Remote Sensing as a Tool for Monitoring Wetland Habitat Change

Thomas E. Dahl[1]
U.S. Fish and Wildlife Service

[1] *Wetlands Biologist, U.S. Fish and Wildlife Service, Branch of Habitat Assessment, Fish and Wildlife Resource Center, 555 Lester Ave., Onalaska, WI 54650. Email: tom_dahl@fws,gov.*

Aguirre-Bravo, C.; Pellicane, Patrick J.; Burns, Denver P.; and Draggan, Sidney, Eds. 2006. ***Monitoring Science and Technology Symposium: Unifying Knowledge for Sustainability in the Western Hemisphere****. 2004 September 20-24; Denver, CO. Proceedings RMRS-P-42CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 990 p.*

Keywords: monitoring wetlands, ecosystem resources, wetlands, wetland trends, surface water, remote sensing, ecological change.

Abstract

The U.S. Fish and Wildlife Service has a long history of determining the status and trends of the nation's wetland habitats. The national Wetland Status and Trends Study monitors wetland extent and change using a statistically stratified, simple random sampling design, the foundations of which are well documented. The Service acquires and analyses various types of remotely sensed imagery for about 4,500 sample plots throughout the conterminous United States. It is a quantitative measure of the areal extent of all wetlands in the conterminous United States. Our Nation's wetlands goals have traditionally been based on wetland acreage and the ability to provide a quantitative measure of the extent of wetland area as a means to measure progress toward achieving the national policy goal of "no net loss". The use of remote sensing is an effective tool in this process. Gross physical alterations to wetlands such as drainage, filling, flooding, channelization or removal of vegetation can be detected using either aircraft or satellite imagery. However, there are unique challenges posed by using remotely sensed data for identifying and monitoring some wetland habitats and changes that may occur over time.
The identification and delineation of wetland habitats through image analysis forms the foundation for deriving all subsequent wetland status and trends products and data results. Because of the limitations of aerial imagery as the primary data source to detect wetlands, the Service excludes certain wetland types from its monitoring efforts. Delineation of all other wetland areas rely on characteristics of the remote sensing data source(s), seasonal conditions at the time of image capture, the quality of collateral data and ground truth information. Change detection and attribution of change over time present additional challenges in correctly analyzing remote sensing imagery.

Remote Sensing of Wetland Habitats

Remote sensing techniques to detect and monitor wetlands in the United States and Canada have been used successfully by a number academic researchers and governmental agencies (Dechka and others 2002; Watmough and others 2002; Tiner 1996; National Research Council 1995; Patience and Klemas 1993; Lillesand an Kiefer 1987; Aldrich 1979). The use of remotely sensed data, weather from aircraft or satellite, has definite advantages in conducting national surveys over expansive areas that need to be cost effective (Dahl 1990). The U.S. Fish and Wildlife Service (Service) has used remote sensing techniques to determine the biological extent of wetlands for the past 25 years. Much of this work is accomplished using high altitude aerial photography (1:80,000 to 1:40,000 scale). In doing so, the Service recognizes several limitations to using remote sensing data to survey or monitor wetlands including limits in detectable size of target areas, inability to accurately map or monitor certain types of wetlands such as sea grasses, submerged aquatic vegetation, or submerged reefs (Dahl 2000), inability to consistently identify certain forested wetlands (Tiner 1990), and resultant datasets represent ecological conditions that may not coincide with regulatory definitions or legal authorities. Photographic evidence of hydrological conditions, in combination with collateral data, is sufficient to accurately document wetland existence. The Service relies on remotely sensed imagery from a variety of sources to conduct habitat mapping and wetlands status and trends work.

Monitoring Wetland Status and Trends

Recent studies have used aerial imagery and statistical sampling to estimate wetland change over time (Hefner and others 1994; Moulton and others 1997; Dahl 1999). Data from wetland trend studies provide important long-term trend information about specific changes and the overall status of wetlands in the United States. The historical data base that has developed through the use and retention of the remote sensing data used to conduct these studies provides a visual archive of land use and wetland extent dating back to the 1950s (fig. 1). This not only provides a legacy for the agency's capital investments but can also provide an accurate record to assist in evaluating land use trends, changes in habitat availability and potentially assist in future habitat restoration efforts.

