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Enumeration of Prairie Wetlands with Landsat and Aircraft Data

A double-phase sampling approach is used which consists of first making a total census of wetlands using Landsat data, and then adjusting the Landsat results on the basis of samples derived from high resolution aircraft data.

Abstract: *A method is described for making an estimate of wetland numbers in the glaciated prairie region. A double-phase sampling approach is used which consists of first making a total census of wetlands using Landsat data, and then adjusting the Landsat results on the basis of samples derived from high resolution aircraft data. The method is relatively simple to use and has general applicability for estimating habitat features not consistently detectable or resolvable on Landsat imagery because their size range includes features less than the resolution capability of the satellite's sensor.*

Introduction

Recent progress in remote sensing technology has demonstrated the capability for conducting synoptic evaluations of wildlife habitat (Gilmer *et al.*, 1979; Roller, 1979; Roller and Colwell, 1979). Biologists and managers now have the potential to make increased use of the regional and repetitive habitat surveys provided by the Landsat series of Earth-orbiting satellites. However, the Landsat system is limited in its ability to resolve small habitat features such as prairie wetlands which may represent key habitat components to wildlife.

The Landsat multispectral scanner (MSS) has a nominal resolution of 0.4 ha. Studies conducted in the glaciated prairie region (Drewien and Springer, 1969; Millar, 1969) have indicated that between 73 and 88 percent of the wetland basins were less than 0.4 ha in size. Consequently, many prairie wetlands cannot be detected using Landsat data (Work *et al.*, 1974). This limitation became apparent in previous efforts aimed at regional evaluation of prairie waterfowl habitat (Work and Gilmer, 1976).

To improve our estimates of wetland abundance, we experimented with a sampling procedure incorporating the use of high resolution aircraft imagery as a means for adjusting counts made over a larger regional area using Landsat data. This paper describes the sampling procedure used for estimating the total number of surface water areas in the study area, based on the integrated analysis of high resolution aircraft and Landsat data.

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Prairie Wetlands and Duck Productivity

The prairie pothole region of North America includes an area of more than 700,000 km^2 in south-central Canada and north-central United States. This region makes up only 10 percent of the breeding range of North American ducks, yet it produces about 50 percent of the young in an average year (Smith *et al.*, 1964).

The abundance of water in the prairie pothole region varies considerably on an annual and seasonal basis. To a great extent the availability of water determines duck productivity and the size of the fall flight (Crissey, 1969). A mathematical model developed by Brown *et al.*, (1976) demonstrated the relationship between production of mallards (*Anas platyrhynchos*) and number of wetlands in the prairie pothole region during May and July. Aerial surveys conducted each spring and summer by the U.S. Fish and Wildlife Service (FWS) in cooperation with state and Canadian biologists, obtain estimates of number of breeding ducks, wetland numbers, and production of young in the prairie pothole region of North America (Henny *et al.*, 1972).

FWS survey Stratum 46 (38,876 km^2), located in east-central North Dakota, was selected as the study area. It had been established to survey waterfowl breeding ground populations and habitat conditions (Martin *et al.*, 1978). The area is within the glaciated prairie pothole region and contains two biotic subregions; the Missouri Coteau (43 percent) and the Drift Plain (57 percent) (Stewart, 1975). The subregions differ greatly in composition of wetland types and their response to precipitation. Details of the study site are described by Colwell *et al.* (1978).

Procedures

Computer aided analysis techniques suitable for handling large volumes of Landsat data were developed to generate regional statistics describing the wetlands present (i.e., distribution, size, and length of shoreline). Open surface water was identified on the basis of its distinctive reflectance in MSS band 7, one of the two near-infrared bands (Work and Gilmer, 1976). For each individual wetland that was recognized, its apparent size and shoreline length were calculated, and its location designated by a set of Universal Transverse Mercator (UTM) coordinates. Once a data file was compiled, it was possible to then summarize the number, total area, and size distribution for the wetlands contained within any geographic unit by designating a computer search of the area within the UTM coordinates of that unit.

Landsat overflights of Stratum 46 occurred on 4 May and 15 July 1975. These overflights resulted in coverage of 87 and 100 percent of the stratum on the respective dates. A National Aeronautics and Space Administration (NASA) aircraft subsequently collected medium scale (1:20,000) imagery within the stratum on 15-16 May and again on 18-19 July, close to the dates of the Landsat overflights. Relative to satellite data, aircraft data were more costly to obtain and analyze, and we therefore sought to minimize the size of the aircraft sample. The limited availability of the NASA aircraft also required that our sample be held to a minimum.

