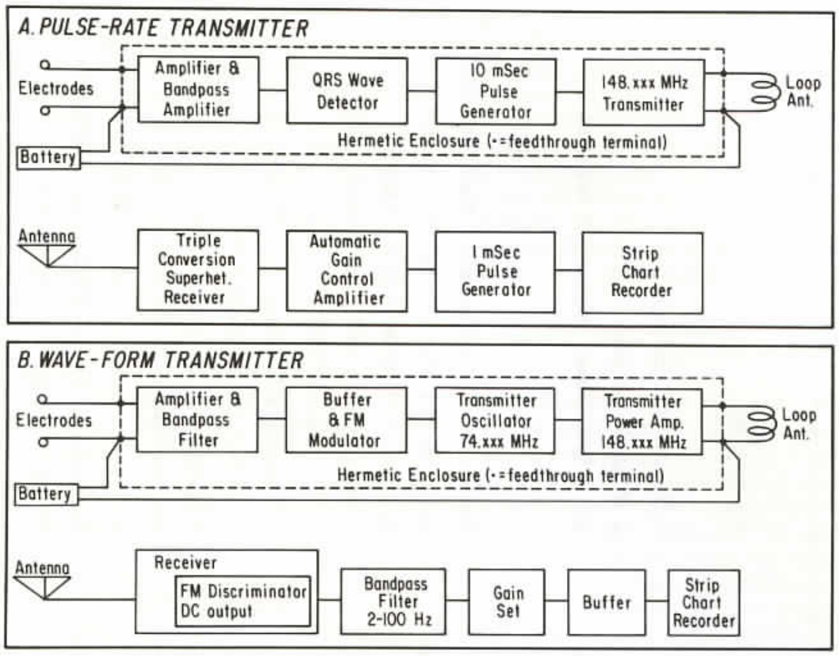


Figure 1. Block diagram of surface-mounted units for telemetric transmission of the pulse-rate and wave-form of the cardiac cycle. The battery pack, antenna, and electrode connectors are external to the electronics, mounted inside a container filled with dry air and hermetically sealed.

subject's body and thus utilize it as an extension of the antenna. The transmitter is crystal-controlled, thus permitting the use of a sensitive narrow-band receiver to detect the radiated pulse. A triple-conversion superheterodyne receiver (Telonics, Model TTR-1) with a modified automatic gain control is used; the signal is amplified, differentiated, and then used to trigger a one-millisecond pulse generator (fig. 1). Once the pulse is recorded on a strip-chart record (Gilson, Model ICT-5H), the heart rate is easily determined from the chart speed.

The wave-form transmitter (Stuart, EKG-3) amplifies and filters the signal detected by the surface electrodes to provide a suitable voltage to drive the FM modulator, causing the frequency of the transmitter to shift in proportion to the amplitude of the electrocardiogram (ECG). The radiated signal is sensed by the receiver antenna and processed through a standard dual-conversion FM receiver (Radio Shack, programmable 2001) modified to make the discriminator accessible before filtering and routing to the audio amplifier. The discriminator output is passed through a low-frequency bandpass filter (2-100 Hz) to eliminate the DC component and spurious noise (fig. 1). The amplitude and wave-form of the recovered ECG signal is then displayed on a strip-chart recorder. Since the radio frequency (RF) transmitter is on all of the time in use, the battery lifetime is considerably shorter than with the pulse-rate transmitter. Consequently, this transmitter is equipped with a magnetically operated reed switch and is not designed as a surgical implant. With some circuit changes and a reduction in transmitting range, the life of the unit can be extended considerably for use as an implant. The reduced transmitting range can be compensated for by use of a retransmitting collar worn by the instrumented animal.

Specifications of the two transmitters are summarized in Table 1. The physical size of both transmitters can be reduced to 58 x 20 x 29-mm by relocating the battery pack to the top of the unit.

The form of the recorded heart rate obtained by each type of transmitter is illustrated in Figure 2. While the electrode placement and polarity may not conform to a standard ECG configuration, representative

Table 1. Specifications for pulse-rate and wave-form transmitters.

Parameter	Pulse-rate transmitter	Wave-form transmitter
ECG Signal		
Bandpass	5 to 50 Hz	5 to 50 Hz
Sensitivity	0.5 mV peak to peak (0.2 mV achieved)	
Noise level		0.05 mV peak to peak
Maximum signal	15 mV peak to peak	5 mV peak to peak
Input impedance	AC: 300k ohms; DC: > 10 megohms	AC: 300k ohms; DC: > 10 megohms
Transmitter		
Data mode	PIM (pulse interval modulation)	Continuous FM (frequency modulation)
Frequency	Selected in the 148-152 MHz range	Selected in the 148-152 MHz range
FM sensitivity		Approx. 500 Hz/mV input signal
Stability	0.001% (25 to 50°C); 0.003% (-10 to 60°C)	0.001% (25 to 50° C); 0.003% (-10 to 60°C)
RF signal	10 millisecond pulse	Frequency deviates proportionally to ECG pulse amplitude
Range	1 kilometer nominal, line of sight	500 meters, line of sight
Power requirements	2 mAH/week plus 14 mAH/10^6 pulses	840 mAH/week, 5 mA at 5.4 VDC
Battery system	2 500-mAH mercury cells (#640)	4 250-mAH mercury cells (#625)
Battery lifetime	4 months at 180 beats/min average	Approx. 50 hours continuous operation
Mechanical size	95 mm x 20 mm x 15 mm (LWH)	95 mm x 20 mm x 15 mm (LWH)
Physical weight	47 grams	49 grams
Electrodes	Replaceable with pin connector	Replaceable with pin connector

ECG signals are obtained that facilitate processing of heart rate and activity. The two modes of monitoring each cardiac cycle are not synchronous because of the delay through the pulse-rate transmitter electronics that shape the signal. The frequent (and unpredictable) spurious signal artifacts (termed a heart-beat "doublet") obtained in the pulse-rate record are apparently triggered by electrode movement and the strength of the T-wave of the ECG cycle. The longest interval of recording without doublets was about four hours. Although recordings that are made fast enough can clearly separate doublets from true patterns of heart beats, this characteristic of the pulse-rate transmitter could be misrepresentative of heart rates if averaged by systems that accumulate pulses over fixed sampling intervals.

Continuous monitoring of electrical correlates of the cardiac cycle as a wave-form rather than pulse-rate record offers several advantages in physiological and behavioral research of unrestrained animals: A record is made of instantaneous changes in cardiac responses that are more easily related to activity and behavior; breathing rate can be monitored during lying-resting and often standing activities, because both the amplitude and the interval between QRS complexes of the ECG change with the inspiratory and expiratory phases of the respiratory cycle; changes in the pattern of the electrical activity represented by the wave-form signal can be used to interpret seasonal depressions in metabolic state; and spurious signal artifacts are less likely to be included during data reduction. Finally, changes in the characteristics of the telemetered electrocardiogram, supplemented by visual observation, provide analogues of physical activity (fig. 3); these can be used to determine the minute-by-minute time budgets of the radiotelemetered animal.

DISCUSSION

Prediction of ecological metabolic rate from relationships between heart rate and body weight requires that the possible influence of behavioral or psychological state of the animal be partitioned from physiological responses to changes in activity from one type or another. That is not easily achieved, because many behavioral responses of deer to disturbances are both subtle and vary with experience, age, and season. Thus, the heart-rate record should be paralleled by visual observations of carriage of the head, ears, and tail, orientation of the body, piloerection of body hairs, and gait of the animal. Then, both the direction and magnitude of cardiac responses can be more easily related to

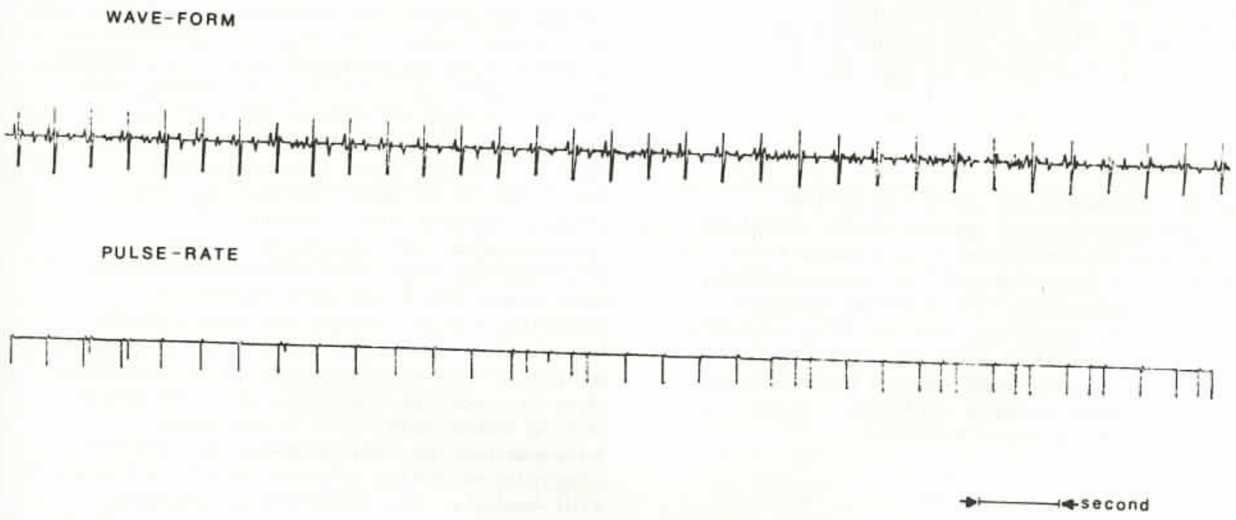


Figure 2. Representative example of chart recordings obtained from the wave-form and pulse-rate transmitters. Each unit was attached to an independent pair of electrodes and carried simultaneously by a female black-tailed deer fawn during standing activity. (Line drawing of strip-chart record.)

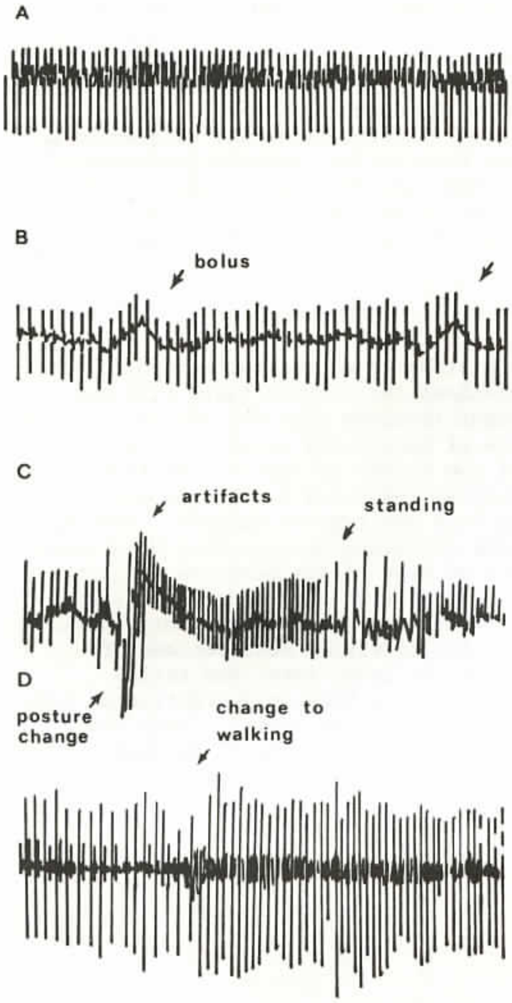


Figure 3. Analogues of animal activity obtained from changes in the characteristics of the electrocardiogram telemetered from unrestrained deer during: A) lying-resting, B) lying-ruminating, C) postural changes from lying to standing, and D) from standing to walking activity. Running activity produced artifacts more exaggerated than obtained during walking activity. (Line drawing of strip-chart record.)

activity and behavior. Some implications of these relationships are discussed.

Fawns often attempt to conceal themselves and remain motionless, rather than flee from approach or loud noises. A physiological correlate of this behavior (fear without active escape) is a decrease in heart rate (alarm bradycardia). This type of behavioral response to disturbance is less common in older fawns, in which increases in heart rate (alarm tachycardia) and fleeing behavior predominate. Cardiac responses of fawns to disturbances therefore represent a continuum, the specific response varying with stimuli type and intensity, the animal, and likely time of day when the disturbance occurs. This is illustrated by the record of variation in heart rate observed in a recumbent black-tailed deer fawn (fig. 4). Although helicopters had flown by at higher altitudes at least once weekly, this was the first occurrence during a telemetry monitoring period. A rapid change in heart rate response, often within one heart beat to the next, was frequent as the helicopter flew a search pattern some 1000 m distance from the deer enclosure. Instantaneous heart rates ranged from 26 to 306 beats/minute (respectively, -71 to 240 percent of the lying-resting rate) during the episodes of alarm bradycardia and alarm tachycardia (Table 2). These patterns of cardiac response were common, but not easily correlated with changes in overt behavior. The fawn remained bedded with its head reclined alongside the flank throughout the 40-minute disturbance.

This sample also illustrates a bias that may be introduced by various sampling intervals. Heart rates for each consecutive one-minute interval of Figure 4 averaged 110, 117, and 94 beats/minute, respectively. Such variation in minute-by-minute heart rate during lying-resting behavior is not unusual with young fawns. It would be possible to conclude from an averaged heart-rate record, particularly one in a digital format, that the fawn exhibited little response to the helicopter. Visual observations also would tend to confirm this interpretation, particularly if made infrequently and without optical aid. Clearly, that conclusion is not supported by the continuously monitored electrocardiogram. When heart rates are partitioned by behavioral state during the measurement, heart rates are higher in all activities of alarmed fawns except during lying activity, when bradycardia responses may also occur during alarm (fig. 5). Since heart rate-metabolism relationships may become dissociated during alarmed behavioral states (for example, see Johnson and Gessaman, 1973), it is unclear whether these cardiac responses reflect changes in energy expenditure of the animal.

The partitioning of alarm behavioral influences permits the basic rhythms of variation in heart rate and activity to

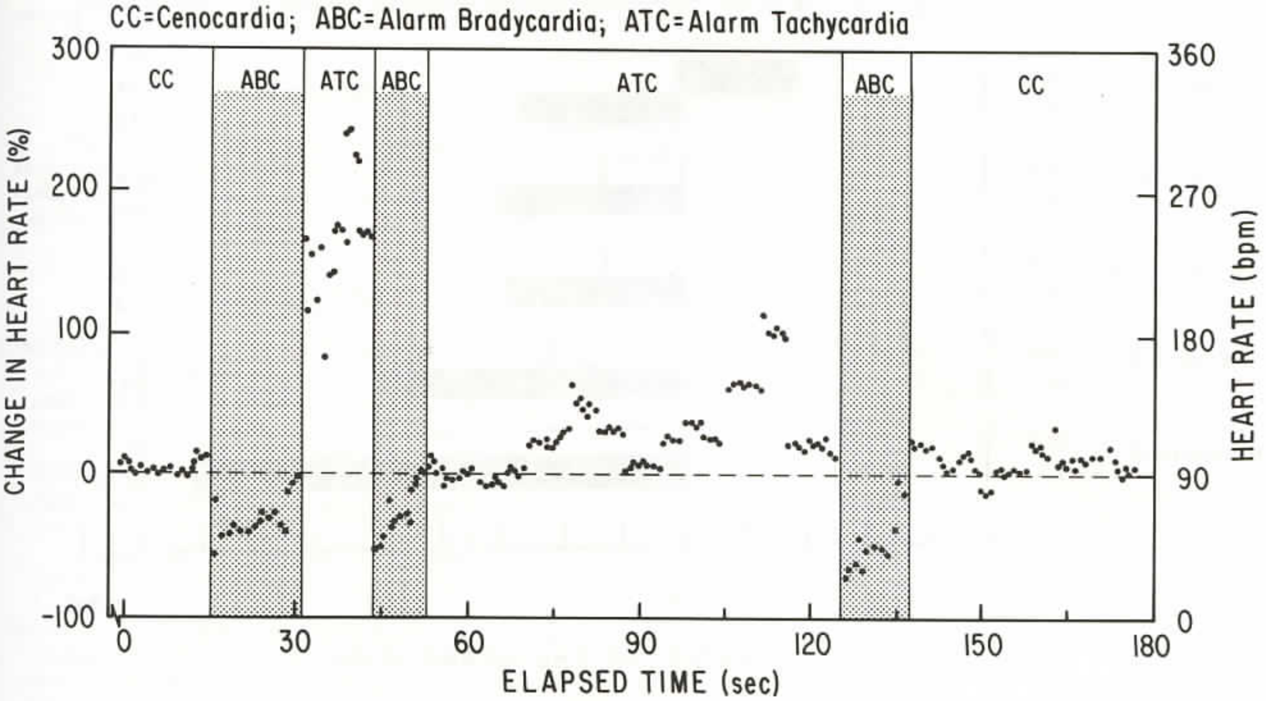


Figure 4. Variation in the heart rate of a recumbent 70-day-old female black-tailed deer fawn that responded with both alarm bradycardia and alarm tachycardia to a helicopter. The instantaneous heart rates in beats/minute (right ordinate) and as a percent of the lying-resting rate (left ordinate) are shown. This three-minute sample of responses occurred at 0240 PST.

Table 2. Changes in heart rate during non-alarm (cenocardia) and alarm (bradycardia or tachycardia) cardiac responses to a disturbance (same 3-minute period of Figure 4).

Cardiac response	Heart rate (beats/minute)		Duration (sec)
	mean ± S.D.	range	
Cenocardia	90 ± 7.9	82 - 110	14
Bradycardia	67 ± 15.1	46 - 88	15
Tachycardia	222 ± 30.4	162 - 306	12
Bradycardia	64 ± 10.8	55 - 78	9
Tachycardia	117 ± 21.0	79 - 176	70
Bradycardia	69 ± 21.0	26 - 95	12
Cenocardia	99 ± 9.0	88 - 122	48

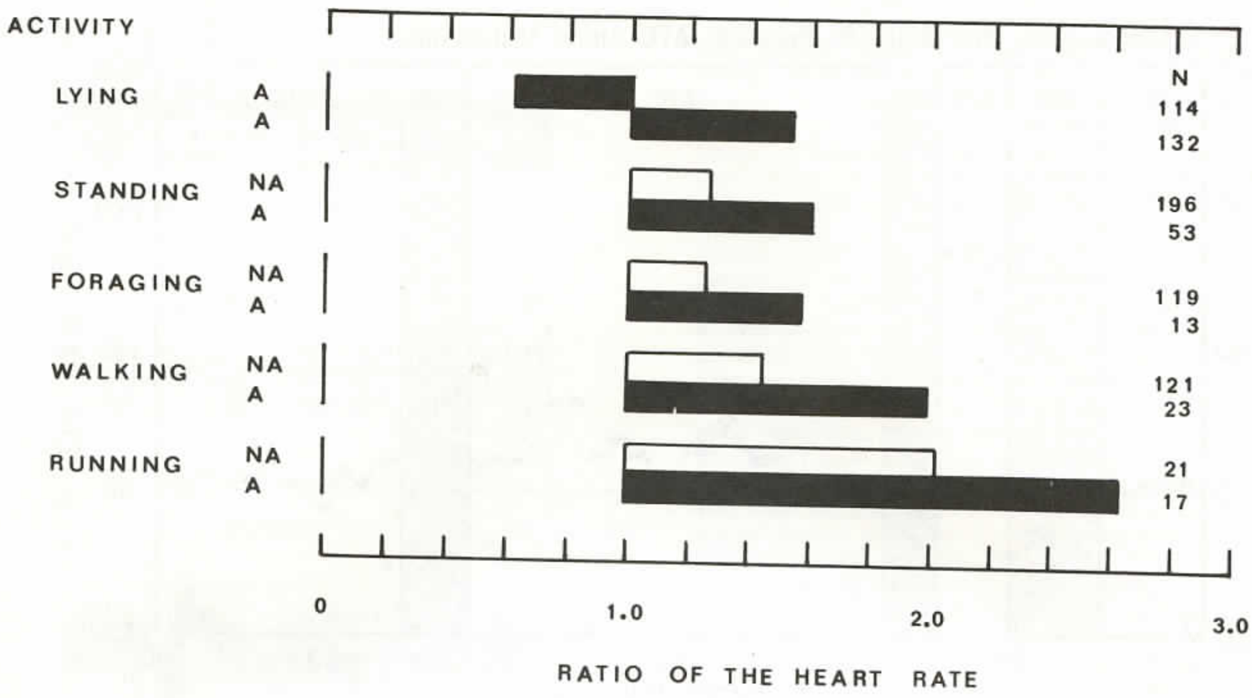


Figure 5. Influence of apparent behavioral state on the heart rate ascribed to an activity of white-tailed deer fawns from 1 to 92 days old. Values for each type of activity during non-alarmed (NA) and alarmed (A) states are ratios of the heart rate during lying-resting activity measured within one hour of the other.

emerge as a function of sex, age and time, both daily and seasonally. These patterns form a baseline to be used in evaluating responses of deer observed during different environmental perturbations, including weather and activities of man (see Jacobsen, 1973). For example, the heart rate of white-tailed deer Odocoileus virginianus during lying-resting activity in late winter is only about half that in early fall. Such marked seasonality in heart rate would be expected to reflect numerous changes in the physiology, thermal insulation, and behavior of deer. The pattern of time-allocation to different activities is one such fundamental rhythm observed to change as winter progresses. Walking or foraging through snow is little done, and lying-resting and standing activities represent larger proportions of each day. Voluntary running activity is negligible. This behavioral pattern is similar to that observed in wild deer, although actual time-budgets have not been determined (Severinghaus and Cheatum, 1956; Ozoga and Gysel, 1972). The impact that displacement from these behavioral patterns may have on the energy economy of deer during the over-wintering period can be evaluated quantitatively by comparison to the energy expended during periods of undisturbed activity. When analyzed event-by-event, small but frequent deviations from these rhythms in response to disturbances may be minor. However, in the context of all changes which occurred over the winter season, productivity or even survival of the animal may be affected.

CONCLUSIONS

Telemetry techniques are essential to studies of the physiological and behavioral responses of captive and wild deer. The usefulness of cardiac responses as an indice of metabolic status of deer is improved by continuous monitoring of the telemetered electrocardiogram in parallel with visual observations. This approach also provides a means of interpreting animal responses to disturbance that is better than visual observation alone. Such knowledge contributes to the biological basis necessary for effective management of deer in changing environments.

ACKNOWLEDGMENTS

This study was funded by a faculty research grant from the College of Agriculture, University of California, Davis, and Hatch Project-3402.