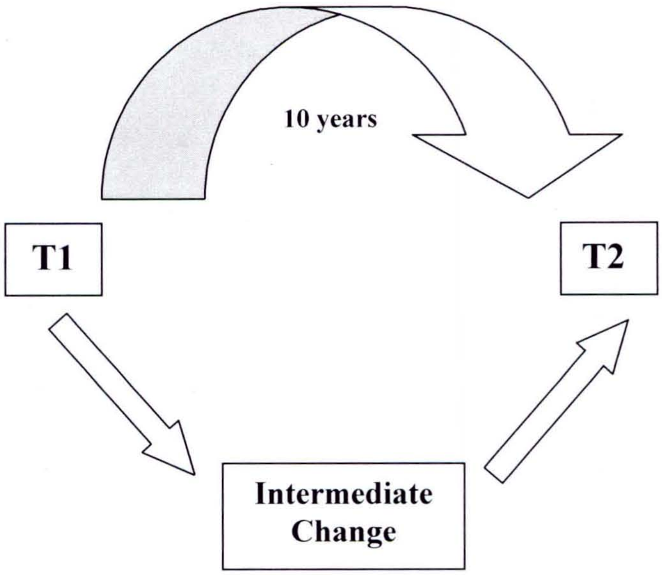


Figure 1. Intermediate changes that take place between image capture dates are not detected.

The Wetlands Status and Trends program is a quantitative measure of the areal extent of all wetlands in the conterminous United States. It relies on elements of remotely sensed observables as well as statistical estimates to produce contemporary wetland status and change information. Wetland losses from drainage, filling, leveling or diking as well as wetland gains resulting from wetland creation or restoration are measured and reported. The ability to provide a quantitative measure of the extent of wetland area and report at periodic intervals provides important information on habitat and land use trends and provides a **measurable element** in the implementation of the national policy goal of achieving "no net loss".
The Service uses the Cowardin *et al.* (1979) definition of wetland. This definition is the standard for the agency and is the national standard for wetland mapping, monitoring, and data reporting as determined by the Federal Geographic Data Committee. Adaptations or modifications to the classification system have been made to accommodate using remotely sensed imagery as the primary data source. For example, water chemistry, halinity, water depth, substrate size and type and even some differences in vegetative species cannot be reliably ascertained from air photos or satellite imagery. Image analysts must primarily rely on physical or spectral characteristics evident on high altitude imagery to make decisions regarding wetland classification and deepwater determinations[2]. Similarly, the hierarchical structure of the Cowardin classification system allows an undetermined number of possible habitat descriptors. The status and trends study limits the number of

[2]Analysis of imagery is often supplemented with limited field work and ground observations.

habitat descriptors to the most dominant types (table 1). This also aids classification accuracy determinations as well as limits variability for more robust statistical estimations.

Table 1. Wetland, deepwater, and upland trend categories (Adapted from Anderson and others 1976; Cowardin and others 1979).

	Cowardin *et al.* (1979) Type	**Common Description**
Salt Water Habitats	Marine Subtidal*	Open Ocean
	Marine Intertidal	Near shore
	Estuarine Subtidal*	Open water/bay bottoms
	Estuarine Intertidal Emergents	Salt marsh
	Estuarine Intertidal Forested/Shrub	Mangroves or other estuarine shrubs
	Estuarine Intertidal Unconsolidated Shore	Beaches/bars
	Estuarine Aquatic Bed	Submerged or floating estuarine vegetation
	Riverine* (may be tidal or non tidal)	River systems
Freshwater Habitats	Palustrine Forested	Forested swamps
	Palustrine Shrub	Shrub wetlands
	Palustrine Emergents	Inland marshes/wet meadows
	Palustrine Unconsolidated Shore	Shore beaches/bars
	Palustrine Unconsolidated Bottom	Open water ponds
	Palustrine Aquatic Bed	Ponds with floating aquatics
	Palustrine farmed	Farmed wetlands/rice
	Lacustrine*	Lakes and reservoirs
	Landuse Type	**Description**
Uplands	Agriculture	Cropland, pasture, managed rangeland
	Urban	Cities and incorporated developments
	Forested Plantations	Planted or intensively managed forests; silviculture
	Rural Development	Non urban developed areas and infrastructure
	Other Uplands	Rural uplands not in any other category; barren lands

*Constitutes deepwater habitat

Monitoring Requirements.

