

T. D. Gustafson and M. S. Adams

REPORT 24 SEPTEMBER 1973 REPORT 24 SEPTEMBER 1973 REPORT 24 SEPTEMBER 1973

THE UNIVERSITY OF WISCONSIN
ENVIRONMENTAL STUDIES PROGRAM
INSTITUTION

NASA-CR-137305) THE REMOTE SENSING OF AQUATIC MACROPHYTES PART 1: COLOR-INFRARED AERIAL PHOTOGRAPHY AS A TOOL FOR IDENTIFICATION AND (Wisconsin Univ.) 26 28 p HC \$4.50	N74-19042
CSCI 08A	Unclas G3/13 33458

THE REMOTE SENSING OF AQUATIC MACROPHYTES

REPORT 24 SEP

UNIVERSITY OF WISCONSIN
ENVIRONMENTAL STUDIES PROGRAM
INSTITUTION

;

THE REMOTE SENSING OF AQUATIC MACROPHYTES

PART I

COLOR-INFRARED AERIAL PHOTOGRAPHY AS A TOOL FOR
IDENTIFICATION AND MAPPING OF LITTORAL VEGETATION

PART II

AERIAL PHOTOGRAPHY AS A QUANTITATIVE TOOL
FOR THE INVESTIGATION OF AQUATIC ECOSYSTEMS*

T. D. Gustafson

M. S. Adams

University of Wisconsin--Madison
Institute for Environmental Studies
Remote Sensing Program

Report No. 24

September 1973

Support for studies reported here was supplied in part by the University of Wisconsin Remote Sensing Program, NASA Multidisciplinary Research Grant in Space Science and Engineering, Grant #NGL 50-002-127 and in part by the Eastern Deciduous Forest Biome Project, IBP, funded by the National Science Foundation under Interagency Agreement AG-199, 40-193-69 with the Atomic Energy Commission, Oak Ridge National Laboratory.

* This report was in part presented at the symposium, "Remote Sensing for Water Resources Management" sponsored by the American Water Resources Association on June 11-14, 1973, in Burlington, Ontario, Canada.

PART I

COLOR-IRRED AERIAL PHOTOGRAPHY AS A TOOL FOR IDENTIFICATION AND MAPPING OF LITTORAL VEGETATION

INTRODUCTION

Ecological investigations of aquatic systems are especially difficult and time-consuming. Aerial photography and other remote sensing techniques may in part fulfill the need for the development of more rapid and accurate methods for investigation of aquatic plant communities. Recent efforts in the remote sensing of wetlands by Anderson (1971), Carter and Anderson (1972), and Anderson and Wobber (1972) have shown that various species and certain plant communities can be differentiated with aerial photography and that the important features can be mapped. In the case of submergent aquatic plant communities there is the difficulty of the intervening water that partially obscures the vegetation or in other ways interferes with attempts to obtain usable imagery. Several submergent species have been characterized with respect to their reflectances in certain portions of the visual and infrared (Spooner 1969), and aerial photography has been tested as a method for identification and mapping of submergent vegetation (Lukens 1968). Lukens found color film to be most satisfactory for this application and reported that the photography allowed recognition of the major features of the underwater vegetation to depths of 6 m. Kelly and Conrod (1969) found that the application of aerial photographic methods to shallow water benthic research resulted not only in savings of time and effort, but that the photographs provided them with ecological insight that was not available with surface and subsurface observations alone.

We initiated our research to use aerial photography as an investigative tool in studies that are part of an intensive aquatic ecosystem research effort at Lake Wingra, Madison, Wisconsin. It was anticipated that photographic techniques would supply information about the growth and distribution of littoral macrophytes with efficiency and accuracy greater than conventional methods.