LITERATURE CITED

Jacobsen, N. K. 1973. Physiology, behavior, and thermal thansactions of white-tailed deer. Unpublished Ph.D. Thesis, Cornell University, 346 pp.

________. 1978a. Changes in heart rate with growth and activity of white-tailed deer fawns (Odocoileus virginianus). J. Comp. Biochem. Physiol. (In press).

________. 1978b. Alarm bradycardia in white-tailed deer fawns. (Submitted to J. Mammalogy.)

Johnson, S. F. and J. A. Gessaman. 1973. An evaluation of heart rate as an indirect monitor of free-living energy metabolism. Pp. 44-54 in Ecological energetics of homeotherms, a view compatible with ecological modeling (J. A. Gessaman, ed.), Utah State University Press, Logan. 155 pp.

Ozoga, J. J. and L. W. Gysel. 1972. Response of white-tailed deer to winter weather. J. Wildl. Manage. 36(3): 892-896.

Severinghaus, C. W. and E. L. Cheatum. 1956. Life and times of the white-tailed deer. Pp. 57-186 in The deer of North America (W. P. Taylor, ed.), Stackpole Company, Harrisburg, and the Wildlife Management Institute, Washington, D.C. 668 pp.

Wildlife Censusing Using Reflectance Spectra

Paper Presented at the PECORA IV Symposium
Sioux Falls, South Dakota, October 10-12, 1978

Clair L. Wyatt, Assoc. Prof.
Department of Electrical Engineering
and
Electro-Dynamics Laboratories
Utah State University, Logan, UT 84322

Manmohan Trivedi, Grad. Student
Department of Electrical Engineering
Utah State University, Logan, UT 84322

David R. Anderson, Leader
Utah Cooperative Wildlife Research Unit
and
Department of Wildlife Science
Utah State University, Logan, UT 84322

ABSTRACT

The feasibility of a multispectral classifier is being investigated as a possible tool for deer census. A field study was conducted during the winter of 1978 to obtain a statistical sample of reflectance spectra over the range of 0.5 to 1.1 μm of 10 specie including deer, snow, and competing background objects. The spectral signatures, considered as n-dimensional vectors, were found to have an amplitude that is primarily a function of ambient illumination, but that the direction-angles of the vector provide a relatively stable characterization of scene-specie under ambient conditions varying from bright sunshine to overcast twilight. A simple 2-color classifier, based upon the direction-angle of the sensor output, was evaluated using Bayes' classifier. The average relative error for a snow, deer, juniper scene is less than 2% where the ratio of the probability of the occurrence of snow to deer is 10^5 and of juniper to deer is 10^4. Further analysis of the data is necessary to evaluate classifiers of more than 2 colors and scenes of more than 3 specie.

INTRODUCTION

This research concerns the application of remote sensing techniques to the area of biological monitoring, environmental impact assessment, and wildlife management. Census information of animal population has been recognized as a basic requirement for effective game management. There is a need for information on population size and the distribution in space and time for fishes, birds, and mammals of importance to man. The principles of management are well known (Leopold 1944), and successful management depends upon the quality of information available. This study is concerned with the detection of mule deer (*O.. hemionus*) on the winter range.

Current deer census techniques are time consuming, costly, and to a great extent ineffective. They include direct and indirect methods. Indirect methods include pellet group counting and consumption of browse. These methods do not detect deer but are evidence of deer activity and such data must be interpreted in terms of population. Direct methods, such as human observation, are theoretically simpler but because of poor visibility are nearly useless.

A new tool is needed that will provide a significant improvement in the quality of the data obtained. Thermal infrared (ir) scanning techniques have been suggested (Croon et al. 1968 and McCullough et al. 1969) as a logical application of a technology that has been developed for the military. However, experimental attempts to detect deer in a natural habitat have generally been unsuccessful. Recent studies (Wyatt et al. 1978a) in which the effective temperature data of deer, snow, trees, etc. have been analyzed using Bayes' classifier indicate that thermal contrast, by itself, is not capable of discriminating between deer and background clutter with acceptable error rates.

Success in detecting deer and discriminating against the background is dependent primarily upon the nature and quantity of information content of the optical signals. Apparently thermal contrast, by itself, has insufficient information to permit accurate detection of deer. Recent studies (Wyatt et al. 1978b), in which the emission and reflection signatures of deer hide and various background objects were investigated, indicate that considerable unique spectra exist from biological samples in the visible and near ir bands in reflected radiation.

The goal of the work, reported in this paper, is to analyze appropriate data to learn if a remote sensing system is feasible using reflection data. This study included the design and implementation of a field study in which a statistical sample of reflected ambient radiation was obtained of deer and background in a winter time setting. The data are now being analyzed and preliminary results, which are reported in this paper, are favorable.

This work was supported by grants from Utah State University Research Foundation and the Utah Division of Wildlife Resources.

METHODOLOGY

This study is limited to that of the information content of electromagnetic signals that result from variations in the spectral reflectance of ambient energy. *Figure 1* shows the basic block diagram of a multispectral system. It consists of three parts:

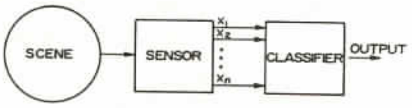


Figure 1. Basic block diagram of a multivariate spectral system.

the scene, the sensor, and a classifier. The scene contains the target and the background, each of which reflect energy of unique spectral content. The sensor contains detectors and associated band filters that provide outputs $x_1, x_2, \ldots x_n$ that are proportional to the energy in the spectrum at corresponding wavelengths. The classifier consists of a data processor that is designed to capitalize on the unique properties of the various spectra to provide a desired classification of scene specie.

Figure 2 illustrates typical normalized spectra of deer, snow and juniper trees with arbitrary bands identified for the illustration of a multispectral classifier. The sensor

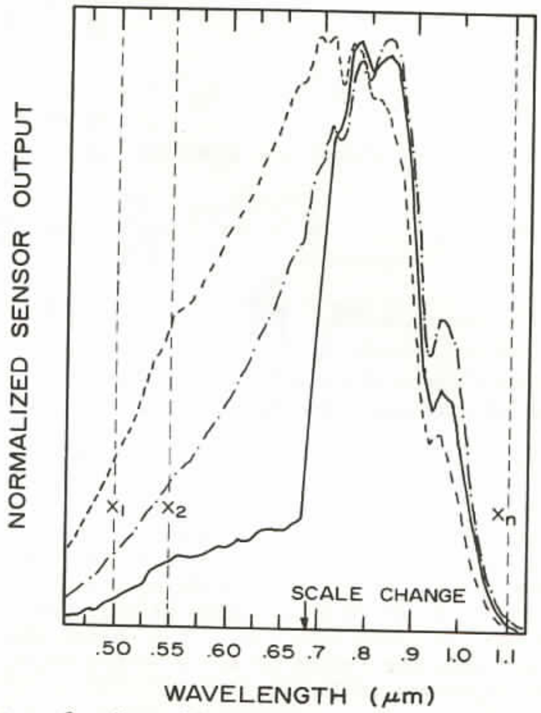


Figure 2. Normalized sensor output scans for snow ---, deer -·-·-, and juniper ———, averaged for approximately 42 scans.

provides a n-dimensional vector representation of the spectral response function as illustrated in *Figure 3* for a 3-dimensional vector. Two properties of the vector are of consideration in a n-dimensional space: the amplitude and the direction.

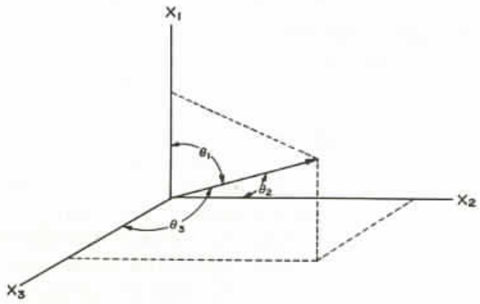


Figure 3. Illustration of 3-dimensional vector.

The amplitude of the ith n-dimensional vector

$$X_i = \begin{vmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_n \end{vmatrix} \qquad (1)$$

is given by

$$|X_i| = (x_1{}^2 + x_2{}^2 \ . \ . \ . \ x_n{}^2)^{\frac{1}{2}} \qquad (2)$$

and the direction-angles are given by

$$\theta_1 = \cos^{-1} \frac{x_1}{|X_i|}, \qquad \theta_2 = \cos^{-1} \frac{x_2}{|X_i|}, \ . \ . \ .$$

$$\theta_n = \cos^{-1} \frac{x_n}{|X_i|} \qquad (3)$$

where i is the index for the specie and n is number of wavelength features for each species.

It is observed that a series of measurements of the vector, of a given scene specie, will yield different values. An observation of the ensemble of measurements indicates that the vector can be considered as a random variable. Hopefully the vectors for a given specie will tend to "cluster" in some region of n-dimensional space, so the classification of the specie can be based upon the region of space within which a particular vector lies.

The problem of classifier design in part is that of feature selection in which the wavelengths are chosen that provide maximum isolation or separation of the clusters based upon appropriate criteria, and the testing of the classifier with appropriate data sets to verify performance.

Field Study

There was no method to find the optimum wavelengths prior to the field study. Examination of laboratory reflectance data on deer hide, snow, and various background objects, indigenous to the habitat, indicate that wavelengths between 0.5 and 1.1 μm contain considerable unique spectra including the cholorophyll absorption band at approximately 0.65 μm. Consequently, a field experiment was designed to measure the reflectance spectrum as a continuous representation of the sensor output over the entire region using a circular variable filter spectrometer. The spectrometer, fitted with a 1-degree field of view telescope, obtains measurements at 50 unique wavelength elements.

The test site consisted of a series of open pens in which deer, sheep, and elk were confined. A 16-foot tower was equipped with a tent-covered platform from which the spectrometer could be pointed to obtain spectra of these animals. Spectral measurements were also obtained of snow, rock, soil, rabbit brush, sagebrush, and juniper. A relatively large sample set of spectra was obtained during January, February, and March 1978 of these 10 specie. Ambient illumination varied from bright clear days to overcast twilight conditions.

Data Processing

The amplitude of the multivariate vector is obviously proportional to the ambient overhead illumination which varied through approximately 4 orders of magnitude in this field experiment. Intuitive judgment suggests that the amplitude is primarily characteristic of the ambient conditions and to a much lesser extent is characteristic of the specie. On the other hand, the *shape* of the spectral signature, which is equivalent to the *direction* of the vector, is likely to provide a much better characterization of the specie. Thus, stability of the shape of the spectrum under varying ambient conditions is of interest.

The stability of the direction of the vector for a given specie was investigated by normalizing all the scans taken under all ambient conditions to eliminate variations due to amplitude and thereafter calculating the standard deviation for each wavelength. Those regions of lowest standard deviation would be considered first as candidate features for a classifier design.

A simple 2-dimensional classifier designed can be based upon a single direction-angle. Wavelengths were chosen that provided the greatest separation in angles. The angle for the 2-dimension vector for the ith specie is obtained approximately as

$$y_i = x_1/x_2 \qquad (4)$$

which is an approximation of the direction-angle.

A normal (Gaussian) distribution is assumed and the mean and standard deviation are calculated for the direction-angles for each specie. This results in a single dimensional threshold classifier, as illustrated in *Figure 4* for a 3-specie case, that can be evaluated using Bayes' classifier. The decision level is obtained as a function of a priori probabilities as in the case of the thermal contrast data (Wyatt et al. 1978a).

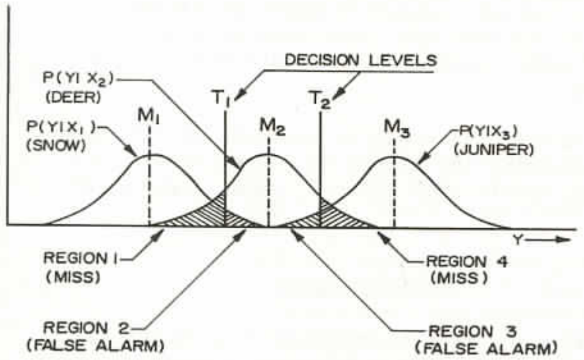


Figure 4. Illustration of normal (observational) probability distribution functions for deer, snow and juniper.

Neyman-Pearson error cannot be utilized for multidimensional Bayes' classifiers. In that case other methods have been suggested for testing the classifier using sub-sets of the data in various combinations.

RESULTS

The data obtained in the field test includes approximately 200 spectral scans of each of the 10 named specie. Each scan contains 50 distinct wavelength features. There exists $2^{50} - 1$ possible feature combinations that might be investigated. An exhaustive analysis is not feasible.

The relative standard deviation (σ/M), where M is the mean, for approximately 42 normalized spectra of snow, deer and juniper are given in *Figure 5* where the region from 0.664 to 0.922 μm appears to be the most stable part of the spectrum. Of the wavelengths within this region 0.664 and 0.843 μm yielded good direction-angle separation in 2-dimensional vector space. These wavelengths were used in a Bayes' classifier for snow, deer, and juniper in accordance with Eq. 4 as follows.

The vector is given by

$$X_i = \begin{vmatrix} x_1 \\ x_2 \end{vmatrix} \quad (5)$$

where the index i = 1, 2, and 3 represents the sensor output for a particular measurement of snow, deer, and juniper respectively. The direction-angle is approximated by

$$y_i = x_1/x_2. \quad (6)$$

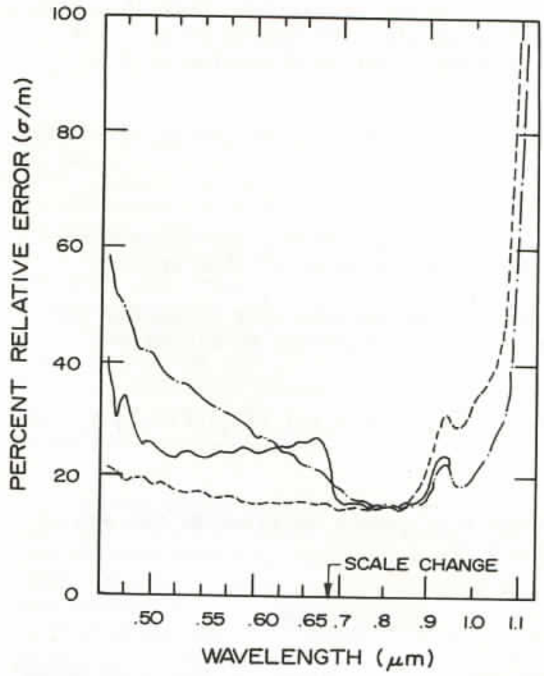


Figure 5. Percent relative error (σ/M) for snow ---, deer -.-.-, and juniper ———.

The statistical parameters for y_i are given in Table 1 where it is noted that two thresholds are required to separate deer from snow and juniper; this is illustrated in *Figure 4*.

Table 1 Multispectral Statistical Data

Index i	Class	Sample Size	$\overline{y_i}$	$\sigma(y_i)$
1	Snow	45	0.950	0.0619
2	Deer	42	1.71	0.1820
3	Juniper	42	6.15	0.6955

The threshold and the average error are determined using Bayes' classifier by the Neyman-Pearson criterion of minimum error. This is equivalent to minimizing the sum of the probabilities of "false alarms" and "misses" as illustrated in *Figure 4*. They are for the snow-deer threshold

$$r_1(y) = \int_{\text{region I}} P(y|X_2)\,dy \qquad \text{(misses)} \quad (7)$$

$$r_2(y) = \int_{\text{region II}} P(y|X_1)\,dy \qquad \text{(false alarms)} \quad (8)$$

where $P(y|X_i)$ is the probability that the ratio x_1/x_2 is y given that the specie is X_i. The average relative error in detecting deer is

$$R(y)/P(X_2) = [r_1(y) + r_2(y)\ P(X_2)/P(X_1)] \times 100\% \quad (9)$$

where $P(X_i)$ is the a priori probability (the probability of occurrence) of that specie.

Similarly the deer-juniper threshold and average error are determined by minimizing

$$R(y)/P(X_2) = [r_3(y) + r_4(y)\ P(X_3)/P(X_4)] \times 100\% \quad (10)$$

The average total error is given by the sum of Eq.'s 9 and 10.

CONCLUSIONS

The results for 3-specie 2-dimension Bayes' classifier is given in Table II as a function of the a priori probabilities. It is noted that for this simple model the deer-juniper error is negligable. This is a consequence of the strong chlorophyll absorption at 0.664 μm.

The average error for an ideal thermal contrast threshold classifier was found to be 48.6% when the ratio of the probability of the occurrence of sagebrush to that of deer was 10,000 (Wyatt et al. 1978a). In comparison, this 2-color classifier has an average error of less than 2% with the stipulation that the snow occurs 10^5 times, and juniper 10^4 times, as often as deer.

These preliminary results indicate that a multispectral classifier might be feasible. This is because the conditions of snow, deer, and juniper closely approximate some winter ranges.

Additional study of the data is called for to determine the effect of adding other competing specie such as soil, rock, log, brush, etc.

REFERENCES

CROON, D.W., D.R. McCULLOUGH, C.E. OLSEN, Jr., and L.M. QUEL. 1968. Infrared scanning technique for big game censusing. J. Wild. Manag. 32:751-759.

LEOPOLD, A. 1933. Game Management. New York: Charles Scribner's Sons. 481 p.

McCULLOUGH, D.R., C.E. OLSEN, Jr., and L.M. QUEALS. 1969. Progress in large animal census by thermal mapping. In "Remote Sensing in Ecology," Chapter 9. Athens Georgia: University of Georgia Press. pp. 138-147

WYATT, C.L., M. TRIVEDI, and D.R. ANDERSON. 1978a. Wildlife censusing by airborne thermal scanners. Submitted to J. Wild. Manag. in 1978.

WYATT, C.L., M. TRIVEDI, and D.R. ANDERSON. 1978b. Remote sensing of large ungulates. Submitted to J. Wild. Manag. in 1978.

Table II Bayes' Decision Level and Average Error for Deer Count with a Background of Snow and Juniper as a Function of a Priori Probabilities

P(Snow)	P(Deer)	P(Juniper)	P(Juniper)/P(Deer)	P(Snow)/P(Deer)	T(1) (y)	T(2) (y)	Deer-Snow % Error	Deer-Juniper % Error	Total % Error
.9	.05	.05	1	18	1.20	2.67	0.31	3.5×10^{-5}	0.31
.9	.00909	.0909	10	99	1.22	2.60	0.43	2.1×10^{-4}	0.43
.9	9.9×10^{-4}	.099	100	909	1.24	2.53	0.64	1.3×10^{-3}	0.64
.9	9.99×10^{-5}	.0999	1,000	9,009	1.27	2.46	0.91	7.5×10^{-3}	0.91
.9	9.999×10^{-6}	.09999	10,000	90,009	1.29	2.38	1.28	4.2×10^{-2}	1.32

Overview of NASA Wildlife Sensing Projects [1]

Paul D. Sebesta[2] and Gordon F. Lund[3]

Abstract.--A history of NASA's wildlife sensing program of the last decade is presented with references to work from key individuals, institutions, and workshops. The approaches taken to explore the three main study areas of location, habitat, and physiology are described, with some results listed. Particular emphasis is made that all three areas of research must be conducted simultaneously in order to best understand a wildlife ecosystem. Aerospace techniques in data gathering are discussed, including topics such as aerospace vehicles and instrumentation implanted in the animal.

INTRODUCTION

During the 1950's and 1960's, several new techniques for gathering information were developed for sensing wildlife and their habitats. Aerial photography and radio tracking were adapted to wildlife sensing as serious techniques. Photography used in forestry and agricultural planning spun off into wildlife management. The growing demand for radio tracking produced the AIBS/BIAC (American Institute of Biological Sciences/Bioinstrumentation Advisory Council). BIAC received significant funding from NASA, with the result of BIAC information modules bringing many investigators, engineers, and technicians up to the edge of the state of the art (AIBS/BIAC, 1968).

In 1969, the National Academy of Sciences (NAS) made recommendations for "a program for satellite tracking of free-ranging animals" and for "a panel composed of experts in the various branches of ecology and in the use and capabilities of multispectral sensing devices, to be convened to carry out an evaluation in depth of this promising application."

By the early 1970's, the need for a coordinated effort to avoid redundancy and waste was further noted by NASA and several future user agencies. As a result, a multi-phased conference/workshop was held over a six-month period which involved users (Interior, Agriculture, Commerce, and State Fish & Game agencies), aerospace and communication industries, and leading wildlife biologists and engineers. This effort was hosted by NASA Ames Research Center at the University of Santa Clara and University of California, Santa Cruz in 1973. In the meantime, the Nimbus 4 satellite carrying the Interrogation, Recording, and Locating System (IRLS) was used to track a free-roaming elk. The tracking of the elk by NASA, Department of the Interior, and the Smithsonian Institution was successful (Craighead, 1970). Immediately, results of other related applications were published concerning different aspects of wildlife monitoring (Buechner, 1971; Craighead, 1971).

With the feasibility study underway, NASA contracted to have a bibliography of tracking systems produced (Werber, 1970). In addition, Dr. John E. Mock (Atlanta, GA) had compiled a survey of each state's needs. His work represented an area where State Fish and Game Commissions spend $140,000,000 annually (1973 figures). The results of these efforts were a stimulus to the completion of a meaningful Santa Cruz report on Wildlife Resource Monitoring (1973).

This report was a statement of the problem from the standpoint of needs, costs, and benefits, and was an effort to define priorities and procedures as well as needed technologies. Public relations, cooperations, collaborations, and coordination of efforts were then proposed (The Santa Cruz Report on Wildlife Resources Monitoring, 1973).

---

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

[2] Research Scientist, NASA Ames Research Center, Moffett Field, California 94035.
[3] NRC Postdoctoral Research Associate, NASA Ames Research Center, Moffett Field, California 94035.

Three major study areas were defined for understanding wildlife. The user manager or investigator must know: location, habitat around that location, and state of the animal's health in that habitat. In order to study more fully the interactions between organisms and their environments, one must first locate the organisms geographically and temporally. The physical and biological characteristics of the environment and the physiological characteristics of the organisms are then studied to identify the state of the animal and changes in these states in an attempt to recognize the stimulus-response interactions. The ever-increasing importance of remote sensing and telemetry in such integrated studies has become obvious.

These three areas (location, habitat, and physiology) enfold a multitudinous number of highly varied biological and technical disciplines, to say nothing of the biopolitics involved in crossing areas of responsibility of different state and federal agencies.

In spite of these complexities, significant examples of accomplishment are presented here. These examples include methodically directed efforts, unscheduled vehicles of opportunity, and combinations of both.

Because of the driving force of the Marine Mammal Protection Act, there is significant progress in the marine wildlife location and habitat studies. Because of the NASA/ARC expertise and fine facilities, there are significant accomplishments in bioinstrumentation studies. We will address these three main study areas separately.