The Emergency Wetlands Resources Act requires the Service to produce national wetlands status and trend reports to Congress at ten year intervals. This legislative mandate established a timetable for acquiring imagery, conducting analyses, and reporting at ten year increments. National reports were produced in 1983, 1991 and 2000. Status and trends reports are used by Federal and State agencies, the scientific community, and conservation groups for planning, decision-making, and wetland policy formulation and assessment. More recently, a consortium of 11 Federal agencies (including the U. S. Army Corps of Engineers, the Environmental Protection Agency, the National Oceanic and Atmospheric Administration, the Department of Agriculture and the Department of Interior) have been working on administrative reform actions aimed at halting wetland loss and accelerating the process of gaining wetlands through restoration and creation. A goal of this effort is to achieve a net increase of 100,000 acres (40,500 ha) of wetlands each year by 2005. The Service's effort to monitor wetland trends provides the only comprehensive performance measure for these agencies to know if they are achieving this goal, but to adequately address these efforts, the reporting cycle for the national status and trends study would need to be accelerated by five years.

On Earth Day (April 2004) a Presidential directive stipulated that the Service would complete an updated wetlands status and trends study five years ahead of schedule. The Service is moving to meet this directive by December 2005.

Past iterations of the status and trends relied on the best imagery available to detect wetlands. During the 1950s through the 1970s choices of aerial photography were limited. Historical imagery was black and white and the dates were widely distributed on either side of the target timeframe. For instance, the normalized date of imagery for the initial study was 1954 but the range in T1 covered a span of 12 years. The establishment of the National High-altitude Aerial Photography Program in the early to mid 1980s, and subsequently the National Aerial Photography Program (NAPP) made much more color infrared imagery available and provided national coverage reducing the variability in photography dates (Dahl and Johnson 1991). The Service relied on aerial photography available from NAPP supplementing coverage with some customized flights to acquire imagery and some satellite imagery through 2000 (Dahl 2000).

In 2004, recent NAPP coverage for large portions of the country is not available. Multiple sources of satellite imagery and National Agricultural Imagery Program (NAIP) digital photography will be used to complete the update study scheduled for 2005. Advantages to this approach include: imagery dates are within 2 years of the target reporting date and all sources provide high resolution digital imagery. Disadvantages include, overall costs to acquire imagery have increased and NAIP imagery is acquired mid-growing season which is not ideal for wetland identification.