THE STUDY AREA

Lake Wingra is an intensive study site in the Eastern Deciduous Forest Biome, U.S. International Biological Program. The lake, a natural, shallow basin on an outwash terrace overlying a feeder stream of the Yahara River, lies in central Dane County, Wisconsin. The surface area is 140 ha and the maximum depth is 6.4 m. A well-defined littoral zone which is heavily colonized by aquatic macrophytes occurs in the lake. The littoral community is dominated by *Myriophyllum spicatum*, which is found in nearly pure stands in water 80 to 270 cm deep. Other species of some importance include *Nuphar variegatum* Engelm. and *Nymphaea tuberosa* Paine which heavily colonize certain areas of

from 35 to 80 cm water depth. Small, scattered stands of *Certophyllum demersum* L. occur at the shallow and deep water edges of the *Myriophyllum* beds. A well developed *Oedogonium* mat is usually found by midsummer overgrowing part of the *Myriophyllum*. The most shallow areas typically have a scattering of *Myriophyllum* plants and various *Potamogeton* species (Nichols and Mori 1971). One of these shallow water species, *P. natans* L., forms a few moderately dense stands near the outlet. A few shallow areas of coarse marl substrate are conspicuous by their almost complete lack of vegetation.

METHODS

A two-camera 35mm aerial photographic system (Rinehardt and Scherz 1972) with color and color infrared film was used to obtain imagery of 1:34,000 and 1:17,000. Overlapping exposures were oriented so that the shoreline and littoral zone areas would lie near the center of the format. Flights were scheduled whenever possible on clear days and at times of low sun angle to avoid glitter.

"Ground truth" (surface attributes corresponding to image features) investigations were facilitated by using white plywood panels that were easily visible in the photographs. These panels were placed at selected vegetational boundaries to test the photographic response to ground truth differences. The color infrared film, Kodak Aerochrome 2443, was found superior for identification purposes and was used exclusively for interpretation and analysis.

Standard methods of visual interpretation (Avery 1968) were used to characterize the important image features. Ground truth data was then used to classify these image types according to their vegetational attributes (Table 1). Munsell colors were also determined when possible.

Microdensitometer analysis of the various image types was conducted to develop an objective method for identification. The analysis system employed was the Gamma Scientific microdensitometer-spectrophotometer described by Klooster and Scherz (1973). A spot size was selected that was equivalent to an area at the water surface of 0.7m^2 in the photographs of the larger scale. This system is able to determine the transmittance characteristic of a film image at any wavelength from 350 to 800 nm. Spectral signatures for the various image types (Figure 1) were examined for wavelengths that could be used to form ratios characteristic of the respective images. Selected ratios were exposed to rigorous testing by lumping data from different times of the season and from different years. Ninety-five percent confidence intervals were calculated and means tested for actual differences by Duncan's new multiple range test (Steel and Torrie 1960).

A projection technique was used for mapping from the color infrared imagery. The images were projected from standard equipment onto shoreline maps (1:1200 or 1:2400 scale) drawn on sheets of "mylar" drawing plastic. Good results were obtained even with low precision equipment by using the shoreline as control for rectification of error caused by slight deviation from the vertical. Features were identified and boundaries traced in with pencil.

The maps were then inked and working blue line copies produced directly from the original. A map prepared by the preceding methods from the Lake Wingra imagery of 14 July 1971 is shown in Figure 2.