LOCATION

Existing satellite communication systems have been the drivers for what specifications a transmitter must demonstrate. This has not always been optimum for use with animals because these frequencies may not be the best for ground tracking; they require heavy batteries for pulsed power, and antennas present packaging problems.

However, a NASA-sponsored study (Varney, 1974), through the Environmental Research Institute at Moose, Wyoming, has produced a transmitter breadboard which has been tracked by Nimbus 6. Results show an accuracy of RMS error in daytime of 10.9 miles and 5.6 miles at night (Fig. 1). In this case, accuracy is a direct function of available funding, not the state of the art. In any case, such tracking locations are well within acceptable ranges for migrating animals such as the great whales, caribou and other ungulates, migratory waterfowl, and raptors which cover great distances.

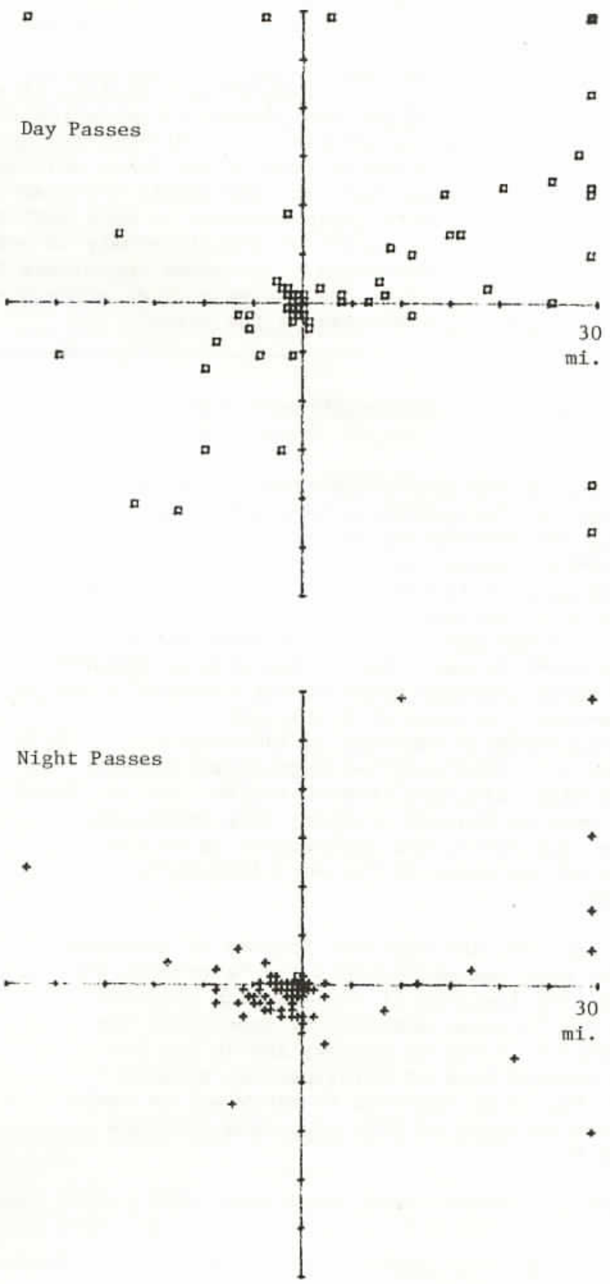


Figure 1. - Typical location accuracy of RAMS miniaturized transmitter used with Nimbus 6 tests. Day passes produce RMS error = 5.6 miles. Transmitter was 401.2 MHz; output power, 1.2 W; input power, 4.8 W at 8 V; DC/RF efficiency, 25%; modulation sensitivity, 0.3 rad/V; oscillator stability, 150 Hz/°C; size, 6.8 in.[3]

This particular design of transmitter can be reduced to 20 gm and its volume to 0.8 in.^{3} (14 cc). Battery weight is a function of needed lifetime, duty cycle, and data channels. It is unlikely that a battery less than 30 gm could drive this transmitter. Varney's predicted battery lifetimes are 3.2 months per 33 gm of battery up to 23.8 months per 289 gm. Therefore, a satellite transmitter package could feasibly be approximately 53 gm for 3 months. This falls well within the weight-carrying capabilities of larger birds. In order to more closely define this concept, a NASA study was carried out to identify the best species, produce a harness for interface between animal and transmitter, and lay out a theoretical study (Craighead, 1978).

Because of priorities identified by the Santa Cruz study, marine mammal tracking has received the attention of several approaches. The Marine Mammal Protection Act, along with its attendant economic, social, and ecological factors, are prime drivers.

Efforts of the combined resources of the Franklin Research Institute and UC/Santa Cruz produced a unique tracking system. This procedure involved the capture of a gray whale calf and the placing of a vest holding the tracking radio and data recorder around the animal in the area of the shoulder girdle. Bolts that corroded at given rates in sea water released the entire configuration which could be retrieved on the sea surface later. The transmitter was the retrieval beacon, and the data recorder stored data such as length of dive, depth of dive, and sea-water temperature. This information, combined with location data, provided new and unique information on mother/young behavior during the critical early days of the calf's life in the Baja lagoons (Goodman, 1975). The methodology of this task is presented as a 16-mm movie in this session's poster exhibit and is impossible to represent here. The data in the recorder were taken back for processing on FIRL's PACER-100 computer (see Fig. 2).

A second approach was the methodology used to track the gray whale "Gigi." This animal was released off the San Diego coast after spending the first year of its life in captivity. This juvenile whale had a NASA-sponsored transmitter that the U.S. Navy sutured to the flesh above the backbone. Tracking of the whale took place from San Diego to just south of San Francisco (Fig. 3) (Evans, 1972).

During the study, unique data were collected concerning unusually warm,

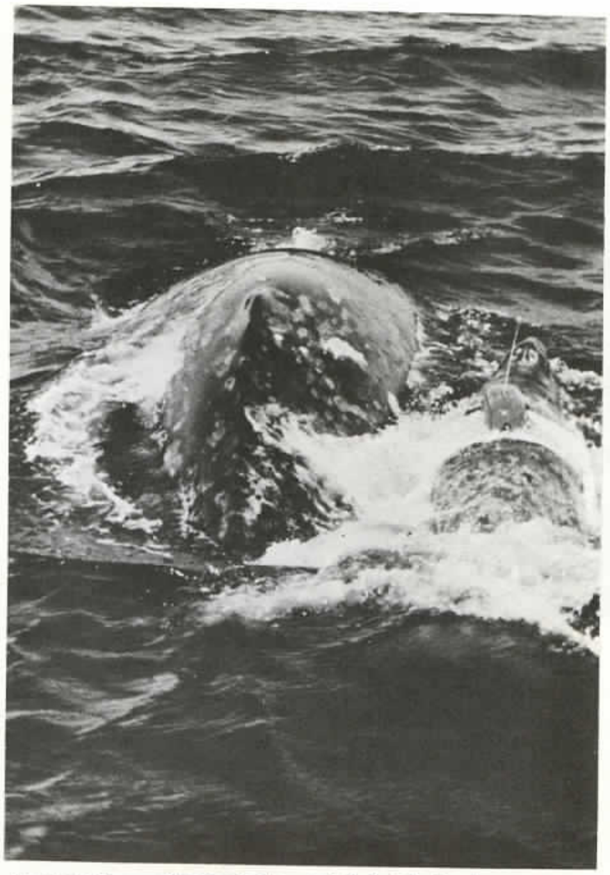


Figure 2. - Gray whale calf in Baja lagoon carrying transmitter package using vest interface with animal. Courtesy of Dr. K. Norris, UC/Santa Cruz, California.

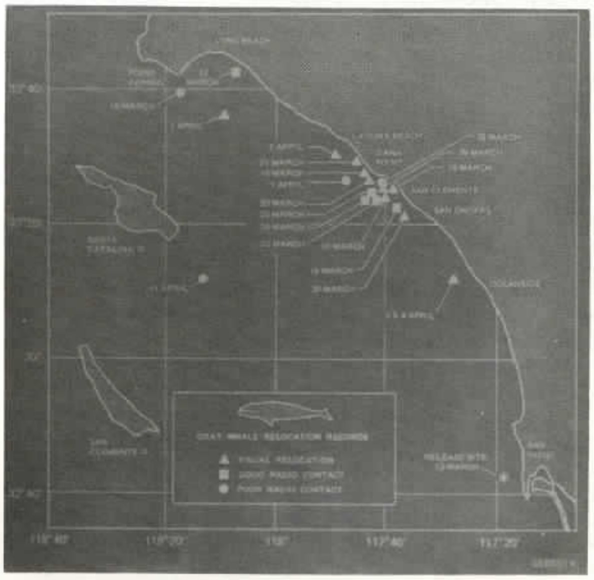


Figure 3. - Map showing Southern California coastline and relocations of yearling gray whale, March 13-April 11, 1972.

deep-water temperatures. The effectiveness of the whale as a mobile marine monitoring platform was well demonstrate (Fig. 4).

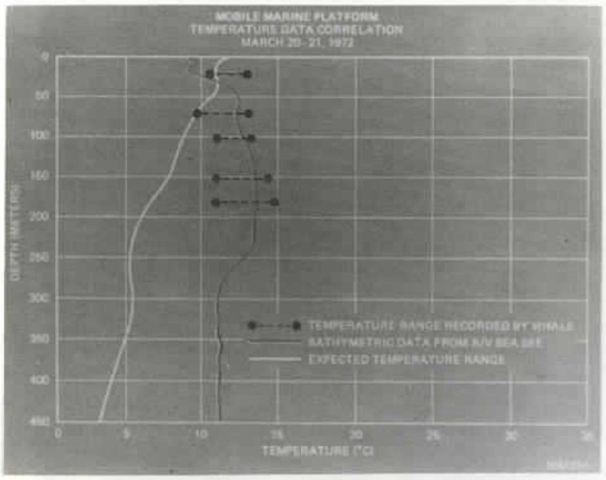


Figure 4. - Temperature vs. depth 1.7 miles off Laguna Beach, California, in comparison with temperatures as collected by the whale's instrument package (mobile marine platform.)

A third approach for whale tracking is the end result of the thinking of four leading natural history scientists (Scheville, Evans, Ray, and Norris). This method involved imbedding a marker tube in whale blubber. The tube carries a radio transmitter with an antenna left to hang outside for the signal transmission. NASA provided developmental funds and procured the first generation of transmitters which were used by Drs. Ray and Wartzok in the Gulf of St. Lawrence to track fin whales. This concept has since been tested and used by many investigators, including NOAA, with varying degrees of success. The problems of delivery and animal rejection still need working out. However, there still remains the insult to the animal as viewed by the public. Results of these tests will appear in other places as the data are processed (Ray, 1978).

The last example of a NASA marine mammal transmitter is a limpet device for pinnipeds. This transmitter features a low profile antenna and squib fired hooks which attach the package to the very thick skin behind the skull above the neck on pinnipeds. Walrus were tracked during initial tests for several days. This tracking was part of a larger effort to address the three main priorities as identified at Santa Cruz: location, habitat, and physiology.

HABITAT

One example is given here of a unique approach to studying a large wildlife ecosystem, the Bering Sea. The problem to be addressed is the productivity of the Bering Sea with the marine mammals as indicator species. Synoptic, general, and specific views are needed of the habitat. These, combined with location telemetry and, eventually, physiological information, would help define the Bering Sea ecosystem and make it possible to assess the impact of man's increasing presence and activity in a highly productive fishing and fragile biological community. The principal investigators are Drs. G. Carleton Ray and Douglas Wartzok. Numerous other special individuals are involved from NOAA, University of Alaska, U. S. Geological Survey, Scripps, USCG, and NASA. This project is called BESMEX (Bering Sea Marine Mammal Experiment). Overall plans for BESMEX are available from the Technical Monitor, Paul Sebesta, Mail Stop 236-5, NASA Ames Research Center, Moffett Field, Calif. 94035 (entitled BESMEX TM X-62,399, 1974).

The habitat is synoptically sensed by satellite (Fig. 5) and high-altitude aircraft (NASA Convair 990).

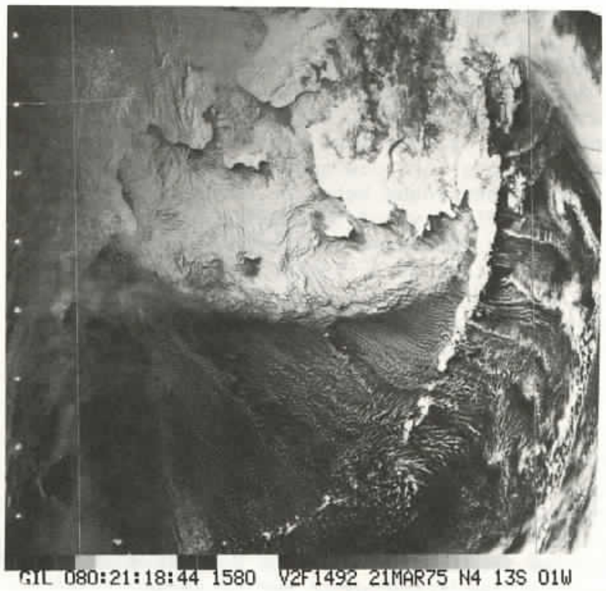


Figure 5. - Satellite picture with synoptic view of sea ice formations in and around critical habitat areas of Beringea marine mammals. Note clear areas detectable on lee side of islands and open lead structure.

Satellite pictures are made available through the US Weather Bureau and the US Air Force. These photographs are used for directing aircraft to search and monitor sea ice and wildlife. The ice is a major component of the ecosystem of the two target species, the walrus and bowhead whale. Once the study areas are defined by satellite, detailed data are gathered by sensors aboard the NASA CV-990 (Ray, 1977). In addition to meteorological data gathered by the aircraft, ice and animal data are sensed by UV cameras, IR scanners, radar and microwave imagery, and black & white and color photography. The major sensor for walrus hauled out on ice is the IR scanner. The scanner quickly separates the warm animals from the cold environment. There is 0.3 of a degree of absolute temporal resolution at 1 milliradian. The instrument used is a Texas Instruments RS 730 on the 8-14-micron channel using a mercury cadmium teluride detector. With a 90° field of view scanning below the aircraft, there was a 5 and 11 milliradian spatial resolution.

The scanner was mounted in series with the photography equipment and run concurrently for data confirmation and enhancement. These instruments were mounted in the CV-990 cargo area where they could be serviced in flight. The scanner data were monitored visually in the flying laboratory of the passenger compartment and recorded on a wide-band, 250 kH_3, 60 IPS tape recorder. These data are stored on magnetic tape onboard for later computer processing. The data were processed on an ESL IDIMS (Interactive Digital Image Manipulation System) using a Series 1 and 2 HP 3000. Data were scaled from 0 to 255 gray levels. Density slicing was used to differentiate the radiant ranges. Pseudo-coloring was used to identify temperature, with the hot animals designated as the brightest (see Fig. 6).

As the figure shows, there is a histogram overlaid on the pseudo-color representation of a walrus haul-out. Each gray level represents a percentage of presence of a specific temperature. As expected, the bell-shaped curve represents largely sea ice, and the hot animals are represented in the far right spectrum of the histogram. These data, combined with photography and ground truth, give real numbers. The end product is possible real time data on location and numbers of animals. The IR data, combined with photography and side-looking radar, will give detailed habitat definition as to age and thickness of ice.

Such combinations of data will tell a user agency if the ecosystem can support the target species under the changing ecological pressures and influences of man. The final BESMEX report is due mid-summer of 1979.

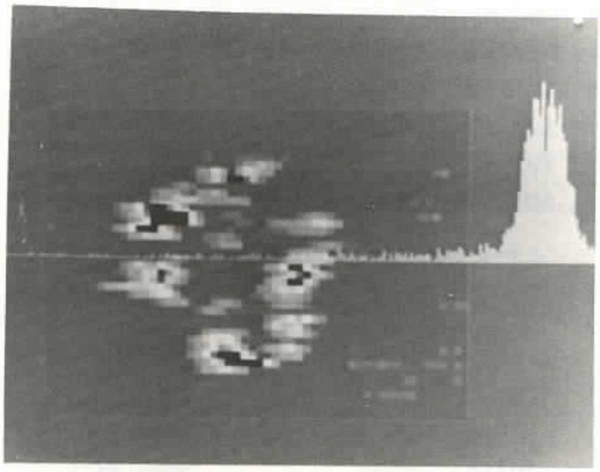


Figure 6. - Pseudo-color representation of walrus in a Bering Sea haul-out. Histogram overlay indicates percentages of 255 gray levels representing presence of different temperatures in habitat. Hot walruses are represented on far right as small percentage as masses of cold ice.

PHYSIOLOGY

The Santa Cruz report prioritized the physiological functions that were most desired and required first effort. Heart rate and deep-body temperatures were first priorities. Previously referenced work of Dr. John Craighead touched on this in measurements of rectal temperatures in hibernating bears. This work was carried further with implanted telemeters in a black bear for temperature-monitoring during hibernation. Another application of this approach was the development of a microminiaturized transmitter by Varney to monitor eggs during incubation in the wild by a parent bird (Varney, 1974).

It is of added advantage to the investigator to have readings of heartrate and multiple temperature from different organs, tissues, and body locations to study changes in the physiological and behavioral functions. One example of this is illustrated in Figure 7.

Note especially the collective patterns of changes over time in the dorsal subcutaneous and deep-body liver temperatures and in

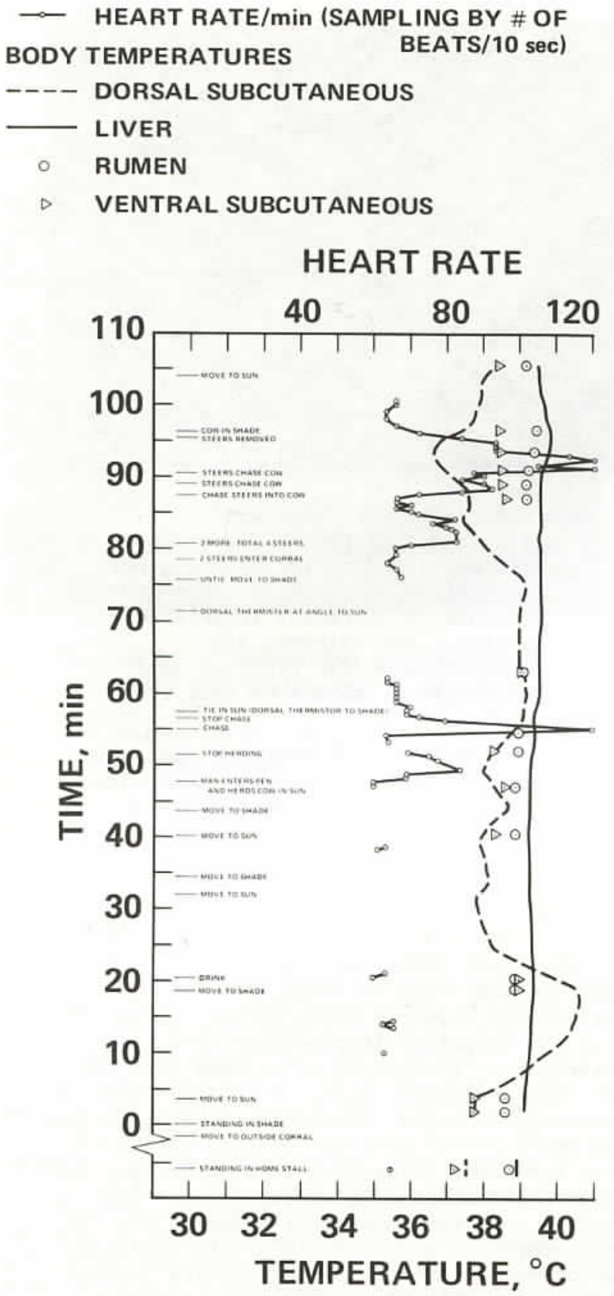


Figure 7. - A record of the changes in heart rates and body temperatures of a tame cow within a corral. The measured variables are indicated by symbols at the top. Changes in the test conditions and/or events are indicated by captions beside the time record that reads sequentially from bottom to top. (Data by G. Lund & G. Moberg with acknowledgement to the NASA/ARC/National Research Council Associate program and UC California/Davis; the transmitter was built by Konigsberg.

the heart rates. Early in the record, the cow moved slowly from a shaded area into the midday sun; this change in environment was reflected by a dramatic increase in dorsal skin temperature but without much change in the other variables. In the middle of the record, the heart-rate increase was consistent with the increased activity of exercise. Toward the end of the record, steers were allowed to enter the corral; heart rates increased as did deep-body liver temperature, but dorsal subcutaneous temperature dramatically fell as a response to the situation of emotional stress. Note especially that much of the information content of these data resides within an attainment of a quality and continuous record over time.

A second example is presented to illustrate the possible use of heart rate as an index of energy allocation (Fig. 8).

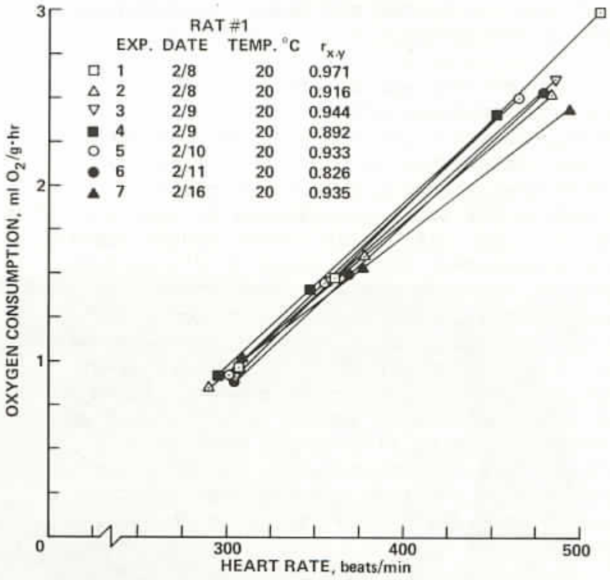


Figure 8. - Least squares linear regressions of oxygen consumption on heart rate of a single albino rat Each line is based on continuous 10-second interval sampling for more than 1 hour during which the rat was subjected to intermittent treadmill exercise. The symbols define the XY mean and range of variation of heart rates after averaging and synchronizing the variables for the comparisons. (Data by G. Lund with acknowledgement to the NASA/ARC/National Research Council Associate program and to Grant NSG-2293 through San Jose State University.)