Stratum 46 was gridded by eight east-west oriented transects, each equally spaced (north to south) and crossing the full width (approximately 220 km) of the stratum. Total length of all transects was 1760 km. Each transect was divided into equal segments 9.7 km long, resulting in 180 segments. These segments then became the potential aircraft sample units. Eighteen sample units were randomly selected without replacement. Before sample selection, the stratum had been divided into two substrata corresponding to the two biotic subregions. Allocation of the samples was proportional to the area of each substratum (i.e., Drift Plain = 10, Missouri Coteau = 8).

For each sample unit, an area 9.7 km by 1.6 km (15.5 km^2) was analyzed on the aircraft imagery. The 1.6 km dimension was distributed equally on either side of the long axis of the transect. The 18 sample units represented a total area of 279 km^2 or 0.7 percent of Stratum 46. Samples were analyzed for the number of wetlands containing water. Ponds as small as 5 metres across were delineated on the aircraft imagery; therefore, the aircraft sample was assumed to represent an enumeration of all significant surface water within the sample frame. The UTM coordinates of each of the sample units were also recorded to enable paired comparisons with units identical in area and geographic location from the Landsat-derived data.

Landsat/Aircraft Derived Pond Number Comparison

The aircraft samples were used to develop a correction factor for adjusting the count of surface water features derived from the large-area, low-resolution Landsat census. Using the paired Landsat and aircraft wetland counts for the areas covered by the aircraft samples, a linear regression analysis was made (Figures 1 and 2) for the May and July observations.

An outlier test by Grubbs (1950:27-28) resulted in the rejection of one data point in the May pond data set. Cloud cover during the May Landsat overflight eliminated three additional samples. The coefficients of determination (R^2) were 0.65 and 0.74 for the respective May and July periods. A standard statistical procedure (Cochran, 1977) was then used to derive the final estimate of the actual numbers of wetlands present.

The following regression expansion formula was used to make the estimate of the actual number of total wetlands present:

$$\hat{Y}_{pop} = N\ [\bar{y} + b\ (\bar{X} - \bar{x})]$$

where $\hat{Y}_{pop}$ = estimate of number of ponds in the population,

N = number of "potential 15.5 km^2 sample units" within the stratum (Total area/15.5 km^2),

$\bar{y}$ = sample mean of aircraft pond counts,

b = slope of the regression line ($\bar{y} = a + bx$) between individual corresponding aircraft (dependent) and Landsat (independent) pond counts,

$\bar{X}$ = population mean of Landsat pond counts per "potential sample unit" (Landsat/N), and

$\bar{x}$ = sample mean of Landsat pond counts.

The estimated number of wetlands in Stratum 46 during May was 168,813 (SE = 17,547) and in July it was 150,565 (SE = 22,487). These figures were 108 percent of FWS pond number estimates that were based upon visual counts made from low-flying aircraft during 17 to 24 May, and 97 percent of the FWS aerial counts obtained 11 to 13 July. It must be emphasized that this was a comparison of one estimate with another, both of which may have been subject to error.

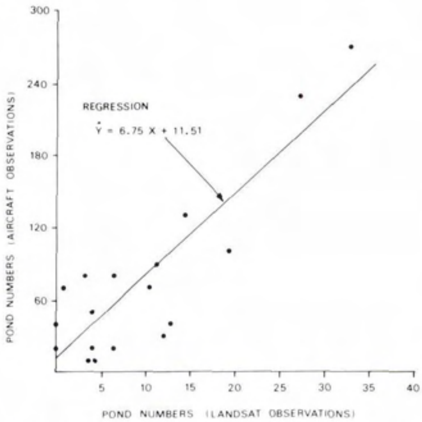

FIG. 2. Sample linear regression of pond numbers (from aircraft data) on pond numbers (from Landsat data) for July 1975. Extreme points were produced by field flooding due to abnormally heavy precipitation in late June.

This approach to estimating wetland numbers used a Landsat/aircraft data relationship to develop an estimate of wetland numbers. The method takes advantage of the benefits afforded by each of the two remote sensing systems. The value of the complete Landsat census was that it gave a better representation of the highly variable characteristics of the entire region, even though many small ponds were not detected. The value of the aircraft data was its high resolution which allowed us to detect wetlands as small as 5 m across.

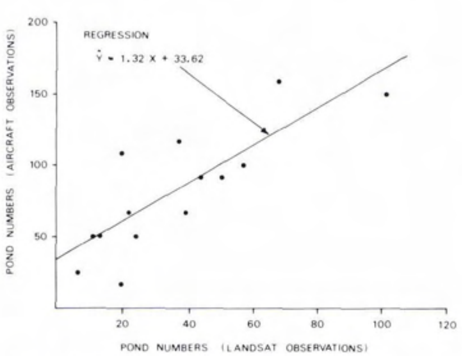

FIG. 1. Sample linear regression of pond numbers (from aircraft data) on pond numbers (from Landsat data) for May 1975.