TABLE 1
Identification Key for the Lake Wingra Image Types

TYPE	TO NE	TEXTURE	LOCATION	SHAPE	MUNSELL COLOR	DENSITY RATIO
MYRIOPHYLLUM	DEEP ORANGE	MOTTLED	MID TO DEEP LITTORAL (70-270 cm)	VARIABLE, BOUNDARIES DISTINCT	7.5R7/10	0.9306
NUPHAR-NYMPHAEA	BRIGHT PINK	FINELY TEXTURED	PROTECTED AREAS SHALLOW TO MID LITTORAL (35-80 cm)	ROUND TO ELONGATE	2.5RP8/6	0.8843
OEDOGONIUM MAT	VERY LIGHT TAN	VERY SMOOTH	OVERGROWTH ON MYRIOPHYLLUM	AMORPHOUS, BOUNDARY INDISTINCT	7.5R9/12	1.0416
CERATOPHYLLUM	DEEP RED	UNIFORM TO ROUGH	EDGES OF MYRIOPHYLLUM BEDS	VARIABLE	7.5R3/12	0.8027
POTAMOGETON-MYRIOPHYLLUM	DARK GREEN	UNIFORM	NEAR SHORE LITTORAL	VARIABLE	-	1.8470 (0.728)
FLOATING-LEAVED POTAMOGETON	MEDIUM PINK	COARSE	MID LITTORAL (100-200 cm)	ROUND	7.5R8/6	-
DEEP WATER	DEEP BLUE	UNIFORM	AREAS MORE THAN 3 m DEPTH	-	2.5PB6/8	2.1620 (6.646)
SHALLOW WATER MARL	LIGHT TURQUOISE	UNIFORM	SHALLOW TO MID LITTORAL	ELONGATE WITH SHARP BOUNDARY	2.5PB8/4	-

Results are for color infrared film (Kodak aerochrome 2443). Density ratios are 600:625 nm except values in brackets which are 450:600 nm.