Note that the relationships between variations in heart rate and in oxygen consumption seem essentially linear and stable for several days, at least for the conditions of measurements of changing levels in activity and at a moderate environmental temperature. While it may be feasible through such studies to use heart rate as an index of absolute rates of energy expenditure, it seems more feasible that the method might serve as a relative index of energy allocation over the natural 24-hr cycle or over a few days. That is, the relative index requires only the assumption of a stable proportional relationship for a short period of time. Also, one does not need to know the absolute XY coordinate of that relationship at that time. For example, the percent of energy allocated to feeding activities would be given by measurement of the average heart rate for 24 hours as the denominator, and the average heart rate over the time periods of feeding multiplied by that time for the numerator. Other methods might be simultaneously applied to determine absolute total daily energy expenditures which could then be multiplied by the percent allocations to achieve absolute energy costs for various behaviors.

The idea of using heart rate as a relative index to obtain estimates of time and energy expenditures was suggested before from work on black-tailed prairie dogs (Lund, 1974; Lund and Folk, 1976).

In order to develop and to apply methodologies such as illustrated by Figs. 1 and 2, the technological prerequisite is a telemetry system that will allow the interface of studies on animals in the laboratory, in enclosures such as corrals, and in the open field. Large volumes of data must be collected and analyzed according to defined experimental designs and protocols. High-quality data for extensive automation by the data acquisition systems are virtually mandatory.

A prototype heart-rate multiple temperature system that we believe will extensively achieve these experimental goals in a versatile way has been under development at the Ames Research Center. A successful preliminary test of this system has been conducted on a Labrador dog at the Center. An implanted transmitter with R-wave detection of each ECG signal transmits pulses either directly to a nearby receiver or to a receiver/retransmitter collar worn by the animal to achieve long range. A brief burst of pulses for the temperatures is periodically transmitted at appropriate heartbeat counts. The system employs extensive signal recognition and conditioning features. Final digital or analog outputs are achieved through a microprocessor, either with or without an intermediate tape storage of the data.

This system will be described more fully elsewhere. Its unit parts as represented at the time of this writing are not illustrated here but were presented in the poster session of this paper for purposes of discussion. This system was developed by G. Lund and D. Westbrook with additional engineering contributions from R. Miranda and T. Fryer, with acknowledgments to the NASA/ARC National Research Council Associate program. A telonics collar transmitter was incorporated into this systems.

LITERATURE CITED

AIBS/BIAC. 1968. Biotelemetry: pro, con, and how. Bioscience 18(4):323-329.

Buechner, Helmut, Craighead, Frank C., Jr., Craighead, John J., and Cote, Charles E. 1971. Satellites for research on free-roaming animals. Bioscience 21(24): 1201-1205.

Craighead, Frank C. 1970. Smithsonian Institution Conference on Animal Orientation and Navigation, Session II: Animal Tracking, pp. 99-111.

Craighead, John J., Craighead, Frank C., Jr., Varney, Joel R., and Cote, Charles E. 1971. Satellite monitoring of black bear. Bioscience 21(24):1206-1211.

Craighead, Frank C., Jr. 1978. Assessment of needs for satellite tracking of birds and suggestions for expediting a program. Final Report, NASA Grant NSC-2157, Environmental Research Institute, Moose, Wyoming 83012.

Evans, W. E. 1972. Mobile marine environmental survey vehicle. NUC TN 758, Ocean Sciences Dept., Naval Undersea Center, San Diego, California.

Goodman, R. M. (FIRL), and Norris, K. S. (UCSC). 1975. Techniques and instrumentation effort for whale migration tracking. Final Report, NASA Contract NAS2-8013, Technical Monitor, Paul Sebesta, Mail Stop 236-5, NASA/ARC, Moffett Field, California.

Lund, Gordon F. 1974. Time and energy budgets, by telemetry of heart rate from free ranging black-tailed prairie dogs in natural and in model environments. Ph.D. Thesis, Dept. of Zoology, University of Iowa, Iowa City.

Lund, Gordon F., and G. Edgar Folk, Jr. 1976. Simultaneous measurements of heart rate and oxygen consumption in black-tailed prairie dogs (Cynomys ludovicianus). Comp. Biochem. Physiol. 55A:201-206.

Ray, Carleton G., and Wartzok, Douglas. 1975. Synergistic remote sensing of walrus and walrus habitat. Proc. Workshop on Remote Sensing of Wildlife. Ministere du Tourisme, de la Chasse et de la Peche, Quebec, Canada, D. Heyland (ed.), pp. 145-150.

Ray, G. C., Mitchel, D., Wartzok, D., Kozicki, V., and Maiefski, R. 1978. Radio tracking of a fin whale (Balaenoptera physalus). Science (in press).

Sebesta, Paul. 1974. Report on 1973 Santa Cruz Summer Study on Wildlife Resources Monitoring. NASA Ames Research Center, Moffett Field, California.

Varney, Joel A., and Ellis, David H. 1974. Telemetering egg for use in incubation and nesting studies. Journal of Wildlife Management 38(1):142-148.

Varney, Joel A., and Pope, Roger L. 1974. Nimbus-F/RAMS DCP transmitter microminiaturization feasibility study. Technical Memorandum 74, Philco-Ford Corporation, Palo Alto, California 94303.

Werber, Morton. 1970. A bibliography of wildlife movements and tracking systems. The George Washington University Medical Center, Dept. of Medical and Public Affairs, Washington, D.C. 20009 (NASA Contract NSR 09 010 027).

Integrated Resource Inventory for the Resources Planning Act[1]

Richard E. Francis[2]

Richard S. Driscoll

Abstract.--The multiresource research and development responsibilities of the USDA Forest Service Resources Evaluation Techniques Program are discussed in conjunction with resource legislation, agency coordination, an ecological data base, and remote sensing.

INTRODUCTION

The Forest and Rangeland Renewable Resources Planning Act (RPA, U.S. Congress 1974), recognizes the vital importance of and increasing demand for America's natural renewable resources occurring on the Nation's forests and rangelands. The necessity for long term planning and the relation to national renewable resources programs administered by the Forest Service and other Agencies is recognized also.

The RPA directs the Secretary of Agriculture "...to make and keep current a comprehensive survey and analysis of the present and prospective condition of and requirements for the renewable resources of the forest and rangelands of the United States, its territories and possessions, and of the supplies of such renewable resources, including a determination of the present and potential productivity of the land...". The authority and responsibility for carrying out this mandate was delegated to the Chief of the Forest Service. The first renewable Resource Assessment (USDA Forest Service 1975a) and accompanying Program (USDA Forest Service 1975b) have been developed.

[1]Presented at the PECORA IV Remote Sensing Symposium...Application of Remote Sensing Data to Wildlife Management; Sioux Falls, South Dakota, Oct. 10-12, 1978.

[2]Associate Range Scientist and Program Manager, respectively, USDA Forest Service, Resources Evaluation Techniques Program, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80526.

THE RESOURCES EVALUATION TECHNIQUES PROGRAM

In response to the RPA requirement for multiresource inventories, a Forest Service Research and Development Program was established in Fort Collins, Colorado at the Rocky Mountain Forest and Range Experiment Station. The mission of the Resources Evaluation Techniques Program (RET) is, "to maintain and improve capabilities for national inventories and analyses of renewable resources".[3] Maintenance of inventory and analysis capabilities requires research into the design and development of modified, combined, or new inventory, classification, and analysis procedures. The techniques and procedures developed within the Program may be modified in line with the established data base, classification system, and/or program requirements. Aldrich (1978) discusses alternative approaches, problems, and progress related to multiresource inventory.

Three major problems have been defined by the Program for completion by December 1981:

1. Conceptualize the framework for a multiresource inventory and develop tools and procedures for operational multipurpose inventories;

2. Develop improved techniques for estimating future biological and economic supplies of and demands for natural resource products;

[3]Research and Development Program Charter, Resources Evaluation Techniques, FS-RM-R&D-4151, Fort Collins, Colo. 1976. 20 p.

3. Develop mechanisms for storage, retrieval, display, and update of data bases for national assessments.

In addition, the Program has the following responsibilities:

4. Summarize and selectively analyze data for the timber, wildlife, and fish Assessments for 1980;

5. Determine information needs and priorities (INA) for the 1990 RPA Assessment; and

6. Recommend a land and resource classification system to be used for future Assessments.

Several studies designated within each problem area are being conducted.

LEGISLATION AND COORDINATION

Recent legislation has additional impacts on the need for and requirements of coordinated multiresource inventory systems, data bases, and analytical processes. In addition to RPA, these Acts are the: 1) National Forest Management Act (NFMA, U.S. Congress 1976a), 2) Federal Land Policy and Management Act (U.S. Congress 1976b), and 3) Soil and Water Resource Conservation Act (U.S. Congress 1977). The Acts are directed toward the Forest Service, Bureau of Land Management, and the Soil Conservation Service, respectively.

Some common themes of these Acts are: 1) to prepare and maintain continuous resource inventories, 2) coordinate and cooperate with other resource agencies and organizations to avoid duplication of inventory and planning efforts, 3) determine the changes in status and condition, both current and potential, of the resource base, 4) determine resource interactions and management alternatives, and 5) submit periodic reports on the resource situation.

To assure coordination and compatibility of Agency resource inventories, resource analysis, and information systems, formal agreements have been made with the Bureau of Land Management (BLM), Economics, Statistics and Cooperative Services (ESCS), Fish and Wildlife Service (F&WS) and the Soil Conservation Service (SCS). These agreements identify areas of responsibility, define some basic terms and concepts, provide for personnel exchange, and establish channels of communication. Currently, one BLM and two SCS people have been assigned full-time and one person each from the ESCS and the F&WS have been assigned to the Program on a part-time basis. Similar liaison and coordination is carried out informally but purposefully with other agencies, organizations, and institutions to develop continuity.

WILDLIFE ASSESSMENTS

The RPA set no firm guidelines for resource inventory parameters to be measured, analyzed, or interpreted. However, rules have been developed to guide National Forest System (NFS) resource planning (USDA Forest Service 1978). The proposed regulations will implement provisions of the RPA as amended by the NFMA. The affected NFS lands and resources are to be managed according to the planning process set forth in these regulations. "The planning process is intended to integrate all functional resource planning...". Included within the Forest planning process are general criteria for inventory data and information collection. "Inventory data must be collected about: 1) soils and geology; 2) natural water occurrences, including quality and quantity, and wetlands and flood plains; 3) existing plant life, including threatened and endangered species; 4) existing fish and wildlife, including threatened and endangered species; 5) habitat conditions for selected vertebrate or invertebrate species; and 6) quantitative data for determining species and community diversity" (USDA Forest Service 1978).

Previous assessments of wildlife and fish have dealt with hunter numbers and characteristics, number of animals and fish, economic returns, demands for hunting and fishing, and management opportunities (USDA Forest Service 1975a). Now, the Forest Service is making a more comprehensive national Assessment of wildlife and fish resources (Schweitzer and Cushwa 1978). Differences among major geographic areas, the impacts on wildlife and fish populations resulting from commodity production, and a discussion beyond the traditionally emphasized game species will be in the RPA Assessment for 1980.

The assessment data will be gathered and applied through resource planning and management standards and guidelines set forth in the proposed planning rules (USDA Forest Service 1978). The proposed rules for resource management standards and guidelines address the functional resource systems of: a) wildlife and fish, b) range, c) recreation, d) timber, e) water and soils, and f) wilderness. Management planning of the fish and wildlife resource will include: 1) the amount and quality of habitat; 2) analysis of habitat modifications, including consideration of year-long suitability of the habitat; 3) determining the relationship of population trends to habitat changes; and 4) determining critical habitat for threatened and endangered species.

Aligned very closely with the selected habitat specific requirements listed above, is management planning that affects the range resource. The standards and guidelines set forth in the proposed regulations are "to determine the ability of the range to supply long-term grazing and browsing". Included are: 1) "range condition, range trend, successional stages of vegetation and changes in the diversity of plant and animal communities will be determined; 2) records of current levels of use by grazing and browsing animals will be maintained; 3) existing or potential grazing or browsing competition between animals will be evaluated; and 4) existing and potential development and management systems will be considered" (USDA Forest Service 1978).

INVENTORY AND THE CONCEPT OF AN ECOLOGICAL DATA BASE

Informed decision-making requires inventories and update (monitoring) at all management levels to determine the kind, areal extent, quality, quantity, location and juxtaposition of resources. Inventories are necessary also to assess the interactions of demand and supply, and cause/effect relationships between and within resource systems, and to provide quantitative information to classify the landscape.

National resource assessments have been developed by the USDA Forest Service (1975a) with the assistance of others according to resource systems (timber, range, wildlife/fish, water, and outdoor recreation/wilderness); continuing assessments will deal with resource interactions. For assessments that account for resource interactions, vegetation and soils information must be collected and analyzed in a manner that is responsive to functional resource systems. To do this, one must realize all systems are interactive and the components of one system may be related to and accounted for in other systems. Therefore, if inventories are done on a strictly functional basis (i.e.: range, timber, or wildlife habitat), "double counting" may occur or different methods may be used for some system components (i.e.: plant species composition). Other components of the resource system may not be measured; this will depend upon inventory requirements of the system for which the estimates are obtained.

Regardless of the level of intensity, inventories based on compatible classification systems are ecologically sound, and have common definitions required for aggregating and dissagregating data to and from national level assessments for program direction and management.

If multiresource inventory defines the structure of the plant community sampled, including measurements such as herbage production, timber volume, and plant cover, with associated soils and physiography, then a truly ecological system should provide realistic interactive analyses. A prerequisite for an ecological data base is inter- and intra-agency method compatibility, at least within resource systems (Francis 1978). Compatible inventory methods, standards, and definitions would allow data to be combined for evaluating resource interaction, management alternatives, and national statistics. It should also avoid duplication of inventorying the same piece of landscape except for special purposes.

The procedures necessary to deal with the above inventory concepts are to: 1) prepare an information needs analysis (INA) which will define data and information requirements for resource systems and identify linkages for information among systems; 2) prepare a land resource classification system that is ecologically based, compatible with inventory design, and compatible with other major national renewable resource classification systems; 3) develop, integrate, and/or modify existing inventory systems into a multiresource system with alternatives; 4) develop, modify, or incorporate existing measurement procedures for the basic elements defined in the INA; 5) prepare sampling procedures, including the integration of remote sensing tools, that are effective and efficient for measuring the basic resource elements; and 6) prepare data summary procedures and techniques from which interpretation for land use and management can be made.

INTERPRETATION OF AN ECOLOGICAL DATA BASE

Basic data and planning requirements overlap between resource systems. Therefore, the concept of a non-functional, ecological data base applies.

Given that quantitative data are collected for vegetation and soils including: standard soil survey information to taxonomically classify the soil to series, the vegetation attributes of density, production/utilization, foliar cover, height, age/form class, and phenology; several parameters are interpretable. These parameters include, but are not limited to: vertical vegetative strata, horizontal pattern of vegetation, plant species composition, ecological response unit, ecological stage, and periodicity. These parameters can then be grouped to make interpretations to functional resource systems, such as wildlife habitat or rangeland ecological stage (condition). The resource systems or parameters can also be grouped to determine cause/effect relationships (interactions), and the base data can be used to classify the landscape unit.

TEST AREAS

Three test areas are being used by the RET Program. The areas are: 1) Colorado--Grand County (Middle Park) within the Rocky Mountain Complex, 2) South Carolina--five counties within the Piedmont and Coastal Plain Complex, and 3) Alaska--the Susitna Valley within the Boreal, Tundra and associated Complexes. These areas were chosen for their diversity of vegetation, soils, land use, physiography, and on-going inventories or studies. The purpose of the areas is to test measurement, sampling and analysis techniques, test the proposed Land Classification System (Driscoll et al. 1978), and serve as demonstration areas for implementing promising techniques. Included in the data collection techniques are both ground based and remote sensing tools.

The results from these test areas will provide recommended inventory procedures applicable to various vegetation-soil communities and various levels of sampling intensity, depending on objectives. The concept of an ecologically based inventory should apply regardless of the specific techniques used.

DATA ACQUISITION TECHNIQUES RESEARCH

Ground Methods

There are no "new" ground data collection methods, just modifications, refinements, and/or new application of existing methods. The realm of new techniques falls into the category of combining, modifying, and/or applying the most efficient, effective, accurate, and precise techniques to meet multiresource data collection objectives. Techniques also include sample designs.

Within each of the test sites, ground based inventory techniques are being tested. These techniques address the parameters and interpretations necessary within some of the functional resource systems (soils, timber, range, wildlife habitat).

The objective is to measure or estimate functional resource system attributes for an ecological data base, and from that ecological data base, analyze and interpret data for selected functional needs. Additional objectives included within that broad framework are: 1) apply and evaluate sample designs, 2) apply and evaluate the proposed Land Classification System, 3) evaluate the cost-effectiveness and efficiency of the techniques tested, and 4) recommend a compatible inventory method, and/or alternatives, with input and review from BLM, ESCS, FS, F&WS and SCS.

Remote Sensing

Remote sensing is the acquisition of information from a distance using aerial platforms. It also includes the subsequent display, analysis, and interpretation of that information.

The remote sensing research activities of the Program are to: 1) develop techniques using available data, 2) develop an interface with the proposed National Land Classification System, 3) develop and test remote sensing techniques to provide data needs. 4) keep informed on new developments in remote sensing, 5) test data from improved optical systems, 6) work on unresolved remote sensing problems relating to plant community structure, soils, and atmospheric effects, and 7) test remote sensing in an operational framework.

The overall objectives are to: 1) correlate soil-vegetation data obtained from the ground with that obtained from remote sensors, 2) develop sample designs incorporating remote sensing as a tool, 3) develop cost-benefit ratios, and 4) solve some of the basic energy-matter relationships that affect remote sensor application.

In general, remote sensing studies conducted by the Pacific Southwest and Rocky Mountain Forest and Range Experiment Stations (Aldrich 1976, Carneggie and Reppert 1969, Driscoll 1971, Heller 1975) conclude that: 1) satellite photos or imagery can be used to stratify broad vegetation classes using both manual and computer-aided techniques; 2) low resolution CIR photos or imagery can be used to classify vegetation at the upper levels of a vegetation classification hierarchy; 3) multistage photo and ground sampling can be used to determine the areal extent of plant community types and analyze some habitat components; 4) large-scale (1:600-1:2,400) aerial photos have been used for habitat component analysis--estimates of foliar cover, density, production, litter and soil; and that 5) remote sensing provides a "picture" of an area for reference, change detection, juxtaposition, and more effective sampling.

SUMMARY

The Resources Evaluation Techniques Program is research and development oriented with four project areas: inventory, classification, analysis, and remote sensing.

To develop inter- and intra-agency coordination and help solve researchable problems, the Program is coordinating and cooperating directly with five resource agencies: BLM, ESCS, FS, F&WS, and SCS.

The Program objectives are working toward developing compatible information needs and requirements, inventory techniques, definitions, land and resource classification, ecological (non-functional) data bases, and information management systems.

LITERATURE CITED

Aldrich, R.C. (tech. coord.). 1976. Evaluation of Skylab (EREP) data for forest and rangeland surveys. USDA For. Serv. Res. Pap. PSW-113, 74 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Aldrich, R.C. 1978. A national multiresource inventory system: possibilities, problems, and progress. In Integrated inventories of renewable natural resources: Proceedings of the Workshop. p. 474-480. G.H. Lund et al. (tech. coord.). Gen. Tech. Rep. RM-55, Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Carneggie, D.M. and J.N. Reppert. 1969. Large-scale 70mm aerial color photography. Photogram. Eng. 35:249-257.

Driscoll, R.S. 1971. Color aerial photography: a new view for range management. USDA For. Serv. Res. Pap. RM-67, 11 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Driscoll, R.S., J.W. Russell, and M.C. Meier. 1978. Recommended national land classification system for renewable resource assessments. USDA For. Serv., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 44 p. draft mimeo.

Francis. R.E. 1978. Current rangeland inventory methods-compatibility toward a ecological base? In Integrated inventories of renewable natural resources: Proceedings of the Workshop. p. 91-103. G.H. Lund et al. (tech. coord.). Gen. Tech. Rep. RM-55, Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 482 p.

Heller, R.C. (tech. coord.). 1975. Evaluation of ERTS-1 data for forest and rangeland surveys. USDA For. Serv. Res. Pap. PSW-112, 67 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

U.S. Congress. 1974. Forest and rangeland renewable resources planning act. 88 STAT. 476, PL93-378, 93rd Congress, Wash., D.C., Aug. 17.

U.S. Congress. 1976a. Federal land policy and management act. 90 STAT. 2743, PL94-579, 94th Congress, Wash., D.C., Oct. 21.

U.S. Congress. 1976b. National forest management act. 90 STAT. 2949, PL94-588, 94th Congress, Wash., D.C., Oct. 22.

U.S. Congress. 1977. Soil and water resources conservation act. 91 STAT. 1407, PL95-192, 95th Congress, Wash., D.C., Nov. 18.

USDA Forest Service. 1975a. RPA: The Nation's renewable resources--an assessment. Wash., D.C. 345 p.

USDA Forest Service. 1975b. RPA: A recommended renewable resource program. Wash., D.C. 658 p.

USDA Forest Service. 1978. National forest land and resource management planning--proposed rules. Fed. Regr. 43(170):39046-39059.

Schweitzer, D.L. and C.T. Cushwa. 1978. A national assessment of wildlife and fish. Wildl. Soc. Bull. 6(3):149-152.

Characterization of Terrestrial Vertebrate Habitats Using Remotely Sensed Imagery[1]

Duane A. Asherin[2]

James E. Roelle[3]

Henry L. Short[3]

Abstract.--Land cover maps obtained from photo-interpreted aerial imagery were used for predicting avian use of sections of land in southeastern Montana. Number of polygons of vegetation per section was the most important predictor of the number of bird species per section, and was a far better predictor in sample sections containing homogeneous vegetation than in sample sections containing diverse vegetation. The vertical dimension of habitat is possibly more important when areas of greater diversity are considered and it is suggested that remote sensing efforts attempt to include an interpretation of this vertical dimension.

INTRODUCTION

Prospective large-scale energy developments in the western United States, especially coal and oil shale strip mining, make it extremely desirable that decisionmakers have a means of rapidly assessing the probable impacts of those developments on fish and wildlife resources. Time, money, manpower, and accessibility constraints make regional or large site-specific evaluations difficult or impossible using conventional field inventory techniques. The Western Energy and Land Use Team (WELUT) of the Office of Biological Services, U.S. Fish and Wildlife Service, is attempting to develop a process that utilizes remotely sensed imagery, existing data on wildlife habitat requirements, and a computerized geographical information system for characterizing the relative utility of blocks of habitat to the total vertebrate community.

Development of the process has been guided by several basic assumptions.

(1) The methodology should be objective and capable of being implemented over large areas using existing or easily acquired information.