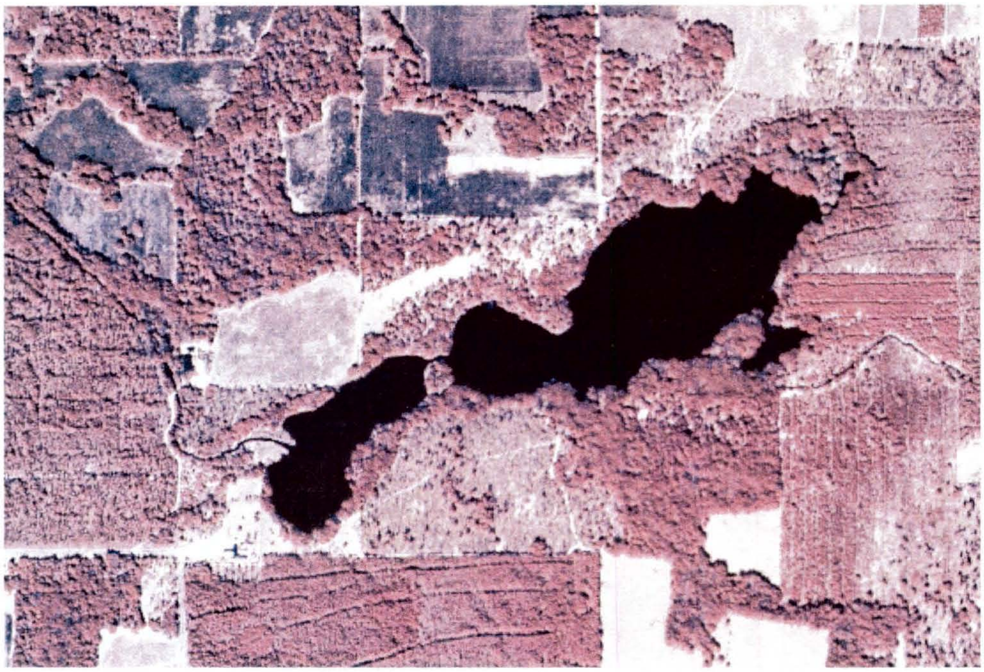
Wetland Change Detection

Remotely sensed imagery provides the primary data source for wetland change detection. It is used in conjunction with reliable collateral data such as topographic maps, coastal navigation charts, soils information, and historic imagery or studies. Field verification also plays an important role and is used to address questions regarding image interpretation, land use classification and attribution of wetland gains or losses. Field work is also done as a quality control measure to verify accurate sample plot information. Field verification includes a cross section of wetland types, geographical settings, and sample areas with different image types, scales and dates.

Difficulties in determining wetland change can be related to timing or quality of the imagery. Imagery acquired at the time of abnormal hydrologic conditions, such as flooding or drought, can make determination of wetland change challenging (fig. 2a and b; fig. 3). In these instances field work is required to assist image analysts in making appropriate wetlands determinations.

(a)

(b)



Figures 2a and b. Aerial photographs of north-central Florida (a) 1989, during drought conditions and (b) 1996, during higher water conditions (Original photography was color infrared 1:40,000 scale acquired by the National Aerial Photography Program).