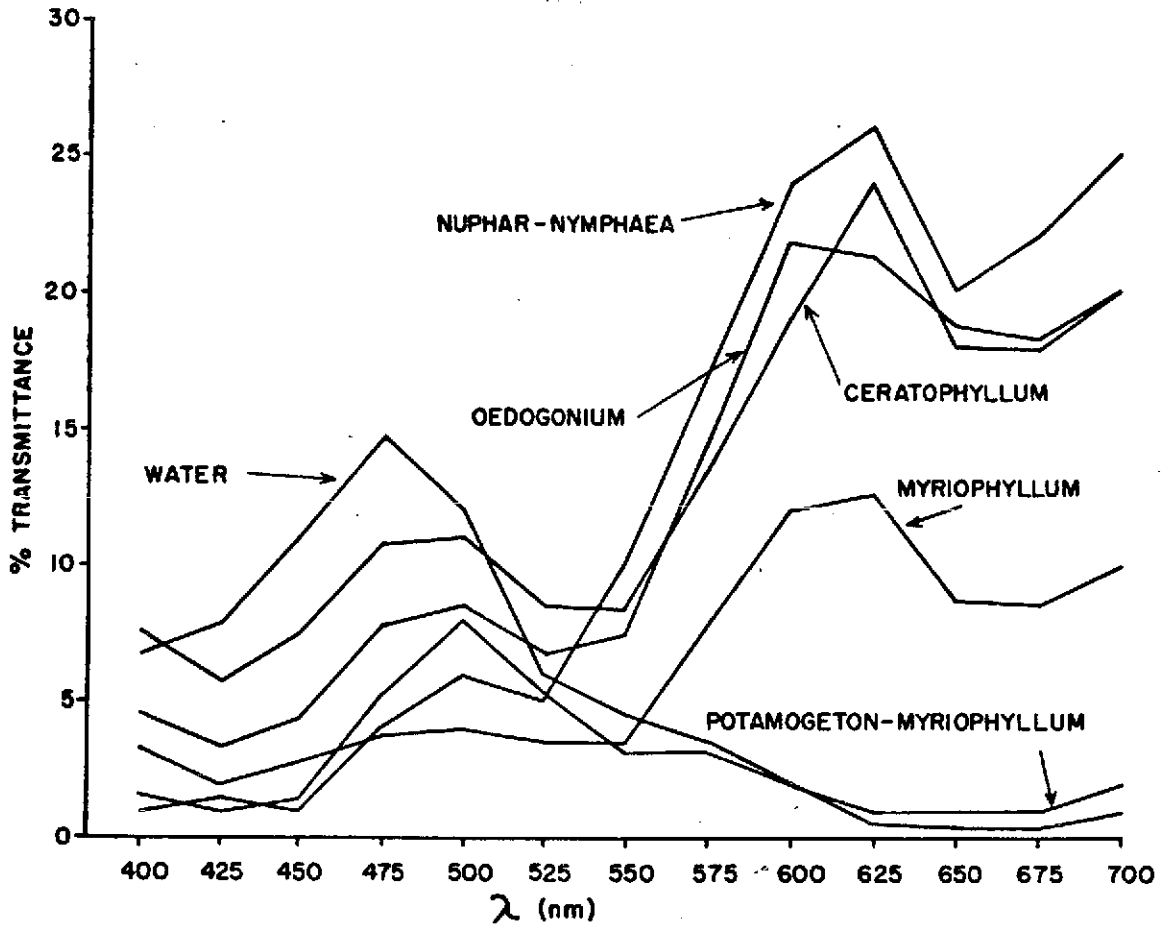


Figure 1. Spectral signatures of some of the Lake Wingra image types. Data from microdensitometer-spectrophotometer analysis of 35 mm aerial color infrared photographs (Kodak aerochrome 2443).

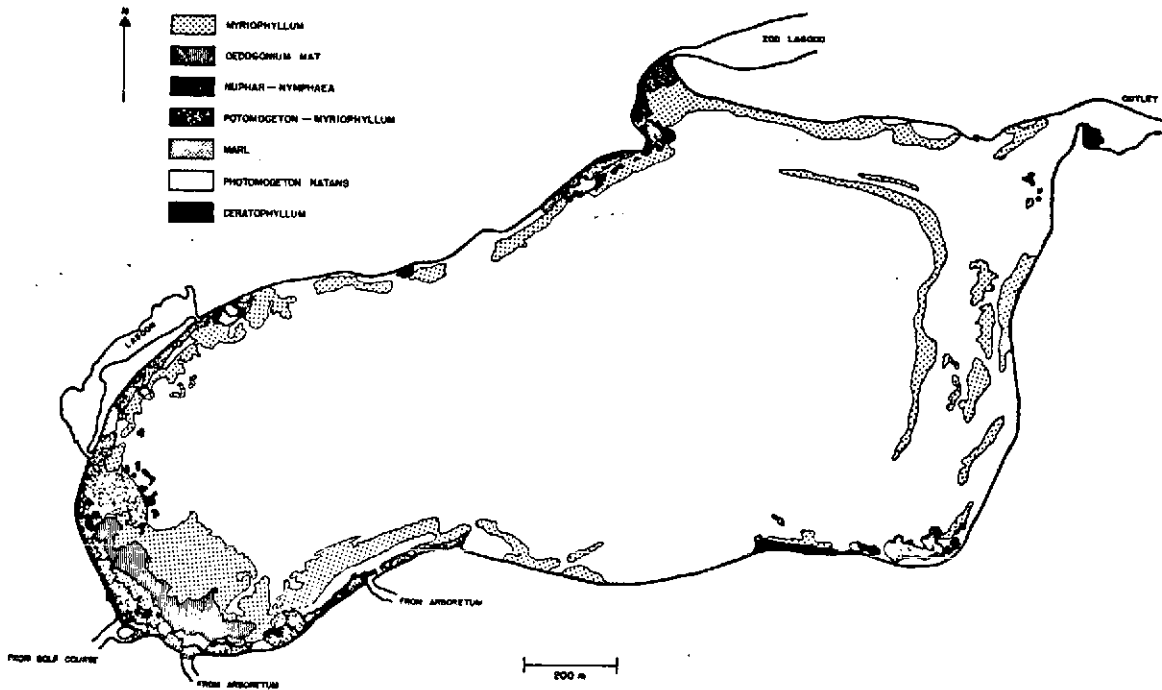


Figure 2. Lake Wingra vegetation map of 14 July 1971. Map was constructed from aerial color infrared photographs by using projection techniques.