(2) The methodology should provide a basis for establishing, from a wildlife perspective, a preferred sequence of development for those large areas.

(3) The methodology should be transferable, without major modification, to any geographic area.

(4) Since other efforts within the Fish and Wildlife Service are adequately addressing the question of species-specific habitat suitability, the methodology should integrate information for as many different vertebrate species as possible.

This paper discusses the initial application and field testing of the resulting characterization process on 350 mi^2 (907 km^2) of land in southeastern Montana.

---

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

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

[3]Terrestrial Ecologist, U.S. Fish and Wildlife Service, Western Energy and Land Use Team, Fort Collins, Colorado 80526.

STUDY AREA

For the purposes of this project and other related studies the Western Energy and Land Use Team has identified a series of five regional test areas in the western United States where large scale energy developments are likely to be important for many years in the future (Fig. 1). We concentrated our initial efforts on the Montana/Wyoming Test Area because of the current and potential degree of development activity. In particular, we began with the Hardin NE Quadrangle because it was the first portion of the Montana/Wyoming Test Area for which interpreted aerial imagery was available.

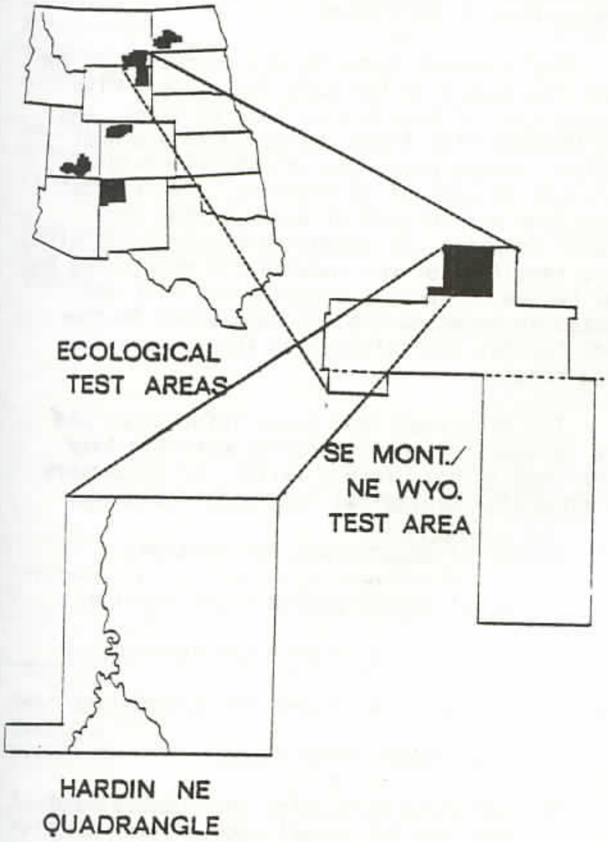


Fig. 1.--Regional test areas identified by the Western Energy and Land Use Team and location of Hardin NE Quadrangle.

The Hardin NE Quadrangle is located in Powder River and Rosebud Counties, Montana, within the drainages of the Tongue and Powder Rivers. The area is underlain by coal beds of the Tongue River member of the Fort Union Formation (Matson and Blumer 1973) and falls largely within Küchler's potential vegetation type number 16, Eastern Ponderosa Forest (Küchler 1964). Ponderosa pine (*Pinus ponderosa*) and juniper (*Juniperus scopulorum*) dominate the higher elevations, while vegetation typical of Küchler types 55 (Sagebrush Steppe), 64 (Grama-Needlegrass-Wheatgrass), and 66 (Wheatgrass-Needlegrass) is found in more xeric areas. Occasional stringers of Küchler type 98 (Northern Floodplain Forest) are also found along water courses. For a more detailed description of the vegetation in the vicinity of the study area, see Knapp (1977).

METHODS

The terrestrial vertebrate characterization process being developed at WELUT involves the following major steps.

(1) Development of a land cover classification system reflecting the important wildlife habitat components of the area.

(2) Acquisition of remotely sensed imagery for the area to be characterized.

(3) Interpretation of the imagery and production of maps according to the land cover classification system.

(4) Digitization of the resulting maps for use in a computerized geographic information system (GIS).

(5) Development of a data base relating breeding and feeding requirements of terrestrial vertebrate species to the land cover types in the classification system.

(6) Investigation of actual use of sample sections of habitat by the vertebrate community.

(7) Utilization of the GIS and species data base for calculating a variety of ecological parameters and indices concerning these same sections.

(8) Comparison of field- and computer-derived values for the development of predictive relationships concerning utilization of habitats by terrestrial vertebrate species.

In the development of the characterization process, we used color infrared (CIR) aerial imagery flown in 1976 at 1:31,680 scale. The land cover classification system (Tom 1978, Table 1) was designed by WELUT personnel specifically for use in the characterization process. Imagery was interpreted according to this classification system (40-acre minimum polygon size) in a process briefly described by Parker (1978). HRB-Singer will have available early in 1979 a more detailed report concerning this mapping capability. Field verification studies conducted during the summer of 1978 on the Montana/Wyoming Test area indicated an 83 to 85% photo interpretation accuracy at the 95% confidence level.

Acetate overlays (1:24,000 scale) of the resulting land cover maps were manually digitized using Altek and Tektronix graphics tablets. Following entry and editing, the digital map data were transferred to the GIS for storage, retrieval, and analysis (Salmen et al. 1978).

The vertebrate species-habitat use data base developed for the characterization process contains feeding and breeding information relating 231 species of birds, 74 species of mammals, 14 species of reptiles, and 6 species of amphibians to the land cover types contained in the classification system. Sources for the data base included published information on species distribution and habitat use patterns as well as the professional opinions of state and federal biologists about those species for which documented material was lacking. The vertebrate species-habitat use information obtained by our 1978 summer field crew was also used to supplement this data base (see below).

During the summer of 1978 we conducted a field validation study in the Hardin NE Quadrangle of southeastern Montana. The objective of the field study was to assess the actual terrestrial vertebrate use of land cover types in the Hardin NE Quadrangle for comparison with ecological parameters determined from the species-habitat use data base and the photo-interpreted CIR imagery. The 330 sections of land in the Hardin NE Quadrangle were divided into six diversity strata based on the number of mapped polygons per section. Eight sample sections were then randomly drawn from each of the six diversity strata. Two crews of two persons each attempted to sample the bird and small mammal species present on the 48 selected sections during June and July. Only 38 of the 48 selected sections could be completed because of a decrease in bird song activity in mid-July. Birds and mammals in each of the 38 sections were intensively sampled by one crew for 2 consecutive days. Extensive searches for other vertebrate species (e.g., reptiles and amphibians) were also conducted on the same sections of land.

For each section, the sampling design for birds consisted of 16 sampling stations located systematically at 220-yard intervals in a square approximately 1/4 mile within the section boundary. Bird censuses began 1/2 hour before sunrise and continued until bird activity dropped off significantly, usually about 1000 to 1100 hours MDT. All birds seen or heard were recorded at each of the 16 sampling stations for a 3-minute period after waiting a suitable interval at each station for normal feeding and singing activity to resume, usually 2-5 minutes. The observer also recorded all birds flushed or heard between stations. Flushing-transect and observation-station samples were treated separately so that the same bird could be recorded on both types of samples. Field notes were taken on cassette recorders and later transcribed to data forms.

Small mammal sampling was conducted at the same stations used for sampling birds. Five Museum Special snap traps, two rat traps, and two Sherman live traps, baited with a peanut butter, rolled oats, and animal fat mixture, were set at each of 16 stations. "Best site" locations within 10 m of each station were used. Trapping was conducted concurrently with bird sampling for two consecutive nights and the day between. Special trapping was also conducted in selected habitats and areas to provide habitat use information for the species data base.

The digitized land cover information and the vertebrate species-habitat use data base were used to calculate a variety of parameters of potential ecological interest, including:

(1) Number of cover types per section;

(2) Number of mapped polygons per section;

(3) Number of miles of edge per section;

(4) Proportion of each section occupied by

   a. individual cover types,

   b. wildland (excluding agricultural and residential areas) with greater than 20% tree canopy coverage,

   c. wildland with less than 20% tree canopy coverage,

   d. upland grassland, and

   e. non-wild lands;

(5) Number of polygons of woodland (greater than 20% tree canopy coverage), shrubland (greater than 20% midstory coverage), and grassland per section, where adjacent

Table 1.--Percent vegetation cover types on experimental sections of the Hardin NE Quadrangle.

		Percent vegetation cover as mapped				
	No. of Sections	Shrubs to 80%, herbs greater than 20%, trees less than 2%	Shrubs to 80%, herbs to 20%, trees less than 20%	Trees to 80%, herbs and shrubs variable	Tree canopy greater than 80%	Other
All Surveyed Sections in Hardin NE	38	53.9	15.5	25.1	0.3	5.2
Sections Containing Primarily Ponderosa Pine Upland	11	21.8	17.8	54.6	1.1	4.7
Sections Containing Primarily Sagebrush Steppe	9	78.7	14.7	0.3	0	6.3

Table 2.--Number of variables entered into step-wise multiple regressions to achieve the indicated multiple R values in the prediction of number of bird species per section.

	No. of sections	Multiple R Values			
		0.70	0.80	0.90	0.99
All Surveyed Sections in Hardin NE	38	6	9	15	>20
Sections Containing Primarily Ponderosa Pine Upland	11	1	2	3	7
Sections Containing Primarily Sagebrush Steppe	9	1	1	2	4

polygons from the detailed mapping effort were lumped together in these broader categories;

(6) Miles of edge per section when polygons were lumped into woodland-shrubland-grassland groupings;

(7) A faunal diversity index; and

(8) A juxtaposition index.

The faunal diversity index is a summation for the section of the products of the acreage of each cover type in the section times the number of species utilizing that cover type as a focus for breeding or feeding. The juxtaposition index is a measure of the quality of habitat edge consisting of the summation for the section of products of the linear extent of each edge type in the section times the number of species feeding in both cover types making up the edge. A step-wise multiple regression analysis was performed to ascertain the utility of these variables as predictors of the number of bird species observed in each section during field sampling. Data from the other vertebrate groups are still being analyzed.

RESULTS AND DISCUSSION

The vegetative composition of the 38 sampled sections in the Hardin NE Quadrangle is summarized in Table 1. Over 50% of the area is sagebrush steppe with widely scattered trees (less than 2% canopy coverage). About 25% of the area is characterized by a ponderosa pine canopy between 20% and 80% coverage, while an additional 15% of the area supports a mixture of shrubs (20-80% ground coverage) and ponderosa (2-20% canopy coverage). Also summarized in Table 1 is the vegetative composition of two fairly homogeneous subsamples of the 38 sections, one consisting largely of ponderosa pine, the other largely of grassland-sagebrush steppe.

When all 38 sections were considered, correlation and regression relationships between number of bird species observed per section and independent variables derived from photo interpretation were statistically significant but not strong. Number of polygons of mapped vegetation per section was the most important variable in the regression, but accounted for only 16% ($R = 0.40$) of the observed variation in number of bird species. Many more variables had to be entered into the regression to account for a major proportion of the variation (Table 2).

However, many fewer variables were necessary for predicting the number of bird species observed in the more homogeneous subsamples. The first of these subsamples consisted of 11 sections containing primarily ponderosa pine upland (Table 1), and represented the most heavily timbered area inventoried during the summer of 1978. Number of bird species observed per section could be predicted in this homogeneous subsample with far greater precision than for the total 38 sections (Table 2). Number of lumped (into major vegetation types) polygons per section was the most important variable in the regression, accounting for about 56% ($R = 0.75$) of the variability in the number of bird species observed.

Similarly, our data indicate that estimates of the quantitative distribution of bird species can be obtained with good efficiency on fairly homogeneous sagebrush steppe habitats in the northern Great Plains (Table 2). Once again number of mapped polygons per section was the most important independent variable, accounting for about 66% ($R = 0.81$) of the variability in the number of bird species observed.

Thus, our preliminary results seem to indicate that some measure of the number of vegetative polygons is an important variable in the prediction of use of an area by birds. This is perhaps not surprising since the number of polygons is closely correlated in most cases with the amount of habitat edge ($r = 0.90$ for the 38 sample sections), and increased edge has long been known to contribute positively to bird species diversity (Odum 1971).

Furthermore, it is of interest that the relationship between numbers of vegetative polygons and numbers of bird species is stronger within homogeneous samples than across samples that are quite diverse. It seems possible that when the vertical dimension of the habitat tends to remain constant (as in either the ponderosa pine or sagebrush subsamples) a two dimensional representation of habitat diversity is a sufficient predictor of avian species diversity. However, when the vertical dimension of the habitat is extremely variable, the two dimensional representation of habitat diversity is no longer adequate. Bird species diversity has been related to several indices of habitat diversity that contain a vertical component, including foliage height and foliage height diversity (Balda 1975). We interpret these results to mean that we have not yet adequately described the structure of complex habitats in our two-dimensional representation and that our future efforts must stress an interpretation of the vertical dimension of habitat if we are to be successful in utilizing aerial imagery and its photo interpretation in the prediction of use of an area by the vertebrate community.

ACKNOWLEDGEMENTS

This study is funded by the Coal Project, Office of Biological Services, U.S. Fish and Wildlife Service. We are indebted to Lisa Langelier, Barbara Schrader, John Gimbel, and Curt Mack for their excellent work in field sampling the bird and small mammal vertebrate groups during the 1978 summer field season. Messrs. Steve Amstrup, Dean Biggins, Mike Lockhart, Terry McEneaney, and Bob Phillips of the Denver Wildlife Research Center were helpful in providing information for the wildlife species-habitat use data base. We are also grateful to Carol Boggis, Nancy Derey, Shelley Nolde, and Barbara Wiese for assisting in the analysis of data and the preparation and design of graphics for the poster board. Our appreciation is also extended to personnel of the Data Support Group for photo interpretations of vegetative information, map preparation, digitization of map based information, and data analysis using the geographic information system.

LITERATURE CITED

Balda, R. P. 1975. Vegetation structure and breeding bird diversity. Pages 59-80 in Dixie R. Smith (technical coordinator). Proceedings of the Symposium on Management of Forest and Range Habitats for Nongame Birds. USDA Forest Service, General Technical Report WO-1. 343 p.

HRB-Singer, Inc. 1979. Research study and technical services project entitled: Western Data Support Center remote sensing development project - development of operational capability. Contract No. 14-16-0009-78-011. (In preparation)

Knapp, S. J. 1977. Birney-Decker wildlife study, final report. Montana Department of Fish and Game, Unpublished Report. 163 p.

Küchler, A. W. 1964. Potential natural vegetation of the coterminous United States. American Geographical Society, Special Publication No. 36.

Matson, R. E., and J. W. Blumer. 1973. Quality and reserves of strippable coal, selected deposits, southeastern Montana. Montana Bureau of Mines and Geology, Bulletin 91. 135 p.

Odum, E. P. 1971. Fundamentals of ecology. W. B. Saunders Co., Philadelphia. 574 p.

Parker, H. D. 1978. Remote sensing for regional habitat analysis in the United States. In Proceedings of the Fourth William T. Pecora Memorial Symp., Sioux Falls, S. D.

Salmen, L., J. Gropper, J. Hamill, and C. Reed. 1978. Geographic Information System users manual. FWS/OBS-78/96. U.S. Fish and Wildlife Service, Western Energy and Land Use Team, Fort Collins, CO. (In press)

Tom, C. 1978. Image processing applications to western wildlife habitat inventory. In Proceedings of the Fourth William T. Pecora Memorial Symposium, Sioux Falls, S.D.

Use of Remote Sensing Techniques on the Ohio River in West Virginia by the U.S. Fish and Wildlife Service [1]

Roger L. Collins[2]

David B. Harris[3]

Abstract.--Three hundred and forty one miles of the Ohio River are being remotely sensed by the Elkins Sub-office, Ecological Services, U.S. Fish and Wildlife Service. This data is being used in the evaluation of a major navigation project and to improve efficiency in permit review and other activities. A methodology for habitat cover mapping and permit review is developed and presented. Costs for the remote sensing effort is included as well as a discussion of costs and savings associated with remote sensing permit review.

INTRODUCTION

Coastal and riverine environments are being altered at an alarming rate by actions related to energy development, industrialization, and urbanization. Consequently, much prime fish and wildlife habitat is being destroyed or adversely modified. To quantify these losses, baseline natural resource data is essential.

The U.S. Fish and Wildlife Service, through its policies, philosophies, and legislative mandates, is the lead federal agency responsible for protection of fish and wildlife resource values as related to water and land resource development. The Service, as well as state natural resource agencies, is faced with ever increasing responsibilities and workload commitments. At the same time personnel and operational funds often remain the same or decline. To continue to adequately meet our responsibilities as resource managers, more efficient methods of performing tasks are needed. In response, the Elkins Sub-office of Ecological Services is actively utilizing and accelerating its use of remote sensing techniques to develop sound ecological information base maps on various projects on the Ohio River and interior West Virginia. Wobber (1975) presents case histories for five eastern states on their remote sensing programs and the trend to use this technology for more practical problem-solving in natural resource management.

Two major activities on the Ohio River where remote sensing technology is being used include the Gallipolis Locks and Dam Replacement Study, Huntington District, Army Corps of Engineers and the Corps' Permit Program in the Huntington and Pittsburgh Districts.

The Gallipolis study is an evaluation of the direct and indirect effects of providing a longer, deeper navigation facility at Gallipolis. The major implication of the project is increased barge traffic on the Greenup and Gallipolis Pools of the Ohio River above and below Gallipolis and in the Kanawha and Big Sandy Rivers. The study will identify additional cargo handling facilities needed to support increased barge traffic. The Fish and Wildlife Service's role in the study, under the authority of the Fish and Wildlife Coordination Act (48 Stat. 401, as amended; 16 U.S.C. 661 et seq.), is to provide a map of fish and wildlife habitats and resources associated with the river. This map forms the basis for evaluation of direct impacts associated with site

---

[1] Paper presented at the Poster Session of the Fourth Annual William T. Pecora Memorial Symposium - Application of Remote Sensing Data to Wildlife Management, Sioux Falls, South Dakota, Oct. 10-12, 1978.

[2] Wildlife Biologist, Ecological Services, U.S. Fish and Wildlife Service, Elkins, WV.

[3] Senior Staff Biologist, Ecological Service, U.S. Fish and Wildlife Service, Elkins, WV.

development and increased river traffic. Data will be used to assess locations of proposed new commercial facilities. In addition, areas of high resource value will be delineated and recommendations concerning their management, conservation or preservation will be developed.

The Corps of Engineers, under its Regulatory Program, is responsible for administering various federal laws regulating certain activities within navigable waters. Section 404 of the 1972 and 1977 amendments to the Federal Water Pollution Control Act (FWPCA) establishes regulations for the disposal of dredge and fill materials. Section 10 of the Rivers and Harbors Act of 1899 establishes regulations to control construction activities in navigable waters. The Fish and Wildlife Coordination Act authorizes the Service to review and comment on public notices issued under this program. Typical activities reviewed on the Ohio River include coal loading and barge fleeting facilities, sheet pile cells, barge docks, recreational boat docks, commercial marinas, bank stabilization, and highway related fills. Our analyses of such proposals is complemented to a considerable degree by photo-interpretation.

Currently, extensive field level use of remote sensing techniques by Ecological Services is limited. We propose to present a detailed scheme by which field level personnel engaged in habitat and resource inventory of large areas may utilize remotely sensed information. This can be accomplished with simple photogrammetry equipment and limited photo-interpretation experience. However, a more cost effective program can be developed with increased capital investments.

STUDY AREA

For purposes of the study, the historical floodplain area was defined as from toe of ridge to toe within the Ohio River Valley proper. West Virginia's jurisdiction on the Ohio River begins at river mile 40.1 and extends to river mile 317.2. The Gallipolis Study area also encompasses the Greenup Pool which extends downstream to river mile 341.0. Therefore, this lower reach was also included in our study area.

The Ohio River, and it's islands, embayments, and wetlands are some of West Virginia's most important fish and wildlife habitats. The river is the best and most heavily utilized fishery in the state and is also the most significant water area for migrating waterfowl and shore birds. The value of the river and it's habitats is high. These areas become even more important as industrialization of the valley progresses and threatens prime fish and wildlife habitats.

MATERIALS AND METHODS

The Service purchased color infrared (CIR) aerial photography of the Ohio River from river mile 0.0 to river mile 341.0, acquired by Clyde E. Williams & Associates, Inc. (CEWA), of South Bend, Indiana. Scale was 1:24,000 (1" = 2,000'). Format was 9 by 9 inch positive transparencies. Coverage included a 60% forward overlap for stereoscopic interpretation and an approximate ground width of 18,000' centered on the river. A Wild RC-8 precision mapping camera with a 6" focal length lens and a Wratten 12 filter were used. Exposure was made on Kodak Aerochrome Infrared film 2424 at an altitude of 12,000 feet between May 8 and June 4, 1977, inclusive.

Initially, clear acetate copies of U.S. Geological Survey (USGS) 7.5 minute topographic maps were obtained to provide a base for mapping purposes on the Gallipolis Study (river mile 237.5 to river mile 341.0). A tabulation form was also exposed on the acetate to provide a systematic method of recording data delineated on the topo sheets. However, we elected to change to a frosted mylar minus the tabulation sheet for the remainder of the river in West Virginia. Rough draft maps were prepared in pencil on frosted mylar work sheets. Final baseline maps were prepared by posting delineated areas onto the acetate or mylar topographic sheets with Artone acetate ink and Pelikan China T ink, respectively. Ziptone or other transfer type letters and numerals were used for legends. The final product (scale 1:24,000) was prepared by making "blackline" copies of the camera-ready quad sheets superimposed with the completed data tabulation form.

The transparencies, encased in plastic folders, numbered and dated, were indexed according to river mile and topographic map for quick reference and retrieval. Photography was interpreted monoscopically with a hand magnifying glass and by conventional techniques utilizing a mirror stereoscope (1X,5X) and light table. Topographic maps and CEWA data aided in the photo analysis.

All wetlands larger than two acres were identified and typed according to FWS Circular 39 (Shaw and Fredine 1971). Four broad land use categories (forest, urban, industrial, agricultural) were mapped according to the criteria established by USGS Professional Paper 964 (Anderson et al. 1976) Riparian and river bottom hardwoods were specifically delineated within the forest category.

Embayments and high quality resource areas were also mapped. High quality areas are those having above normal recreational, terrestrial, and aquatic values for fish and wildlife. Supplemental information provided by various state, federal, and private organizations was especially important in the designation of high quality fish, wildlife, and recreational areas.