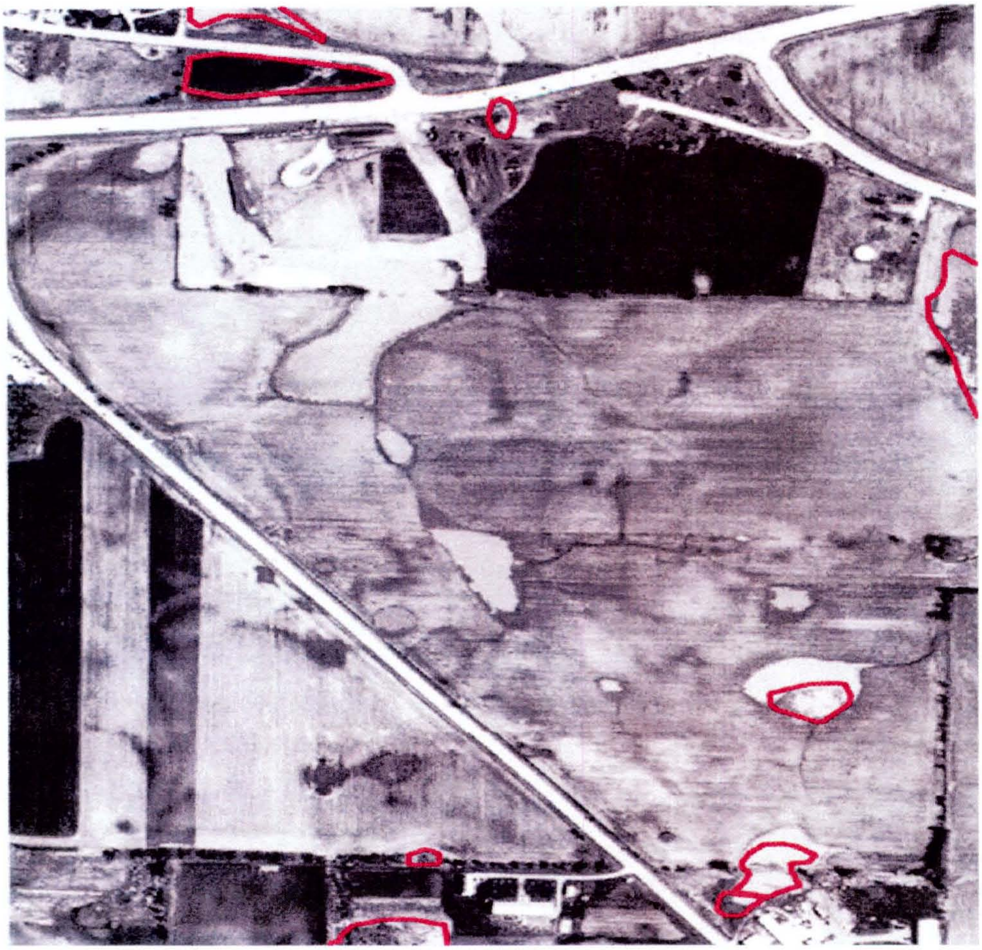


Figure 3. This aerial photograph, taken following heavy rains, shows ponded surface water in topographic depressions throughout farm fields. Too much water can make wetland identification more difficult (Original image 1:40,000 scale, black and white aerial photograph, 1998).

Some land use practices can also affect wetland change detection. Disturbed sites include areas where remote sensing indicators are ambiguous. Disturbed areas are often indicative of lands in transition from one land use to another (fig. 4). Upon field inspection, these areas often have had the hydrology, soils or vegetation altered making wetland classification and determination more difficult.

The examples mentioned above are all potential source of procedural error. Procedural errors are not considered in statistical probability estimates, but they occur in the data collection phase of any study and must be considered. Virtually all statistical measurements and reliability rely on the accuracy of the measurements. A well designed statistical study may still produce erroneous results if the procedural error is unacceptable (Dahl 2000).

Procedural error is related to the ability to accurately recognize and classify wetlands both from multiple sources of imagery and on-the-ground evaluations. Types of procedural errors that can occur include: missed wetlands, inclusion of upland as wetland, misclassification of wetlands or misinterpretation wetland loss or gain attribution. The amount of procedural error is usually a function of the quality of the source data, the number, variability, training and experience of data analysts, and the rigor of any quality control or quality assurance measures. Estimated procedural error for wetlands status and trends studies range from four to six percent when all quality assurance measures have been completed.

Figure 4. This aerial photograph shows a new housing development in the early stages of construction. Former wetland extent is shown by the red polygons. New water bodies are evident throughout the project area. Lands in transition, such as this example, often exhibit dramatic wetland change (Original imagery was black and white, digital orthophoto quarterquad courtesy of the State of Illinois).

Summary

In recent years the use of wetland trends information has been institutionalized in discussions or initiatives dealing with wetland and other resource issues. National legislation and Congressional report make direct reference these data and there is no lack of interest in updated and expanded monitoring. A national "no-net-loss" policy goal for wetland would seem to hinge on obtaining accurate and current status and trends data for wetlands. Changes in the availability of remotely sensed data as well as changes in historic land use trends make this monitoring effort technically challenging.

The Fish and Wildlife Service will continue to produce national updates on wetlands status, as well as more rigorous information on wetland trends. This information should contribute policy evaluation and help guide future management and research decisions.

Reference Cited

Anderson, J.R., E.E. Hardy, J.T. Roach and R.E. Winter. 1976. A land use and land cover classification system for use with remote sensor data. U.S. Geological Survey Professional Paper 964. U.S. Geological Survey, Washington, D.C. 28 p.

Aldrich, R.C. 1979. Remote sensing of wildland resources: A state-of-the-art review. USDA Forest Service, General Technical Report RM-71, Rocky Mt. Forest and Range Experiment Station, Ft. Collins, CO. 56 p.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC. FWS/OBS-79/31.