RESULTS AND DISCUSSION

The superiority of the color infrared film for differentiation of terrestrial and emergent aquatic plant species or communities has been reported by many investigators. Knipling (1969) described the relationship between the reflectance characteristics of vegetation and image formation on the color infrared film. Leaves show especially high reflectance in the near infrared and green regions. Film sensitivity at 750-850 and 550 nm results in near total exposure of the blue and yellow forming emulsions by vegetation. The magenta forming layer remains only slightly exposed to form a red image since the region of its sensitivity (675 nm) is strongly absorbed by the leaves. This allows the ready distinction of vegetation from the other features in the photograph. The conspicuous tonal differences (red, orange, or pink, etc.) that are often exhibited by different types of vegetation are primarily due to leaf orientation and subtle differences in absorbance characteristics at 550 and 675 nm (Carter and Anderson 1972).

While attempting to photograph deeply submerged aquatic plants much of the advantage of using color infrared film is lost since the near infrared radiation is quickly absorbed by a few centimeters of water (Spooner 1969). When remote sensing these deeply submerged communities rigorous ground truth may be necessary since vegetation may be easily confused with other underwater features.

Most of the littoral zone vegetation of Lake Wingra appears red in the color infrared photography (Table 1). This is expected for the floating leaved water lily or pondweed communities, but the submergent (*Myriophyllum* and *Ceratophyllum*) also produce a red tone. The latter may be the result of these species growing with leafy stems very near the surface. The observation that a darkened image is produced by those areas of *Myriophyllum* growth that lack sufficient vigor to approach the surface supports this hypothesis.

The *Oedogonium* and *Potamogeton-Myriophyllum* image types did not show the characteristic red tones of vegetation. The very light image of the algal mat may be the result of greater reflectance in the red region and could be the result of less efficient absorption of photosynthetically active radiation because of marl accumulation on these plants. In contrast to the algal mat, the *Potamogeton-Myriophyllum* community appears very dark. These shallow areas contain relatively few plants, and the resultant image is probably strongly affected by the reflective properties of the bottom material.

Some of the factors that can affect the photographic image and make interpretation difficult are exposure, processing, sun angle, sky conditions, water turbidity, and wave state. We used photography taken over a period of two years and found that certain interpretive criteria (especially tone contrasts between types) were quite variable. We used microdensitometry to try to include a greater degree of precision in the interpretive process.

In a single exposure the spectral signature produced by microdensitometric analyses of the image types are quite characteristic (Figure 1). Using a simple transmittance value at a selected wavelength as a discriminatory criterion for the image types was found ineffective when using photographs from

different flights or even from several frames of the same flight. We achieved satisfactory results only by using transmittance ratios at selected wavelengths. The mean values for four of the image types (*Nuphar-Nymphaea*, *Oedogonium*, *Ceratophyllum*, *Myriophyllum*) (Table 1) are quite similar, but the differences were significant at the 1% level. The use of an additional ratio of 450:600 was required for separation of the water and *Potamogeton-Myriophyllum* (Figure 3). The transmittance ratio procedure was found unreliable for separation of the *Nuphar-Nymphaea* from the *Potamogeton natans*. These floating-leaf types have very similar tone but usually can be easily differentiated visually on the basis of texture.

Successful application of the densitometer analysis required care. The results were quite sensitive to equipment alignment, and exact calibration of the monochromator was essential for reproducible results. The analysis techniques were not tested using the photoscales available with the larger mapping camera format. It is anticipated that a change in illuminated spot size would not be sufficient correction and that a recalibration of transmittance ratios would be required. In addition, we expect that the transmittance ratios in Table 1 will not be applicable when using color infrared film of other types.

We prepared detailed vegetation maps similar to the one in Figure 2 for selected times during 1971-72, and these maps have been used to measure seasonal and annual change in the growth areas of *Myriophyllum spicatum*. We have used the information to refine harvest sampling procedures. The data has been correlated with nutrient and climatological factors. It could also be used to assess the effectiveness of harvesting or applications of chemicals for weed control and to measure the results of watershed management efforts. An anticipated use of the Wingra data is for ecosystem model verification and testing. The distribution and phenology of the various communities can also be followed through the season or contrasted from year to year. An annual photographic record for several lakes through a period of years could be easily obtained and would provide a very good source of information for studies of lake succession.