Extensive ground truth investigations were conducted to check land uses and wetland areas that were difficult to classify by photo-interpretation. Nearly all wetlands and embayments were field checked because we were gathering additional site specific data on their habitats, quality, usage by wildlife, and recreational resource potential. Discrepancies were noted and appropriate changes were made on the draft maps in the field. A "field board" was devised for use of the topographic maps and draft mylar base maps during our field reconnaissances. This consisted of two carriage bolts with wingnuts appropriately spaced through the top of a 3/8" sheet of plywood and through a firring strip which bound the maps at the top. Holes of the appropriate bolt diameter were punched in the topo's and mylar for this attachment. This offered a relatively lightweight but stable platform for keeping the maps flat, clean, and accessible.

Following the field inspections, acreages of all land use categories, wetlands, embayments, and high quality areas were measured and calculated with a compensating polar planimeter and/or dot grid. This, as well as all other descriptive information, was recorded on the data tabulation form for each quadrangle.

Methodology - Permits

In general, for permit analysis on the Ohio River, we utilized the CIR photographs for a site specific interpretation of resources and to determine if an on-site inspection was warranted. Among other information, Corps' public notices provide descriptions of an applicant's proposed work and the specific location of this construction by river mile. Since the CIR photography is indexed by topographic map and river mile we easily extract the desired photographs for interpretation. The photos were viewed both monoscopically and stereoscopically. Particular attention was focused on such factors as land uses adjacent to the proposed site, extent of riparian habitat, maturity and interspersion of habitat types, condition of streambank, and cultural encroachments.

Subjective judgement was exercised to determine if a sufficient amount of data had been interpreted correctly from the photographs or if a field investigation was warranted. If the former, the interpreter assimilated this information with existing resource information available from the files, literature, other field personnel, and personal knowledge of the area. This data forms the basis for assessing impacts of the proposed project on fish and wildlife resources.

Realizing that land use patterns might have changed since the photographs were taken and assessment errors could occur, we generally included the following "remote sensing paragraph":

> In assessing this public notice, the Service has utilized remote sensing techniques. The most current aerial photography available to our office has been analyzed. This photo-interpretation serves as the basis for the assessment of existing habitats and land use at the project site. Remotely sensed data, integrated with available biological data, has been utilized in an appraisal of this public notice in lieu of an on-site investigation. If there are any questions regarding our photo-interpretation or assessment of existing conditions please contact the Elkins Sub-office of the Fish and Wildlife Service, 304-636-6586.

RESULTS AND DISCUSSION

Scale

Photographic scale of 1:24,000 was utilized primarily because of its compatability with the scale of USGS 7.5 minute topographic quadrangles, immediate availability of such photographs, and because it provided a suitable scale to address resource, land use, and habitat inventories of a diversified Fish and Wildlife Service program. Lack of sophisticated photogrammetry equipment made it desirable to develop a cost-effective mapping methodology that would utilize a single scale for photography, draft inventory maps, and the final map product. Additionally, this scale provides a format conducive to standardization, computerization, and quick reference and retrieval. Resource information assimilated in this manner can more effectively be retrieved and distributed to complement other state, federal, or private resource inventory programs.

Land Use Classification

USGS Professional Paper 964 (Anderson et al. 1976) describes a land use classification scheme for use with remote sensor data. Classification levels are described for data of different characteristics. Generally, medium altitude data gathered from 1:24,000 photography would be classified as Level III and provide a high degree of subcategorization of major land uses. For example, urban or built-up land (Level I) might be subdivided in Level II to include residential; commercial and services; industrial; transportation, communication, and utilities; industrial and commercial complexes; mixed urban or built-up land; and other urban or built-up land. Level III would contain even further subdivisions. However, the objectives of our studies do not require such a high degree of classification. We, therefore, optioned to use a partial listing of the classes normally identified from Level I, LANDSAT type of data. If future priorities require a breakdown of primary land use categories, our mapping can easily be updated to include this information.

Acreages

Determination of acreages for habitat components has been a time consuming and laborious aspect of our cover mapping procedure. Large regularly shaped areas were measured by dot grid. Small areas, 10 acres or less, and slender irregularly shaped embayments and wetlands were more accurately measured by planimeter. In general, use of the dot grid was less time consuming and compared in accuracy with the planimeter.

The CIR photography used in our projects was not rectified (i.e., corrected for errors due to scale, tilt, relief). Consequently, posting of data from the photographs to the photo base maps of the same scale incorporated an unquantified degree of error into our acreage calculations. Since our objectives of identifying and delineating major resource areas does not require "mapping standards accuracies", we believe that error of this nature is within acceptable limits.

Our experience indicates that approximately 3/4 of a man day is required to determine acreage per quadrangle. For the Gallipolis Study this amounts to about 12 man days or about $700.00 in salary. For 341 miles of the Ohio River, approximately 39.5 man days will be required and will cost about $2,300 in salary. This cost is not excessive considering the area and the complex mosaic of habitats involved. However, use of an electronic planimeter would reduce required man hours from about 6 man hours per quad to about 2 man hours per quad. This would reduce the man hour requirement for acreage determination on 341 miles of the Ohio River to approximately 13 man days or about $770.00. Capitol investment for the equipment is between $1,200 and $1,500. In addition to a substantial man power savings, accuracy remains as high or higher as with other methods.

Costs

Total cost associated with the remote sensing effort on the Ohio River for the Gallipolis Locks and Dam Replacement Study was approximately $6,131.00. This cost is broken down as follows:

Capital Expenditures for Materials	
CIR photography	$625.00
Topographic sheets	32.00
Acetate/mylar topographic sheets	400.00
Miscellaneous supplies	77.00
Final black line maps	24.00
	$1,158.00
Manpower	
Mapping time (90 man-days)	4,208.00
Ground truth (13.5 man-days)	765.00
	$4,973.00
TOTAL	$6,131.00

Mapping time included preliminary map preparation, map correction following ground truth, labeling, acreage determination, and final map production. This cost does not include capital outlay for basic photo-interpretation equipment such as stereoscopes, light tables, planimeters, lamps, and other equipment.

Approximate costs for obtaining a basic remote sensing laboratory are presented below:

Light table	$224.00
Chair	23.00
Planimeter	100.00
Rapidograph pen set	30.00
Lamp	49.00
Mirror stereoscope	1,470.00
TOTAL	$1,896.00

Based on a cost of $6,131, the cost for mapping the Ohio River floodplain within the Gallipolis Study boundaries was about $59 per mile. This can further be broken down to approximately $.06 per acre, assuming an average floodplain width of 1.5 miles. This may very well be an over-estimate on a per acre basis.

Wetlands

Since this has been our initial effort at wetlands inventory and classification, we are fortunate to have at our disposal data from the Ohio River Basin Wetlands Study[4]. This study provided a basic framework we could adapt to and modify to meet the objectives of our study. It also afforded the opportunity to compare inventory methodologies that utilized slightly different criteria.

Our study on the Ohio River identified the following numbers of embayments and wetlands within the Greenup and Gallipolis Pools:

Wetlands

Type 1. - Seasonally flooded basins or flats	16
Type 2. - Inland fresh meadows	5
Type 3. - Inland shallow fresh marshes	11
Type 4. - Inland deep fresh marshes	7
Type 5. - Inland open fresh water	43
Type 6. - Shrub swamps	9
Type 7. - Wooded swamps	8
	99
Embayments	49

Embayments were rather easy to discern on the CIR photographs. Therefore, very few differences were noted between the CEWA data and our study. However, the CEWA study only typed 53 wetlands within the same pools, 46 (46%) less than our study. In addition, we believe 18 (34%) of these wetlands were typed incorrectly. The difference in numbers of wetlands is partially due to their criteria of mapping only wetlands five acres or larger, wetlands not connected to the Ohio River by standing water, and only Types 3, 4, 5, 6, and 7. The predominant types listed by CEWA were Types 5 and 6. This is consistent with our results, but also represents the most easily identifiable inland fresh water wetland types from aerial photographs of a 1:24,000 scale.

Additional discrepancies in data, especially wetland classes, might be a result of our extensive ground truth surveys and the absence of any field verification by CEWA. The CEWA contract did not specify field verified data because of time limitations on the data request and funding constraints. We cannot over emphasize the importance of field checks of inventory data if a high degree of accuracy is to be achieved. Only because of these measures could we accurately classify wetland Types 1, 2, 3, and 4. It is probable that some interpretation errors by CEWA resulted from being unfamiliar with the area and the associated wetland types. We suggest that familiarity with the physical parameters of the river valley and a good knowledge of the ecology of the area helped us achieve a more accurate determination of wetland types. Cowardin and Myers (1974), in mapping Minnesota wetlands, considered the latter essential to mapping and classifying wetland communities.

Permits

The effectiveness and credibility of our use of remote sensing techniques on permit reviews lies solely on the availability of up-to-date photography and the ability of the biologist -- photo-interpretor. The ability of the interpretor to correctly identify existing habitats and a knowledge of associated floral and faunal communities is paramount to accuracy. Impact assessment can be greatly enhanced by personal knowledge and familiarity of an area. Since our initiation of remote sensing for permit review, we have commented on 10 permits by this "modified" method. On one occasion, we were challenged by the applicant on our photo-interpretation. However, a subsequent field inspection with a Corps representative and the applicant revealed our appraisal was correct.

Experience to date indicates it generally takes one hour or less to review a permit application, analyze the CIR photography, and formulate a response. Any site on the Ohio River is no closer than three hours drive from the office. Therefore, a minimum of one man-day would normally be expended for a site inspection alone. Since 1976, this office has reviewed approximately 130 public notices per year, of which 36% were located on the Ohio River. Consequently, the potential to reduce our overall time and manpower involvement in the permit program is evident.

West Virginia is predominently within the mixed mesophytic forest region (Braun 1974). Forest sub-types are not easily delineated via photo-interpretation. Consequently, remote sensing in the state is practically limited to broad vegetational categorization. In coastal areas where wetlands and riparian habitats are usually monotypic and more easily identified on aerial photography, remote sensing technique has even greater utility (Klemas et al. 1974, McEwen et al. 1976, Brown 1978). We believe

---

[4]Conducted by Clyde E. Williams & Associates, Inc. of South Bend, Indiana, for the Ohio River Basin Commission, Cincinnati, Ohio, 1977.

coastal offices substantially involved in regulatory permitting activities can significantly increase productivity and credibility as well as reduce report preparation costs by integrating remote sensing techniques into their permit review process.

Future Potential

Future plans include completion of cover mapping and inventory on the remainder of the Ohio River (river mile 0.0 to river mile 237.5) under jurisdication of this and our parent office. This will provide us with additional documentation of existing conditions. Upon completion, we will have available ground verified information on land uses, wetlands, development, and important fish, wildlife, and recreational areas on the Ohio. We propose to monitor changes, quantify habitat and resource losses occurring along the river, and update our information base yearly by implementing our own photo acquisition program. This would consist of utilizing a small format 35mm camera system (Meyer and Grumstrup 1978) to obtain new photography. Following photo-interpretation we could modify our master data maps to reflect current conditions. Costs for this operation would be relatively minor. Additional photography could also be obtained by use of the 35mm system on other major rivers or areas within projects requiring current photography.

Baseline information on the Ohio River, acquired initially in response to the Gallipolis Locks and Dam Replacement Study, will also apply to other projects. This data would be very valuable for developing a refuge or land acquisition proposal, as the Division of Refuges (FWS) prepared in 1963 and 1964 on the lower Ohio River marshes. In addition, supportive data and documentation of existing conditions would aid policy formulation studies concerning major activities on the river such as commercial sand and gravel dredging operations on the Ohio River in West Virginia, Ohio, and Pennsylvania.

We believe data from our ground verified wetland study could be utilized for the National Wetlands Inventory (NWI) being conducted by the Fish and Wildlife Service. To preclude duplication of efforts it would only be necessary to post data from our maps, utilizing NWI criteria, to maps of scale for the NWI. The NWI is presently attempting to reclassify Circular 39 wetland types, according to the Service's new operational draft for wetlands classifications (Cowardin et al. 1977). Therefore, our wetland designations would have to be transformed to the new classification scheme.

Remote sensing may play an important role in the near future in data collection and analysis on coal mining activities in West Virginia. Title IV of the Surface Mine Reclamation and Control Act of 1977 recommends an inventory of disturbed lands prior to development of a statewide reclamation proposal. Remote sensing techniques utilizing ERTS, LANDSAT imagery, or high altitude, high resolution photography could provide a most reasonable and effective means of accomplishing this type of inventory (Anderson and Schubert 1976, Anderson et al. 1977). The State of Indiana has used small scale color infrared photography to conduct a statewide coal refuse inventory and determine environmental impacts and associated reclamation costs (Wobber 1975, Wobber et al. 1975). Further remote sensing applications to surface mine reclamation are discussed by Cousin et al. (n.d.). Additionally, Grumstrup and Meyer (1977) have reported on the utility of a 35mm camera system for analyzing fish and wildlife resources on disturbed mine lands in western Virginia. They note that the system capabilities exist but practical application is hindered by absence of clearly defined data needs at the surface management level.

The Environmental Contaminants Evaluation (ECE) program is especially well structured for the integration of remotely sensed data. Data on high quality fish and wildlife habitats, identified and mapped in this study, and Corps data on river traffic and locations of hazardous chemical and oil facilities will be integrated. This data will be utilized to cooperatively develop action plans for control of oil spills and hazardous contaminants. For example, action plans would be developed for particular high quality embayments that might be located within a reach of river with a high potential for a hazardous chemical spill or oil spill. This plan would provide a practical approach to minimizing environmental damages that might occur.

CONCLUSION

We believe that we have implemented a cost-effective resource inventory and mapping system that highly complements and improves our overall programs in responding to Service goals and objectives as related to habitat preservation. We believe that this system, in conjunction with supplemental information, provides a means of characterizing existing resources and identifying areas of high quality fish and wildlife values that should be protected. We do, however, recognize that there are inherent limitations to the use of remote sensing as it relates to projects in West Virginia and on the Ohio River. Essentially, our information can be used as resource planning documents and will aid the Service in impact assessment and water resource development planning.

In addition to the NWI, the Fish and Wildlife Service is actively engaged in remote sensing applications on coastal characterization studies of the Coastal Ecosystems Project. However, we believe that the capabilities of remote sensing technology, interfaced with current Fish and Wildlife Service needs, justifies a greater Service involvement in programs previously discussed. Additionally, we recommend that any state or federal agency, or private organization engaged in data base resource inventory over large areas consider remote sensing technology as a means to complement conventional efforts and reduce project costs and time.

ACKNOWLEDGEMENTS

We believe the Army Corps of Engineers, Huntington District, deserves recognition for their cooperative support of our use of remote sensing technology on their projects and programs.

All color-IR aerial photographs used on the Ohio River were acquired by Clyde E. Williams & Associates, Inc., of South Bend, Indiana. These were provided to the Ohio River Basin Commission, Cincinnati, Ohio, in conjunction with an Ohio River Basin wetland study. The Commission graciously permitted us to have duplicates made of the transparencies.

Special thanks are extended to Ronald L. White, Biological Technician, for his dedicated efforts on photo-interpretation and mapping. We also acknowledge William A. Tolin (Wildlife Biologist) and Christopher M. Clower (Fish and Wildlife Biologist) who provided constructive criticism, advice, and editorial assistance. In addition, the authors wish to thank Charles J. Kulp (Field Supervisor, Ecological Service, State College, Pa.) for his advice and review of the manuscript. Lastly, we certainly appreciate the efforts of our secretary, Wilda J. Cross, for editing and typing the manuscript.

LITERATURE CITED

Anderson, A. T., and J. Schubert. 1976. ERTS-1 data applied to strip mining. Photogram. Eng. and Remote Sensing 42(2):211-219.

Anderson, A. T., D. Schultz, N. Buchman, and H. M. Nock. 1977. Landsat imagery for surface mine inventory. Photogram. Eng. and Remote Sensing 43(8):1027-1036.

Anderson, J. R., E. E. Hardy, J. T. Roach, and Richard E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. U.S. Department of the Interior, Geological Survey, Professional Paper 964. 28pp.

Braun, E. L. B. 1974. Deciduous forests of Eastern North America. MacMillam Publishing Co., Inc., New York, New York. 596pp.

Brown, W. W. 1978. Wetland mapping in New Jersey and New York. Protogram. Eng. and Remote Sensing 44(3):303-314.

Cousin, S. B., W. M. Knuth, and E. L. Fritz. n.d. Use of remote sensing in surface mine reclamation. HBR-Singer, Inc., State College, Pa. 23pp.

Cowardin, L. M. and V. I. Myers. 1974. Remote sensing for identification and classification of wetland vegetation. J. Wildl. Manage. 38(2):308-314.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1977. Classifications of wetlands and deep-water habitats of the United States (an operational draft). U.S. Department of the Interior, Fish and Wildlife Service. 100pp.

Grumstrup, P. and M. Meyer. 1977. Applications of large scale 35mm color and color infrared aerial photography to analysis of fish and wildlife resources on disturbed lands. IAFHE RSL Research Report 77-3, University of Minnesota, St. Paul. 70pp.

Klemas, V., F. C. Daiber, D. Bartlett, O. W. Crichton, and A. O. Fornes. 1974. Inventory of Delaware's wetlands. Photogram. Eng. 40(4):433-439.

McEwen, R. B., W. J. Kosco, and V. Carter. 1976. Coastal wetland mapping. Photogram. Eng. and Remote Sensing 42(2):221-232.

Meyer, M. P., and P. D. Grumstrup. 1978. Operating manual for the Montana 35mm aerial photography system - 2nd revision. IAFHE RSL Research Report 78-1, University of Minnesota, St. Paul. 62pp.

Shaw, P., and C. Fredine. 1971. Wetlands of the United States. U.S. Department of the Interior, Fish and Wildlife Service, Circular 39. 67pp.

Wobber, F. J. 1975. Remote sensing trends in state resources management. Photogram. Eng. and Remote Sensing 41(6):735-740.

Wobber, F. J., C. E. Wier, T. Leshendok, and W. Beeman. 1975. Coal refuse site inventories. Photogram. Eng. and Remote Sensing 41(9):1163-1171.

Relevance of Landsat to Kangaroo Management in Queensland, Australia

G.J.E. HILL*   A. FALCONER* **

Abstract. Limited data are available on the impact of commercial exploitation on kangaroo populations. Research has been conducted into the relationship between habitat structure and seasonal forage status and the vulnerability of grey kangaroos to hunting pressure. LANDSAT imagery has proved a suitable base for monitoring these factors at a scale relevant to kangaroo management problems.

INTRODUCTION

Commercial exploitation of kangaroos has been a controversial issue in recent years. Concern over harvest rates led to federal intervention into control of the kangaroo industry by the state governments in 1973. A ban was imposed on the export of kangaroo products until the states complied with certain management guidelines, relating mainly to annual quotas policed by a tag system. For Queensland, traditionally the centre of Australia's kangaroo industry, this ban was lifted in 1975. However, external restrictions on the import of kangaroo products, notably skins into the USA, and the collapse of the kangaroo meat market still effectively govern exploitation rates. Although annual quotas of 600,000 were granted for 1973 and 1974 and 800,000 per year since 1975, returns to the end of 1976 indicate an average annual harvest of only 473,000 since 1973. This is in stark contrast to the yearly average of over 920,000 for the preceding ten years. Harvest rates are depressed by lack of markets.

According to many pastoralists, this has allowed kangaroo populations to expand to a level that will precipitate serious problems for the grazing industry when the present run of good seasons comes to an end. Large numbers of kangaroos will be brought into competition with domestic stock. With the rural economy in a depressed state, the scaling down of kangaroo harvesting has not been welcomed by the country towns that supported the industry and its infrastructure. On the other hand, this situation and the existence of bans reflect international uneasiness over the conservation of kangaroos.

That this state of affairs has developed is a result of the lack of data relating to kangaroo density and distribution. Other than the long history of heavy culling in Queensland, little evidence can be put forward to suggest that harvest rates are within reasonable limits. Research has therefore been directed towards making an appraisal of the kangaroo industry and its impact on kangaroo populations.

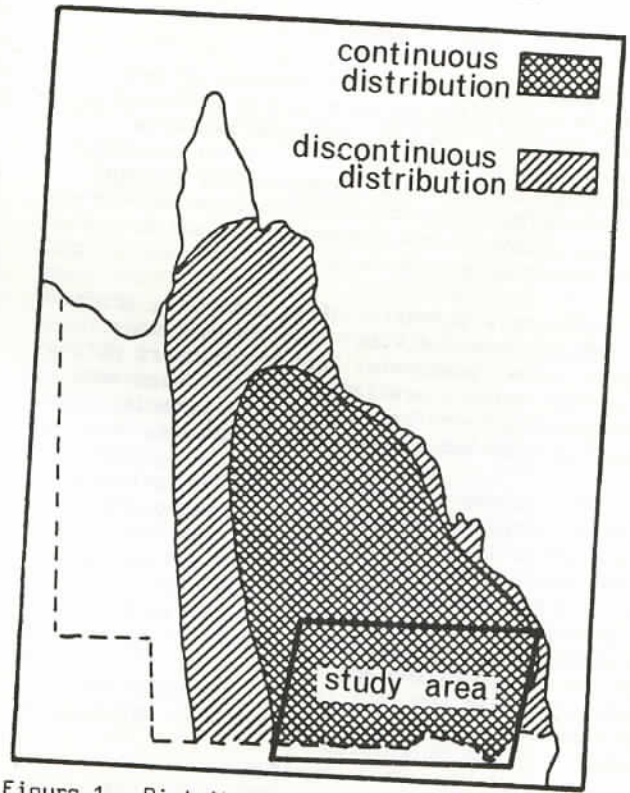


Figure 1. Distribution of the grey kangaroo in Queensland (from: Kirkpatrick, 1974:370)

This paper outlines results obtained to date from a study of the distribution patterns

*Geography Department, University of Queensland, Brisbane, Australia. 4076.
**present address-Remote Sensing Facility, Regional Centre for Services in Surveying and Mapping, P.O.Box 18118, Nairobe, Kenya.

of the grey kangaroo (Macropus giganteus) in southern Queensland. Grey kangaroos account for approximately 75 percent of the annual kangaroo harvest. The study area chosen, while sampling a cross section of the grey kangaroo's range in Queensland, supports the highest exploitation rates in Australia. See figure 1.

Kangaroos are nocturnal and are shot by spotlighting from vehicles. Unless animals feed in ecotones, out in the open or in part cleared country that can be negiotated by motor vehicles, they are protected to a large extent from shooters. Grey kangaroos are cover conscious animals that rarely venture far from forest shelter unless forced to do so by shortages of forage and water in their favoured habitat. Population density, and the extent to which a population is vulnerable therefore depends on two factors, habitat structure and seasonal conditions. Research has concentrated on monitoring these factors.