CONCLUSIONS

An approach similar to what we have described could be used to obtain accurate estimates of wetland numbers for the entire prairie pothole region. This task could be accomplished by first selecting a random sample from the total number of Landsat frames that are needed to cover the pothole region for a particular period (e.g., May, July). Within each Landsat frame a second sample (double sample) could be obtained with remote sensing devices in aircraft. The comparison of wetland counts obtained by Landsat with counts obtained from interpretations of aircraft imagery would provide a means of adjusting the estimates derived from each Landsat frame. Using this double sampling procedure, an estimate of the number of wetlands in the entire region could then be generated in a manner similar to that described earlier.

An important advantage of this approach is that the double sample plots could provide additional data, such as information on wetland types and land-use practices on surrounding uplands, that would increase the value of the regional assessment of waterfowl habitat. It is important that the aircraft double sample be acquired as nearly coincident with the satellite overflight as possible, and that the double sample be accurately located within the Landsat frame.

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References

Brown, G. M., J. Hammack, and M. F. Tillman, 1976. Mallard population dynamics and management models, *J. Wildl. Manage.* 40:542-555.

Cochran, W. G., 1977. *Sampling techniques*, 3rd ed. John Wiley and Sons, Inc., New York. 428 pp.

Colwell, J. E., D. S. Gilmer, E. A. Work, D. L. Rebel, and N. E. G. Roller, 1978. *Use of Landsat data to assess waterfowl habitat quality*, Final Rep. prepared for NASA, Greenbelt, MD. 83 pp.

Crissey, W. F., 1969. Prairie potholes from a continental viewpoint, in *Saskatoon Wetlands Seminar*, Canadian Wildlife Service Report Series No. 6, Ottawa, Ontario, pp. 161-171.

Drewien, R. C., and P. F. Springer, 1969. Ecological relationships of breeding blue-winged teal to prairie potholes, in *Saskatoon Wetland Seminar*, Canadian Wildlife Service Report Series No. 6, Ottawa, Ontario, pp. 102-115.

Gilmer, D. S., J. E. Colwell, and E. A. Work, 1979. Use of Landsat for evaluation of waterfowl habitat in the prairie pothole region, *Proceedings of Pecora IV Symposium on Application of Remote Sensing Data to Wildlife Management*, Sioux Falls, South Dakota, Oct. 10-12, 1978, pp. 197-203.

Grubbs, F. E., 1950. Sample criteria for testing outlying observations, *Annals of Mathematical Statistics*, Vol. 21.

Henny, C. D., D. R. Anderson, and R. S. Pospahala, 1972. *Aerial surveys of waterfowl production in North America, 1955-71*, Special Scientific Rep. Wildlife No. 160. U.S. Fish and Wildlife Service, Washington, D.C. 48 pp.

Martin, F. W., R. S. Pospahala, and J. D. Nichols, 1978. Assessment and population management of North American migratory birds, *Second International Ecological Congress Satellite Program in Statistical Ecology*, Univ. Parma, Parma, Italy. August 1978.

Millar, J. B., 1969. Some characteristics of wetland basins in central and southwestern Saskatchewan, in *Saskatoon Wetlands Seminar*, Canadian Wildlife Service Report Series No. 6, Ottawa, Ontario, pp. 73-101.

Roller, N. E. G., 1979. Quantitative evaluation of deer habitat, *Proceedings of Pecora IV Symposium on Application of Remote Sensing Data to Wildlife Management*, Sioux Falls, South Dakota, Oct. 10-12, 1978, pp. 137-145.

———, and J. E. Colwell, 1979. Wetland inventory and condition evaluation techniques, *Proceedings of Pecora IV Symposium on Application of Remote Sensing Data to Wildlife Management*, Sioux Falls, South Dakota, Oct. 10-12, 1978, pp. 227-234.

Smith, A. G., J. H. Stoudt, and J. B. Gollop, 1964. Prairie potholes and marshes, in J. P. Linduska ed. *Waterfowl Tomorrow*. U.S. Gov. Print. Off. Washington, D.C., pp. 39-50.

Stewart, R. E., 1975. *Breeding birds of North Dakota*, Tri-College Center for Environmental Studies, Fargo, ND. 295 pp.

Work, E. A., and D. S. Gilmer, 1976. Utilization of satellite data for inventorying prairie ponds and lakes, *Photogramm. Eng. and Remote Sensing*, 42:685-694.

———, D. S. Gilmer, and A. T. Klett, 1974. *Utilization of ERTS-1 for appraising changes in continental migratory bird habitat*, Northern Prairie Wildlife Research Center, Jamestown, ND. (NTIS No. E75-10188), 100 pp.

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