Some of the disadvantages of using the 35mm format are the small coverage and lens attenuation toward the edges of the format (Scherz 1972). The low per frame cost (15¢ vs. \$15 for the 9x9) and the availability of quality equipment were strong points in favor of its use. The results do indicate that it is adequate for the methods used in this study. However, recent investigations with methods requiring the extraction of more precise quantitative information from the imagery have shown the desirability of a larger format.

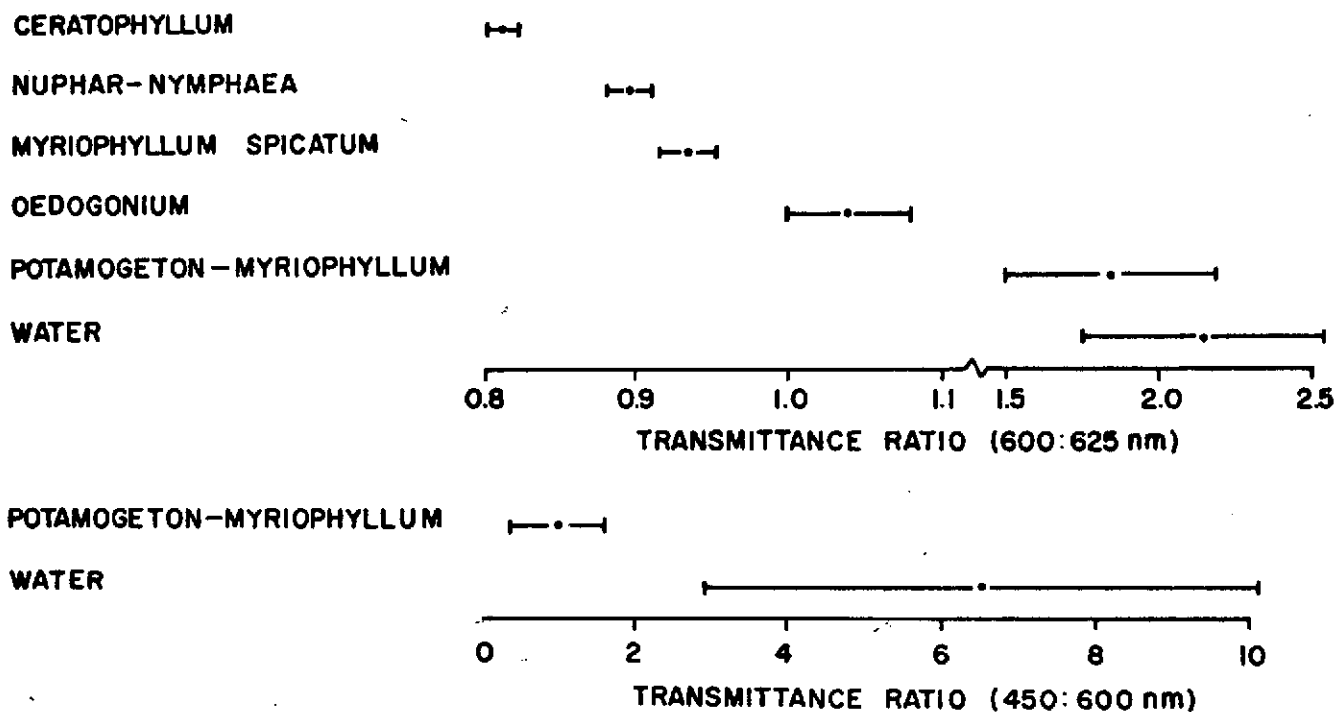


Figure 3. Mean values and 95% confidence intervals for film transmittance ratios used for differentiation of the Lake Wingra image types. The first four types are separated on the basis of film transmittance at 600 and 625 nm. The additional ratio of 450:600 nm is required for the separation of the *Potamogeton-Myriophyllum* type from the open water. Values are from microdensitometer-spectrophotometer analysis of images on color infrared photography.