With Australia's LANDSAT receiving station becoming operational in 1980, the project examined the potential of LANDSAT data for kangaroo management applications.

HABITAT MAPPING

The density or potential density of any wildlife population depends on the suitability of its habitat. The grey kangaroo exhibits wide ecological tolerances and has an extensive geographical range. This adaptability allows the animal to exist in high densities throughout the pastoral zone wherever woodland or shrub cover is available.

With professional shootigg extending across an area of over 1 million km^2, habitat maps needed to be broadscale. Management zones defined by the balance available between cover and open country therefore seemed a reasonable goal for this habitat mapping programme.

Traditional sources of habitat data in the form of large scale, aerial photography are unsuited to tasks of this nature. The smallest scale conventional coverage that could be used for mapping purposes was 1/100,000 photo mosaics. To cover the study area, 90 such mosaics were required. Added to the unweildy nature of assembling and manipulating this collection was the fact that in the majority of cases the photography was 10 to 15 years old.

LANDSAT provided an ideal base for the scale of research being conducted. The study area was covered by 15 scenes and the cost of producing a habitat map from LANDSAT positive chips in one band was less than half that for 1/100,000 photo mosaics.

A map based on manual interpretation of LANDSAT band 7 imagery had been produced by Fox (1974) to define kangaroo habitat zones for the state of New South Wales. However, visual assessment of bands 4,5,6 and 7 suggested that band 5 was the most suitable for identifying cover classes over the study area.

For the semi arid landscape characterizing the western two-thirds of the study area, lack of terrain, wide spacing of herbaceous plants and absence of distinctive blocks of forested country tended to produce 'flat' scenes. While this did not create a problem in separating habitat regions, the visual impression was poor. To overcome this, the band 5 positive chips were reprocessed to maximize contrast. The results proved satisfactory. Black and white prints were then used to produce the mosaic, figure 2.

Six major habitat zones were delineated from this base. Homogeneity and characteristic structure of the zones were checked against conventional aerial photography and fieldwork throughout the area. The boundaries of the area are defined by the New South Wales border to the south, the Darling Downs agricultural area to the east and to the north by a belt of rugged country associated with a westward extension of the Great Dividing Range.

The distinguishing characteristics of each zone are listed below.

Zone 1. Cover classes are dominated by eucalypt and callitris woodland communities. Much of this natural woodland is located across hilly areas with poor soils and is state forestry reserve. Land use practices have produced sharp boundaries between forest and cleared land. Kangaroo exploitation within this zone is confined to part time shooters. With favourable rainfall patterns (600-700mm per year) and an abundance of dense cover, shooter access is limited. The access problem is illustrated by aerial survey work completed for this zone which has returned average densities of only 1 to 2 kangaroos/km^2. Ground surveys indicate much higher overall population totals. Faecal pellet counts have indicated approximate densities of between 10.5 and 12.5 kangaroos/km^2 for the forest blocks surveyed.

Zone 2. This zone which features more fertile soils than adjoining areas has been extensively cleared. With a low proportion of cover available shooter access is high although this is balanced by low kangaroo densities. Little commercial shooting takes place for the zone.

Zone 3. Zone 3 forms a transitional area

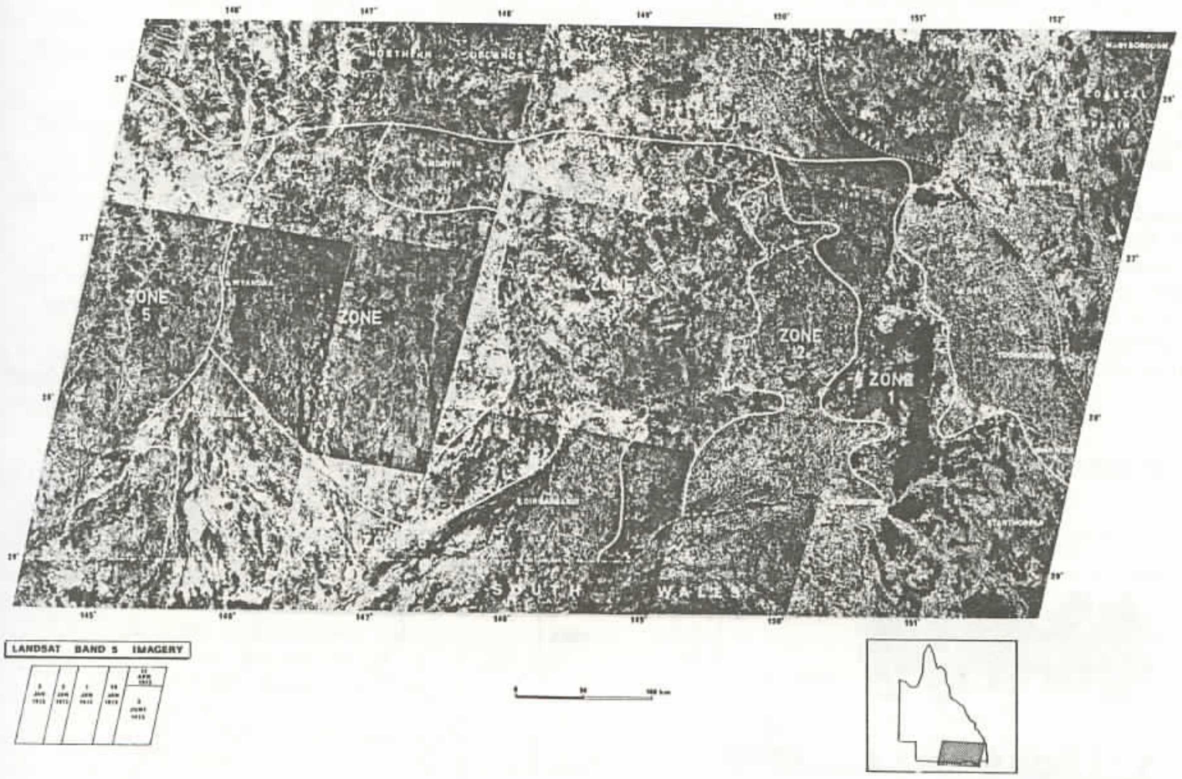


Figure 2: Habitat zones for the grey kangaroo in southern Queensland

between eucalypt dominance in the east and acacia in the drier west. A diverse range of habitat types are represented. Land use is mainly grazing on native pastures although agriculture is practised in the wetter north in the Roma district and within the St George irrigation area. Annual rainfall varies from around 600mm in the east and north to 500mm along the western boundary. Definition between cover and cleared country is not as well defined by the LANDSAT imagery as for Zone 1. This results from the tendency to 'thin' forested areas rather than clear them completely. As well, regrowth of woody species is a serious problem and this tends to mask the characteristics of cleared areas very quickly. A favourable balance between cover zones and cleared country provides excellent conditions for grey kangaroos while restraining the mobility of shooters. Clearing activities of pulling, poisoning and ring barking also tend to limit shooter access. Grey kangaroo densities probably reach a maximum for the state in this zone. Exploitation rates are the highest in Australia. St George has been the major kangaroo harvesting centre in Queensland for many years while Mitchell, to the north is another important processing town.

Zone 4. Mulga (*Acacia aneura*) woodlands are a dominant feature of Zone 4 although various other acacias and the poplar box (*Eucalyptus populnea*) are well represented. The lower rainfall pattern (350-500mm/year) that characterizes this region probably limits population density over poorer seasons. As for Zone 3, clearing, though extensive, tends to be a temporary cycle with regrowth characteristically producing dense thickets in many areas. Kangaroo populations have ample shelter to meet ecological requirements and to afford good protection from shooting. Kangaroo density is high and professional shooting well organized.

Many property boundaries are well represented by the LANDSAT imagery as tracks are often bulldozed around boundary fences. These tracks are the major access routes patrolled by shooters.

Zone 6. A broad area of more open country coinciding with the floodplains of the Warrego and Maranoa River systems. With less cover available than for the zones to the north, kangaroo density is correspondingly lower and only limited professional shooting takes place.

Zone 5. Acacia shrublands characterize

this arid zone (less than 350mm/year). A broad transition rather than a sharp boundary separates Zones 4 and 6. As habitat conditions become more open and water less plentiful red kangaroos take over from greys as the dominant species. Grey kangaroo density drops off with further movement westward. (Refer fig. 1).

Cunnamulla and Charleville are important nodes for the kangaroo industry and are the two most westerly processing centres. Shooting to the west of these towns concentrates on the red kangaroo (partly because they bring a higher price than greys) while to the east in Zone 4 the ratio of greys to reds is in the vicinity of 10:1.

SEASONAL MOVEMENT PATTERNS

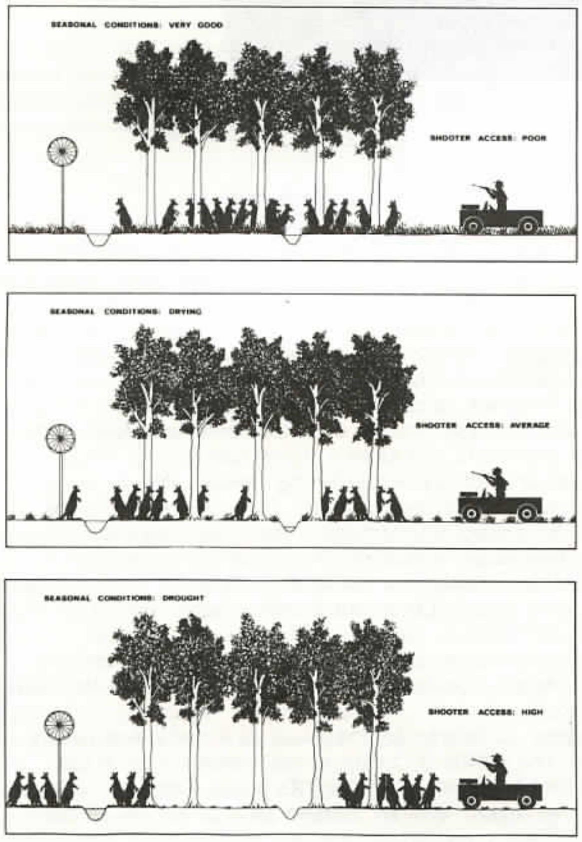


Figure 3. Seasonal movement patterns of the grey kangaroo and relevance for harvest rates.

While the grey kangaroo has evolved for life in a woodland type habitat, the floristic structure of these associations classes them as largely unsuitable for food production. Woody species yield little forage for the grey kangaroo which is primarily a grass eater. The sparse ground cover of natural forest country is only adequate and attractive for relatively short periods following rain.

Figure 3 attempts to define the manner in which grey kangaroos respond to prevailing climatic conditions. These movement patterns reflect environmental stress on the population and determine accessibility of kangaroos to shooters. When droughts occur, animals which were previously able to confine themselves to habitats with a high cover status are forced into the open, often during daylight hours to seek food and water. Under these circumstances harvest rates are high due to the concentration of kangaroos on cleared country. The influence of seasonal conditions on harvest rates is illustrated in figure 4 which graphs annual harvest for grey kangaroos in Queensland against the rainfall average for each year across the six meteorological forecast districts that pro-

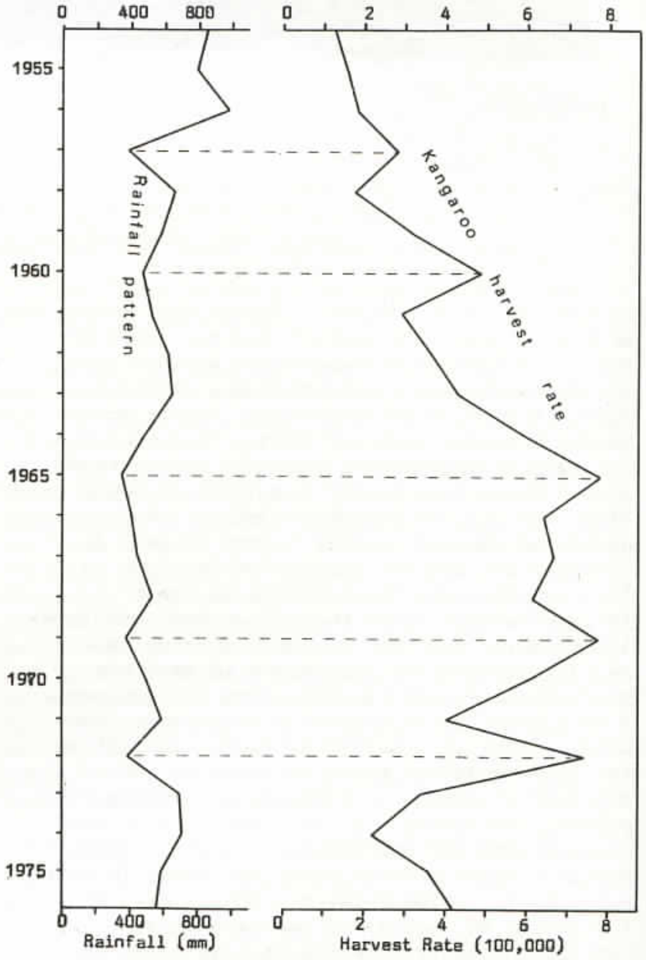


Figure 4. Grey kangaroo harvests and corresponding rainfall averages for the associated pastoral districts.

Economic conditions within the kangaroo industry play a role in harvest rates. For example, the development of an export market for kangaroo meat in the early 1960's led to a marked increase in rate of exploitation. However, the tendency for an inverse relationship between harvest total and rainfall total is clear.

It is interesting to note that the bans on the kangaroo industry in 1973 coincided with a marked upturn in the rainfall trend. This would have depressed harvest rates to some extent without restrictions. The 'kangaroo crisis' years of the late 1960's and early 1970's can also be identified as drought years. Sustained high harvests were a result of natural environmental stress as well as harvesting pressure.

Here it is important to distinguish between the major droughts that regularly occur in pastoral Australia and the annual dry season which for most of Queensland is winter, May-August. Monitoring the extent and severity of dry periods allows a general appraisal to be made on likely harvest rates. Such a model is important as under the present management system there may be delays of up to 12 months before harvest totals become available.

For Zone 1 the impact of rainfall totals on seasonal movement patterns has been examined with a view to quantifying seasonal vulnerability of populations utilizing this class of country.

Owing to the problems of observing a cover conscious nocturnal animal, faecal pellet counts were used to gauge usage of cleared country adjacent to forest. For kangaroos, most faeces are passed during the night feeding session. As this coincides with shooting activity, density and dispersion of faeces give a reliable guide to availability of kangaroos to shooters. A 6km strip of ecotone was selected and at 2 monthly intervals, 20 randomly selected transects, run at right angles to the forest were surveyed. For each count, pellets judged to be less than 2 months of age were counted on .001ha circular plots spaced at 20m intervals along transects 500m in length.

Results are displayed in figure 5 along with rainfall pattern for the study area over this time. There is a strong correlation (.83 with 90% confidence limits) between pellet density and rainfall over the preceeding 2 months. The retarding influence of winter temperatures on grass growth is also reflected in the pellet densities from May to August. With drying conditions forage reserves within woodland zones deteriorate and are eaten out more quickly than those of cleared country. Kangaroos therefore make progressively greater use of grassland as pasture status declines.

The reluctance of grey kangaroos to venture far from cover is also well illustrated by the pellet density histograms of figure 5. Faecal pellet density drops off rapidly with distance from cover.

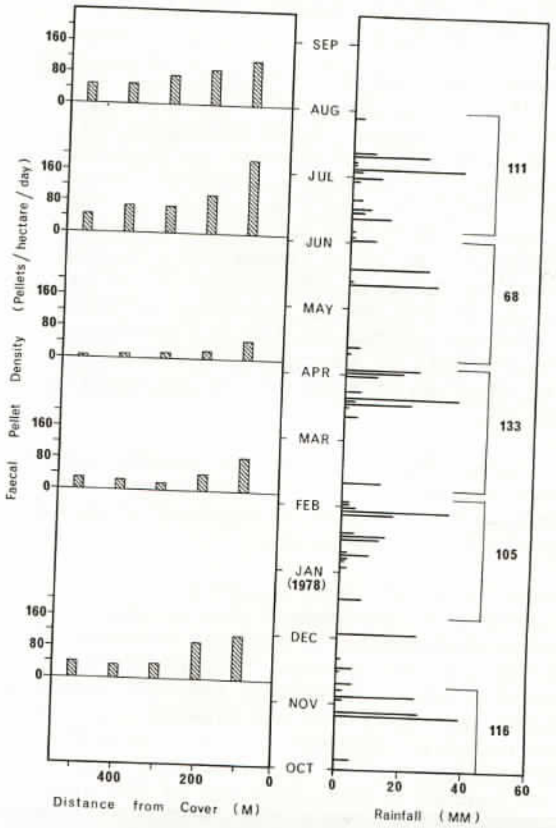


Figure 5. Relationship between rainfall and usage of cleared country by grey kangaroos in south-eastern Queensland.

In terms of vulnerability to hunting, this indicates that kangaroo usage of open country varied by a factor of more than five over the monitoring period. As the winter of 1978 was above average in rainfall terms, usage of cleared areas could be expected to be higher. It should be noted also that only part of the total population utilizes cleared country at any one time. Pellet densities for forest and partly cleared forest were higher than those of adjacent grassland for all times of the year. For this region, overall vulnerability would therefore appear to be low although the proportion of the population at risk increases significantly with dry conditions.

As kangaroo movement patterns were closely associated with pasture status, the harvesting pressure being exerted on a population in spatial or temporal terms could be determined by following pasture trends.

Recording forage status by photographic and visual interpretation suggested that the growth stages and dryness levels associated with kangaroo usage of cleared country were easily distinguished.

Research reported by Carneggie et al (1975), Ashley & Rea (1975) and Western (1976) demonstrates that greenness levels of vegetation can be successfully monitored by photographic and densitometric analyses of LANDSAT imagery. Using the LANDSAT coverage available for the Zone 1 study area it was decided to examine the feasibility of using LANDSAT as a device for recording seasonal progression in native pasture status and spatial variation in this across the area. These two factors are important determinants of shooter impact on total kangaroo reserves of a region for any specific time period.

For scene 096/080 three good quality coverages were available. As these coincided with varying seasonal conditions they were obtained through the EROS Data Center.

Manipulation of these scenes on an I^2S multi spectral viewer showed that visually detectable differences in spectral response of native pasture were apparent between scenes and within scenes. Analysis of rainfall patterns preceeding recording date and time of the year when scenes were recorded suggested that the imagery provided a readily interpreted indication of pasture status. Analysis of MSS digital data was not attempted. It was considered that for LANDSAT to be of use as a management tool on a broadscale and regular basis, low cost processing and evaluation was a necessity.

Figure 6 illustrates pasture status for the southern section of Zone 1 during June,1976 (winter-dry) and January, 1973 (summer-wet). The area covered is that of a whole scene (096/080) and includes the sites of research into kangaroo movement patterns.

Forested country and agricultural land are clearly defined with the remainder of the scene comprised of cleared pastoral land, most of it of open woodland status. The constant tonings across the pastoral land in the June scene record the influences of low winter temperatures and moisture shortages. Conditions such as these correspond with high utilization of open country by kangaroos.

For January, the pink colourings of much of the cleared country record summer growth of grasses. The availability of green grass as recorded by LANDSAT reflects favourable pasture status within nearby forested areas and low utilization of cleared country by kangaroos. On this scene several dry zones can be identified by their lack of pink tonings. Such areas would still be receiving heavy usage by kangaroos.

Following this study a proposal has been approved by NASA to record scenes 096/080 and 099/079 at 36 day intervals by LANDSAT 2. Synchronization of fieldwork with satellite overpasses will allow pasture status and

June 1976

January 1973

Figure 6. Seasonal pasture status scene 096/080

kangaroo movement patterns to be correlated with the LANDSAT data.

DISCUSSION

Assessments of kangaroo exploitation in Queensland have been severely hampered by problems of scale. The geographical range of kangaroos together with their behavioural patterns and the environments they occupy all mitigate against population monitoring programmes of the type normally associated with rational exploitation of a wildlife species.

Broadscale habitat zones of the type delimited in this study are a logical base to analyses of kangaroo density and distribution and the impact of commercial harvesting. With background knowledge of habitat structure and extent, decisions can be made regarding the impact of factors such as natural regulatory processes, land development programmes or intensification of professional shooting. For surveys to be conducted into kangaroo density, the identification of distinctive zones is a desirable prerequisite if sampling efficiency is to be maximized. This is a crucial factor when the enormous geographical range of the grey kangaroo is considered. Habitat structure, its influence on kangaroo populations and the interactions this determines between kangaroos and shooters has been a neglected facet of research into the conservation of kangaroos.

LANDSAT offers scope for monitoring forage status, a reliable indicator of kangaroo usage of cleared country. The higher the proportion of a population using cleared country becomes the greater the impact of commercial harvesting. Sets of colour composites along with brightness level data derived from densitometer readings could provide a reference against which any prevailing conditions might be compared. Research carried out demonstrates that such information may be translated into terms of kangaroo accessibility.

The habitat analysis procedures discussed in this paper are not new and are in fact quite basic. However, that this fundamental information does not already exist for the kangaroo harvesting zones of Queensland demonstrates the importance of LANDSAT to wildlife management applications of this sort. It is difficult to find any reference to habitat, accessibility or movement patterns in the bulk of the literature dealing with kangaroo harvesting. Hopefully LANDSAT technology will change this state of affairs and lead to a more detailed and meaningful appraisal of the kangaroo industry and how it should be controlled.

REFERENCES

Ashley & Rea (1975) Seasonal Vegetation Differences from ERTS Imagery. Photogrammetric Engineering & Remote Sensing 41(6):713-720

Carneggie et al (1975) Usefulness of LANDSAT Data for Monitoring Plant Development & Range Conditions in California's Annual Grassland. NASA Earth Resources Survey Symposium Vol 1A pp19-31. Houston, Texas.

Fox, A.M. (1974) Kangaroos in N.S.W. National Parks and Wildlife Service, N.S.W.

Kirkpatrick, T.H. (1974) Kangaroo Harvesting & Survival. Qld. Ag. J. 100(8):368-375

Western, D. (1976) Distribution of Animals in Relation to Resources. Serengeti Ecological Monitoring Programme, Handbook No 2. Grimsdell, J. & Russell, H. (Eds) African Wildlife Leadership Foundation, Nairobi.

Use of Remote Sensing Data to Interactively Simulate Wildlife Habitat Quality[1]

Peter F. Ffolliott[2]
and
William O. Rasmussen[3]

Abstract.--To estimate the impacts of management practices on animal habitats, a prototype simulation model, called HABRAN (HABitat RANking), has been developed. Using inputs of crown closure obtained from aerial imagery, ranked response predictions are synthesized, summarized, and arrayed as pattern recognition models.