Dahl, T.E. 2000. Status and trends of wetlands in conterminous United States 1986 to 1997. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 82 p.

Dahl, T.E. 1999. South Carolina's wetlands—status and trends 1982–1989. Department of the Interior, U.S. Fish and Wildlife Service, Washington, D.C. 58 p.

Dahl, T.E. and C.E. Johnson. 1991. Status and trends of wetlands in the conterminous United States, mid-1970s to mid-1980s. U.S. Department of the Interior. U.S. Fish and Wildlife Service, Washington, D.C. 28 p.

Dahl, T.E. 1990. Techniques for conducting variable intensity wetland inventories. *In* Convention on Wetlands of International Importance Especially as Waterfowl Habitat, Fourth Meeting of the Conference of the Contracting Parties, Montreux, Switzerland, Proceedings of Technical Workshop E.

Dechka. J.A., S.E. Franklin. M.D. Watmough. R.P. Bennett and D.W. Ingstrup. 2002. Classification of wetland habitat and vegetation communities using multi-temporal Ikonos imagery in southern Saskatchewan. Can. J. Remote Sensing, Vol. 28. No. 5, pp. 679-685.

Lillesand, T.M. and R.W. Kieffer. Remote Sensing and Image Interpretation 2nd edition. John Wiley and Sons, N.Y. 721 p.

National Research Council. 1995. Wetlands: Characteristics and boundaries. Committee on Characterization of Wetlands, Water Science and Technology Board. National Academy Press, Washington, D.C. 268 p.

Patience, N. and V. Klemas. 1993. Wetland Functional health assessment using remote sensing and other techniques: Literature search. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, SE Fisheries Science Center, Beaufort Laboratory, Beaufort, NC. 60 p.

Tiner, R.W. 1990. Use of high-altitude aerial photography for inventorying forested wetlands in the United States. Forest Ecology and Management, 33/34: 593-604.

Tiner, R.W. 1996. Wetlands, *In*: Manual of Photographic Interpretation, second edition. American Society for Photogrammetry and Remote Sensing, Falls Church, VA. 2440 p.

Watmough, M.D., D.W. Ingstrup, D.C. Duncan and H.J. Schinke. 2002. Prairie Habitat Joint Venture Habitat Monitoring Program Phase 1: Recent habitat trends in NAWMP targeted landscapes. Technical Report Series No. 391, Canadian Wildlife Service, Edmonton, Alberta, Canada. 93 p.

RMRS Online Publication

RMRS-P-42CD: Monitoring Science and Technology Symposium: Unifying Knowledge for Sustainability in the Western Hemisphere

Aguirre-Bravo, C.; Pellicane, Patrick J.; Burns, Denver P.; and Draggan, Sidney, Eds. 2006. **Monitoring Science and Technology Symposium: Unifying Knowledge for Sustainability in the Western Hemisphere**. 2004 September 20-24; Denver, CO. Proceedings RMRS-P-42CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 990 p.

A rational approach to monitoring and assessment is prerequisite for sustainable management of ecosystem resources. This features innovative ways to advance the concept of monitoring ecosystem sustainability across spheres of environmental concern, natural and anthropogenic processes, and other hemispheric issues over a variety of spatial scales and resolution levels. Individuals and institutions, committed to mutual sustainability of ecosystem resources and human institutions, shared experiences and outlined a foundation for advancing the science and practice of monitoring and assessment at multiple geographical and organizational scales. Questions addressed in the proceedings papers include: What is the status and condition, and what are the trends in ecosystem sustainability? What are the strategies and opportunities for solving the sustainability dilemma? What are the individual and institutional responses to the sustainability challenge? Discussion during the symposium fostered the creation of coherent and unified ecosystem resource sustainability assessments and syntheses valuable to support environmental management and decision-making processes. The proceedings is a testimonial to the wealth of information presented at the symposium and a positive indicator of inter- and transdisciplinary scientific and technical success.

Keywords: monitoring, assessment, sustainability, Western Hemisphere, sustainable management, ecosystem resources