PRECEDING PAGE BLANK NOT FILMED

PART II

AERIAL PHOTOGRAPHY AS A QUANTITATIVE TOOL
FOR THE INVESTIGATION OF AQUATIC ECOSYSTEMS

INTRODUCTION

Modern ecological research has an increasing requirement for investigative tools which will reduce the time and effort required by the necessarily detailed field work. This may be especially true of studies of aquatic systems where obtaining an adequate sample for determination of compartment size and dynamics of matter and energy flow is often difficult and expensive. Aerial photography and other remote sensing techniques have been successfully applied to qualitative and quantitative studies of terrestrial communities. Foresters have used aerial photography to efficiently estimate characteristics of timber lands (Aldred and Kippen 1967). Remote sensing is being used on the short grass prairie by International Biological Program investigators in productivity studies of the grassland biome (Miller and Pearson 1970). Optical film densities of images on color infrared film are significantly correlated with yield indicators of crop plants (VonSteen et al. 1969) and image interpretation and analysis are used to estimate cover and standing crop of herbaceous and shrub communities (Driscoll et al. 1972; Gallagher et al. 1972).

Although there is little doubt regarding the value of photographic and multi-band scanning systems for research in terrestrial environments, little attention has been given to their application in aquatic situations with the exception of emergent types. Westlake (1964), investigating an indirect optical method as an alternative to the use of harvest sampling to estimate biomass of aquatic macrophytes, used a submerged photocell to measure light attenuation by aquatic plants in weed bed communities. A linear relationship between optical density and the fresh weight concentrations of the several species was found. Aerial photography can be used to locate underwater vegetation and in some cases differentiate species or community types (Lukens 1968; Kelly and Conrod 1969), and shows promise as a tool for qualitative and quantitative evaluation of phytoplankton blooms (Bressette 1973).

Photographic analysis has been used to determine water turbidity and concentrations of suspended material (Klooster and Scherz 1973), and airborne spectral analysis of marine waters can provide information about chlorophyll concentrations (Clark et al. 1970).

Lake Wingra, Madison, Wisconsin, is presently the site of an intensive aquatic ecosystem study and part of the International Biological Program. The lake (surface area 140 ha) has an extensive littoral zone (43 ha) dominated by the Eurasian milfoil, *Myriophyllum spicatum* L. The growth of *Myriophyllum* and associated periphyton in Lake Wingra is a major focus of

the ecosystem modeling effort since it is considered an important factor in the cycling of nutrients and carbon and a major influence on lake succession by affecting lake chemistry and hydrology. Harvest methods for determining biomass, stem densities, and distribution were found inaccurate, laborious and too expensive to be used to monitor the littoral vegetation for a period lasting several years.

We considered remote sensing as a possible alternative to the harvest method. This paper describes the biomass and distribution of *Myriophyllum* in Lake Wingra at selected times during a three-year period and the aerial photographic methods which were used.

METHODS

A two-camera, 35mm aerial system (Rinehardt and Scherz 1972) was used to obtain simultaneous exposures in normal color and color infrared. The 250 exposure rolls of Kodak high speed Ektachrome type 5257 and Kodak infrared Aerochrome type 2443 used gave superior results and had the advantage of compatibility with standard microfilm storage and viewing equipment.

Photographic flights were scheduled when possible on clear days to avoid the disturbing shadows cast by clouds and at times of low sun angle (early morning or late afternoon) in order to minimize the glitter off the water surface which can destroy the usefulness of the imagery. The aircraft was equipped with a center-line camera mount that facilitated the acquisition of the vertical photography which we required for the quantitative studies. We used photographic scales of 1:17,000 and 1:34,000 with the littoral zone located in the center of the format and as much of the shoreline included as possible.