INTRODUCTION

To aid wildlife managers and land use planners in estimating the impacts of management practices on animal habitats, a prototype computer simulation model has been developed. This model has been structured to allow users at remote locations to readily learn its application and to obtain reliable assessments of wildlife habitat quality for a variety of game, nongame, and domestic animals using modest computer terminal equipment and readily accessible input data. In particular, measurements derived by remote sensing techniques are required to generate desired outputs. To promote use, an interactive mode of operation has been selected rather than batch processing. By adopting an interactive structure, interplay between the computer and the user is achieved.

This paper highlights the development, to date, of the interactive wildlife habitat simulation model, called HABRAN (HABitat RANking), and outlines future directions in the development effort. A prototype of HABRAN is written in ANSI Standard FORTRAN, and it is currently operational on the University of Arizona's DEC-10 computer in an interactive mode. Core requirements of HABRAN are relatively small, requiring 10 K words in the prototype.

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

[2]Professor, School of Renewable Natural Resources, University of Arizona, Tucson, Arizona.

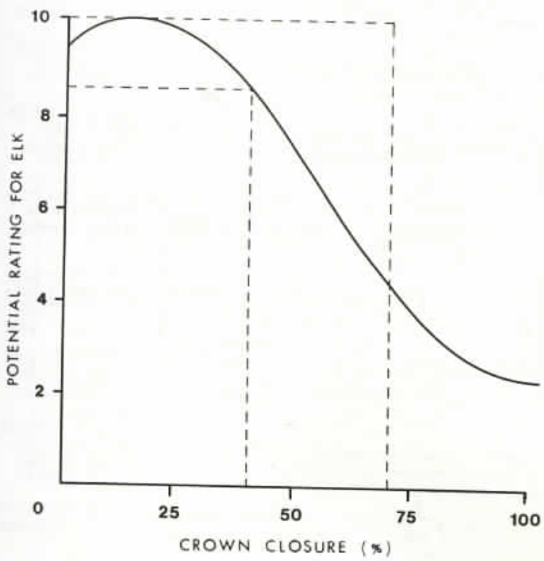
[3]Assistant Research Professor, School of Renewable Natural Resources, University of Arizona, Tucson, Arizona.

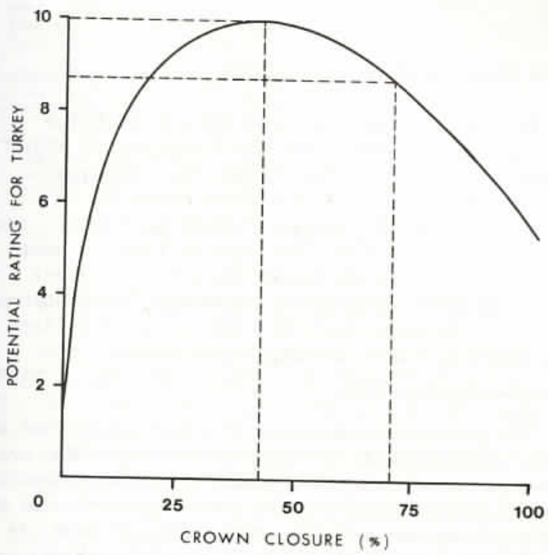
CONCEPTUAL SIMULATION MODEL

In essence, HABRAN involves the synthesis of ranked response predictions of wildlife habitat quality prior to and following the implementation of management practices which, in turn, are summarized and arrayed as pattern recognition models. Within HABRAN, animals are assigned numerical values ranging from 0 to 10, with habitat quality for a particular animal species in a given ecosystem increasing with numerical value. The specific assignment of these values is achieved through analyses of mathematical functions that relate habitat preference to readily accessible input data. The concept of assessing habitat preference in terms of index values related to measurable parameters has been employed elsewhere (Worley and Gill 1969, Ffolliott and Patton 1975, Patton 1977, Boyce 1977).

By comparing habitat quality values that represent conditions prior to a management change with those predicted for habitats modified by management redirection, either an increase (+), a decrease (-), or no change (0) is determined. Then, a matrix of pluses, minuses, and zeros arrayed for all animal habitats and management alternatives of interest (by definition, a pattern recognition model) can be displayed to provide insight into comparative management impacts.

The core of the HABRAN simulation model is the set of mathematical functions that relate habitat preference to readily accessible input data. These functions are developed from existing state-of-the-art knowledge of habitat requirements for particular animal species. It should be noted that these response functions are animal and ecosystem specific (fig. 1).





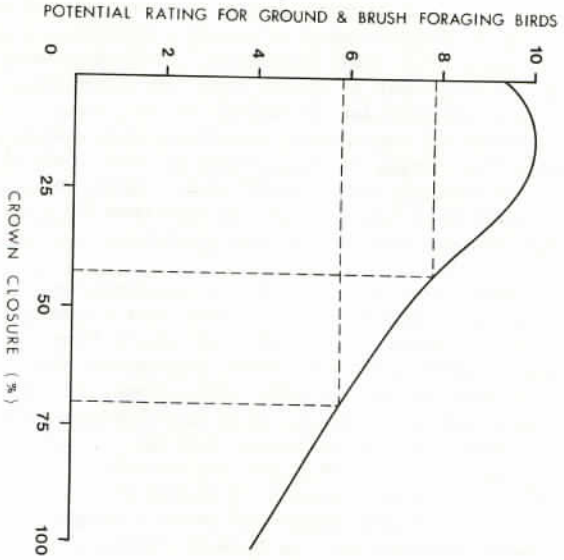


Figure 1.--Response functions for elk, turkey, and ground and brush foraging birds.

As originally developed, habitats for most animals being considered in the prototypical version of HABRAN have been conceptualized as two components: available food and cover (protective and thermal). Therefore, mathematical functions describing changes in food and cover for particular animal species as related to the spatial distributions of forest overstories are defined from existing information. These food and cover functions are then "integrated" to provide a single function that reflects the changes in these habitat components with respect to the spatial distributions of forest overstories.[4]

To facilitate use of the prototypical model, the initial measure of the spatial distributions of forest overstories selected as the primary input to HABRAN was square feet of basal area per acre, a commonly used expression of the density of forest overstories (Avery 1975). Basal area was selected because it is: easily converted to other expressions of density, and many multiresource relationships (including wildlife habitat assessments) have already been developed with basal area as the independent variable.

---

[4]In the prototype of HABRAN, food and cover have been given equal weight. However, a user can assign different weights, depending upon the simulation exercise.

Basal area is a measure of the spatial distributions of forest overstories estimated on the ground from, most commonly, ground inventories of forest resources. Unfortunately ground measurement of basal area may preclude extensive application of HABRAN to estimate the impacts of management practices over large areas. Therefore, an expression of the spatial distributions of forest overstories that was correlated with basal area but obtained by remote sensing techniques was desired.

Close associations often exist between basal area measured on the ground and crown closure of forest overstories obtained from aerial imagery (Moessner 1964, Larson et al. 1971, Bisson et al. 1974). Therefore, it was hypothesized, and subsequently verified, that direct measurements of crown closure can also be used as the primary input to HABRAN. Specifically, measurements of crown closure derived by interpretations of aerial imagery have been employed in the HABRAN simulation model for the evaluation of wildlife habitat quality over extensive areas.

Initial efforts in the development of HABRAN have focused upon the southwestern ponderosa pine forest ecosystem, with emphasis directed toward: big game (specifically deer and elk); small game (including tree squirrels and rabbits); rodents (such as mice, chipmunks, and ground squirrels); nongame birds (grouped by feeding categories); and domestic livestock (including cattle and sheep).

Measurements of crown closure have been obtained from interpretations of large scale aerial imagery (1:15,840) provided by the USDA Forest Service, and from small scale U-2 aerial imagery (1:130,000) obtained from the EROS Data Center.

The conceptual flow of activities that are followed in executing the prototype of HABRAN to estimate the impacts of management practices on animal habitats is illustrated in figure 2.

APPLICATION OF MODEL

Perhaps the best way to illustrate the application of HABRAN in simulating wildlife habitat qualities is through an example. For purposes of illustration, a hypothetical 2,500 acre tract of southwestern ponderosa pine forest will be examined to assess the potential impacts of two alternative silvicultural treatments (i.e., the reduction of the density of the forest overstory to prescribed basal area levels) on a variety of animal habitats.

To apply the prototype of HABRAN using crown closure measurements as the primary input, a user must first structure the simulation exercise. In doing this, specific animal habitats are selected and the initial (or existing) crown closure of the forest overstory that characterizes the area of concern is input.[5] Explicitly, the user responds to questions asking: WHICH ANIMAL'S HABITAT DO YOU WISH TO EVALUATE? and AVERAGE CROWN CLOSURE IN PERCENT?

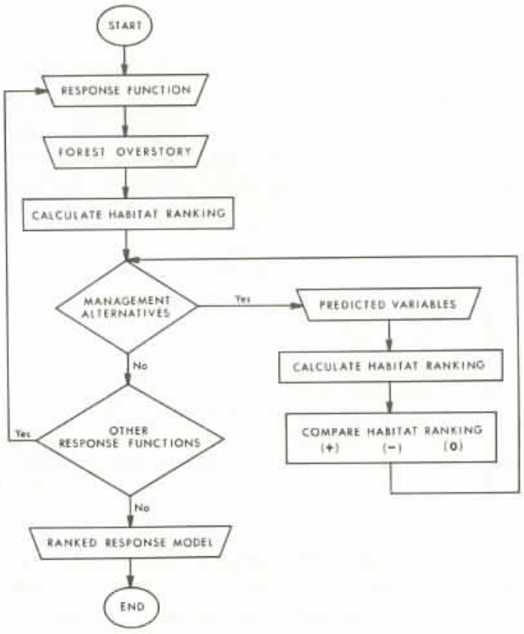


Figure 2.--Flowchart of HABRAN.

In the hypothetical example, a decision has been made to evaluate the habitats of all animals listed in HABRAN (fig. 3). Average crown closure on the 2,500 acre tract is estimated to be 70 percent (which is equivalent to approximately 150 square feet of basal area per acre). From these inputs, an output display of habitat quality rankings (ranging from 0 to 10) that indicate existing conditions is presented. In a sense, these initial

---

[5]It is not the purpose of this paper to outline measurement techniques and sampling procedures necessary to obtain reliable estimates of crown closure. In this hypothetical example, measurements of crown closure have been obtained from large scale aerial imagery (1:15,840) provided by the USDA Forest Service.

habitat qualities are a point of departure from which habitat qualities modified by management redirection can be compared.

```
HABRAN - ANIMALS ARE:
 1 - DEER                          2 - ELK
 3 - ABERT SQUIRREL                4 - COTTONTAIL
 5 - TURKEY                        6 - RODENTS          LIST
 7 - NONGAME BIRDS  LIST           8 - CATTLE
 9 - SHEEP

PLEASE USE NUMBERS WHEN REFERRING TO ANIMALS
WHICH ANIMAL'S HABITAT DO YOU WISH TO EVALUATE?
   (0 FOR LIST, -1 FOR ALL)>-1
AVERAGE CROWN CLOSURE IN PERCENT?   70

DEER                      5.2   ELK                    5.5
ABERT SQUIRREL            9.8   COTTONTAIL             0.1
TURKEY                    9.0   CATTLE                 6.5
SHEEP                     5.3

RODENTS
  DEER MICE               4.6     GROUND SQUIRRELS     9.5
  CHIPMUNK                9.8

NONGAME BIRDS
  TREE FOLIAGE SRCHR  9.6       TIMBER GLEANING        9.3
  GROUND-BRUSH        6.4       FLY CATCHING           9.6
  TIMBER DRILLING    10.0       AERIAL FLYCATCHING    10.0

ARE YOU PROPOSING A LAND MANAGEMENT TREATMENT?
(YES/NO, CR GIVES:NO)>YES
AVERAGE CROWN CLOSURE IN PERCENT?   40

DEER                     10.0   ELK                    9.3
ABERT SQUIRREL            6.5   COTTONTAIL             0.1
TURKEY                    9.9   CATTLE                 8.9
SHEEP                     8.7

RODENTS
  DEER MICE               7.2     GROUND SQUIRRELS     7.2
  CHIPMUNK                9.0

NONGAME BIRDS
  TREE FOLIAGE SRCHR  6.7       TIMBER GLEANING        6.2
  GROUND-BRUSH        9.1       FLY CATCHING           9.7
  TIMBER DRILLING     7.2       AERIAL FLYCATCHING     8.3

ANOTHER LAND MANAGEMENT TREATMENT? (YES/NO) >YES
AVERAGE CROWN CLOSURE IN PERCENT?   20

DEER                      9.8   ELK                   10.0
ABERT SQUIRREL            1.9   COTTONTAIL             0.1
TURKEY                    8.7   CATTLE                 9.6
SHEEP                     9.7

RODENTS
  DEER MICE               8.8     GROUND SQUIRRELS     5.5
  CHIPMUNK                7.0

NONGAME BIRDS
  TREE FOLIAGE SRCHR  4.5       TIMBER GLEANING        3.8
  GROUND-BRUSH       10.0       FLY CATCHING           7.9
  TIMBER DRILLING     4.8       AERIAL FLYCATCHING     6.0

ANOTHER LAND MANAGEMENT TREATMENT? (YES/NO) >NO
```

Figure 3.--A hypothetical example of HABRAN.

Next, the user is asked: ARE YOU PROPOSING A LAND MANAGEMENT TREATMENT? (YES OR NO). At this point, the simulation exercise can be terminated by a negative response. Conversely, potential impacts of alternate silvicultural treatments on wildlife habitats can be analyzed by entering a positive response. In the example, a positive response has been given to assess the impacts of two alternative treatments (fig. 3).

The silvicultural treatments to be analyzed in the hypothetical example are uniform thinnings to prescribed basal area levels of 75 and 40 square feet of basal area per acre. An auxiliary subroutine within HABRAN allows basal area to be converted into estimates of crown closure.[6] Using this subroutine, basal area levels of 75 and 40 square feet of basal area per acre are converted into average crown closure estimates of 40 and 20 percent, respectively. Then, these estimates of average crown closure are inputs to HABRAN, with the resulting output display representing the predicted habitat qualities modified by the two alternative silvicultural treatments (fig. 3).

After the habitat quality rankings have been obtained for existing and predicted conditions following management change, a ranked response (or pattern recognition) model is generated by HABRAN. As previously mentioned, this model is simply a matrix of pluses, minuses, and zeros which represent an estimated increase (+), decrease (-), or no change (0) in habitat quality attributed to a management change. For emphasis, double pluses and minuses are used to indicate a change in habitat quality ranking in excess of 2 units.

In the ranked response model generated in the hypothetical example, habitat quality rankings for existing conditions (assumed to be 70 percent crown closure, which is equivalent to approximately 150 square feet of basal area per acre) are listed under M0 (fig. 4). Using these rankings as the basis, ranked responses for the two alternative silvicultural treatments are listed under M1 (75 square feet of basal area per acre input as 40 percent crown closure) and M2 (40 square feet of basal area per acre input as 20 percent crown closure).

At this point, a user must exercise professional judgement as to which, if any, of the two silvicultural treatments should be implemented. Summarizing and then evaluating source data such as wildlife habitat rankings in a tradeoff analysis is a difficult analytical problem, with no generally acceptable technique (Brown 1976). If all of the animal species being considered have an equal weight in evaluation, a summarization of increases, decreases, and no changes in habitat quality for each of the alternatives may suffice.

---

[6]For the southwestern ponderosa pine forest ecosystem, the subroutine that converts basal area to crown closure is based, in part, upon relationships developed by Moessner (1964).

RANKED RESPONSE MODEL

ANIMAL	M0	M1	M2
DEER	5.2	+	+
ELK	5.5	+	+
ABERT SQUIRREL	9.8	-	--
COTTONTAIL	0.1	0	0
TURKEY	9.0	+	-
CATTLE	6.5	+	+
SHEEP	5.3	+	+
RODENTS			
DEER MICE	4.6	+	+
GROUND SQUIRRELS	9.5	-	-
CHIPMUNK	9.8	-	-
NONGAME BIRDS			
TREE FOLIAGE SRCHR	9.6	-	--
TIMBER GLEANING	9.3	-	--
GROUND-BRUSH	6.4	+	+
FLY CATCHING	9.6	0	-
TIMBER DRILLING	10.0	-	--
AERIAL FLYCATCHING	10.0	-	-

ANOTHER MODULE (YES/NO CR GIVES:NO) ? >
STOP

Figure 4.--The ranked response model produced by HABRAN.

Then, a simple comparison among alternatives may indicate the best course of action. More commonly, however, certain animal species may be valued at a higher level than others in a particular management situation, thus confounding decision making.

If all of the animal species being considered in the hypothetical example are assumed to have equal weight, and if a silvicultural treatment must be considered to meet other management objectives, a decision to implement the treatment calling for a uniform thinning to 75 square feet of basal area per acre (indicated by M1 in figure 4) may be appropriate. Reasons for this decision include: more animal habitats are increased; less animal habitats are decreased; and in most instances, the relative magnitude of inpact is more beneficial (i.e., a higher habitat quality ranking is achieved). However, it should be reiterated that, while HABRAN provides explicit animal habitat rankings, decisions to implement a management redirection depend, in a large part, upon a subjective wildlife habitat analysis by the user.

INTERACTION WITH OTHER MODELS

As presently conceived, the prototype of HABRAN is part of a family of interactive computer models being developed to help natural resource managers and land use planners estimate the impacts of silvicultural treatments (Larson et al. 1978). The family, called ECOSIM (Ecosystem COmponent SImulation Models), includes three general modules: FLORA for estimating responses of forest overstory, herbaceous understory, and organic material; FAUNA for evaluating animal habitats, carrying capacities, and population dynamics; and WATER for assessing streamflow yield, sedimentation, and chemical quality[7]. HABRAN is a component of the FAUNA module, with interfaces with many other models within ECOSIM.

As is the case with HABRAN, all of the models in ECOSIM are structured so that management professionals at remote locations can readily learn and afford their use, thus obtaining reliable predictions while still using modest computer terminal equipment and readily accessible data.

FUTURE DEVELOPMENTS

Future work in the development of HABRAN will follow two directions: (1) incorporation of additional animals into the general framework of the simulation model and (2) extension of HABRAN into other forest and range ecosystems.

At this time, an effort is underway to synthesize mathematical functions that relate habitat preference to readily accessible input data for insects grouped by Orders. In addition, it is hoped to expand the framework of HABRAN to include several species of carnivors that inhabit the southwestern pondersoa pine forest ecosystem.

Extrapolation of the HABRAN concept into other ecosystems is made easier by the generalized structure used in the initial development. Current plans call for the extension of HABRAN into other forest and range ecosystems.

LITERATURE CITED

Avery, Thomas Eugene. 1975. Natural resources measurements. McGraw-Hill Book Co., New York, 339 p.

---

[7] The development and testing of the ECOSIM family of interactive models is a cooperative effort involving the University of Arizona, the Rocky Mountain Forest and Range Experiment Station (USDA Forest Service), and Colorado State University.

Bisson, Henri R., William O. Rasmussen, and Peter F. Ffolliott. 1974. Use of multiple-stage remote sensing techniques to develop forest stocking equations. Symposium on Remote Sensing and Photo Interpretation, International Society for Photogrammetry, Commission VII, Banff, Alberta, Canada, October 1974, pp. 147-155.
Boyce, Stephen G. 1977. Management of eastern hardwood forests for multiple benefits (DYNAST-MB). USDA For. Serv. Res. Pap. SE-168, 168 p. Southeastern For. Exp. Stn., Asheville, North Carolina.
Brown, Thomas C. 1976. Alternatives analysis for multiple use management: A case study. USDA For. Serv. Res. Pap. RM-176, 16 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Ffolliott, Peter F., and David R. Patton. 1975. Production-rating functions for Abert squirrels in southwestern ponderosa pine. Wildlife Society Bull. 3:162-165.
Larson, Frederic R., Karl E. Moessner, and Peter F. Ffolliott. 1971. A comparison of aerial photo and ground measurements of ponderosa pine stands. USDA For. Serv. Res. Note RM-192, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
Larson, F. R., P. F. Ffolliott, W. O. Rasmussen, and D. R. Carder. 1978. Estimating impacts of silvicultural management practices on forest ecosystems. Paper presented at Symposium on Best Management Practices for Agriculture and Silviculture, Rochester, New York, April 1978, 23 p.
Moessner, Karl E. 1964. Two aerial photo basal area tables. USDA For. Serv. Res. Note INT-23, 7 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Patton, David R. 1977. Managing southwestern pondersoa pine for Abert squirrel. Jour. of Forestry 75:264-267.
Worley, David P., and John D. Gill. 1969. Strengthening the wildlife manager's hand in multiple-use conflicts. Trans. Northeast Wildl. Conf. 26:11-26.

Bisson, Henri R., William O. Rasmussen, and Peter F. Ffolliott. 1974. Use of multiple-stage remote sensing techniques to develop forest stocking equations. Symposium on Remote Sensing and Photo Interpretation, International Society for Photogrammetry, Commission VII, Banff, Alberta, Canada, October 1974, pp. 147-155.

Boyce, Stephen G. 1977. Management of eastern hardwood forests for multiple benefits (DYNAST-MB). USDA For. Serv. Res. Pap. SE-168, 168 p. Southeastern For. Exp. Stn., Asheville, North Carolina.

Brown, Thomas C. 1976. Alternatives analysis for multiple use management: A case study. USDA For. Serv. Res. Pap. RM-176, 16 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Ffolliott, Peter F., and David R. Patton. 1975. Production-rating functions for Abert squirrels in southwestern ponderosa pine. Wildlife Society Bull. 3:162-165.

Larson, Frederic R., Karl E. Moessner, and Peter F. Ffolliott. 1971. A comparison of aerial photo and ground measurements of ponderosa pine stands. USDA For. Serv. Res. Note RM-192, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Larson, F. R., P. F. Ffolliott, W. O. Rasmussen, and D. R. Carder. 1978. Estimating impacts of silvicultural management practices on forest ecosystems. Paper presented at Symposium on Best Management Practices for Agriculture and Silviculture, Rochester, New York, April 1978, 23 p.

Moessner, Karl E. 1964. Two aerial photo basal area tables. USDA For. Serv. Res. Note INT-23, 7 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Patton, David R. 1977. Managing southwestern pondersoa pine for Abert squirrel. Jour. of Forestry 75:264-267.

Worley, David P., and John D. Gill. 1969. Strengthening the wildlife manager's hand in multiple-use conflicts. Trans. Northeast Wildl. Conf. 26:11-26.