A projection mapping technique was used in a photointerpretive method for estimating *Myriophyllum* biomass and stem densities. The photographs were projected from standard equipment onto a shoreline map drawn on "mylar" drawing plastic. Using the shoreline control the image was corrected for small deviations from the vertical and the outlines of the various features then sketched in with pencil.

Both color and infrared photographs were used in this interpretive mapping process. The color, because of its superior delineation of the deep water boundaries of plant growth, was first used to map the outline of the vegetation. The color infrared with its advantages for the differentiation of submergent species (Gustafson and Adams, manuscript submitted for publication) was next used to refine the map of *Myriophyllum* and *Oedogonium* occurrence by delineating the boundaries formed with other species. Next, to quantify the photographs of *Myriophyllum* we interpreted image types from within the area of occurrence. This was accomplished using color infrared photographs and differentiating two image types based on tone and texture characteristics that were assumed to be the result of different levels of community vigor.

Areas contained within each class were measured by planimetry. A similar procedure of differentiating plant density levels from color infrared photographs has been used to quantify imagery of emergent salt marsh vegetation (Gallagher 1972). Calibration and testing of this technique was accomplished by comparing the mapping results with concurrently obtained "ground truth" sampling data from the extensive investigation of the Lake Wingra macrophytes conducted in 1970 by Nichols (1971). Harvest sampling points were recorded on the maps constructed from the photography, and mean stem densities were calculated for each of the image classes. The seasonal results were consolidated to three periods and conversion factors from stems to biomass calculated (Table 2). The decrease in the mean weight per stem from 1.11 g for the early period to 0.90 g for the late season agrees generally with the observations of Lind and Cottam (1969), for *Myriophyllum* in nearby Lake Mendota. The area in each class was multiplied by the respective stem density value and the total number of stems converted to a biomass estimate by using the appropriate factor.

TABLE 2

Concurrently Obtained Harvest Sampling Results Used
for Verification and Calibration of Photointerpretive Method
of Estimating *Myriophyllum* Biomass in Lake Wingra

Period	High Density Growth (stems·m ⁻²)	Low Density Growth (stems·m ⁻²)	Mean Weight/Stem (g)
5/15—6/30	300.7 ± 97.8	140.8 ± 36.8	1.11
7/1—8/15	298.0 ± 12.8	138.6 ± 36.4	1.02
8/16—9/15	368.5 ± 52.6	148.6 ± 48.6	0.90

The density categories correspond to image classes differentiated in color infrared aerial photography; 95% confidence limits shown for mean stem counts.

We used optical density measurements of the aerial photography as a second technique for estimating standing crop biomass for *Myriophyllum* in Lake Wingra. This method was tested for its ability to estimate the biomass of the *Oedogonium* mats that overgrow certain areas of the weed beds in late summer. A Gamma Scientific microdensitometer-spectrophotometer was used for analysis of the photographic images. This equipment can examine the transmittance characteristics of a very small area (10 μ - 1 mm) of the photograph at any wavelength from 350 to 800 nm. The conversion from transmittance (T) to density (D) is: $D = L \frac{1}{10^T}$.

We examined the spectral signatures of the *Myriophyllum* community, *Oedogonium* mat, and open water from their images on the color infrared film (Figure 4) to determine the appropriate wavelengths to be used for quantitative densitometry. Six hundred nm provided the near maximum contrast of the *Myriophyllum* with the background water while 555 nm for the *Oedogonium* mat allowed a uniform background by eliminating interference from the *Myriophyllum*. We determined mean film image densities by using a regular sampling method and a spot size equal to 2.5 m² on the water surface. Concurrent ground truth for *Myriophyllum* was provided by the 1970 harvest data (Nichols 1971). To calibrate this method selected areas of *Myriophyllum* growth were separated into 6 test stands to insure sufficient sample size for statistically sound data and to allow a reasonably wide range (Table 3).

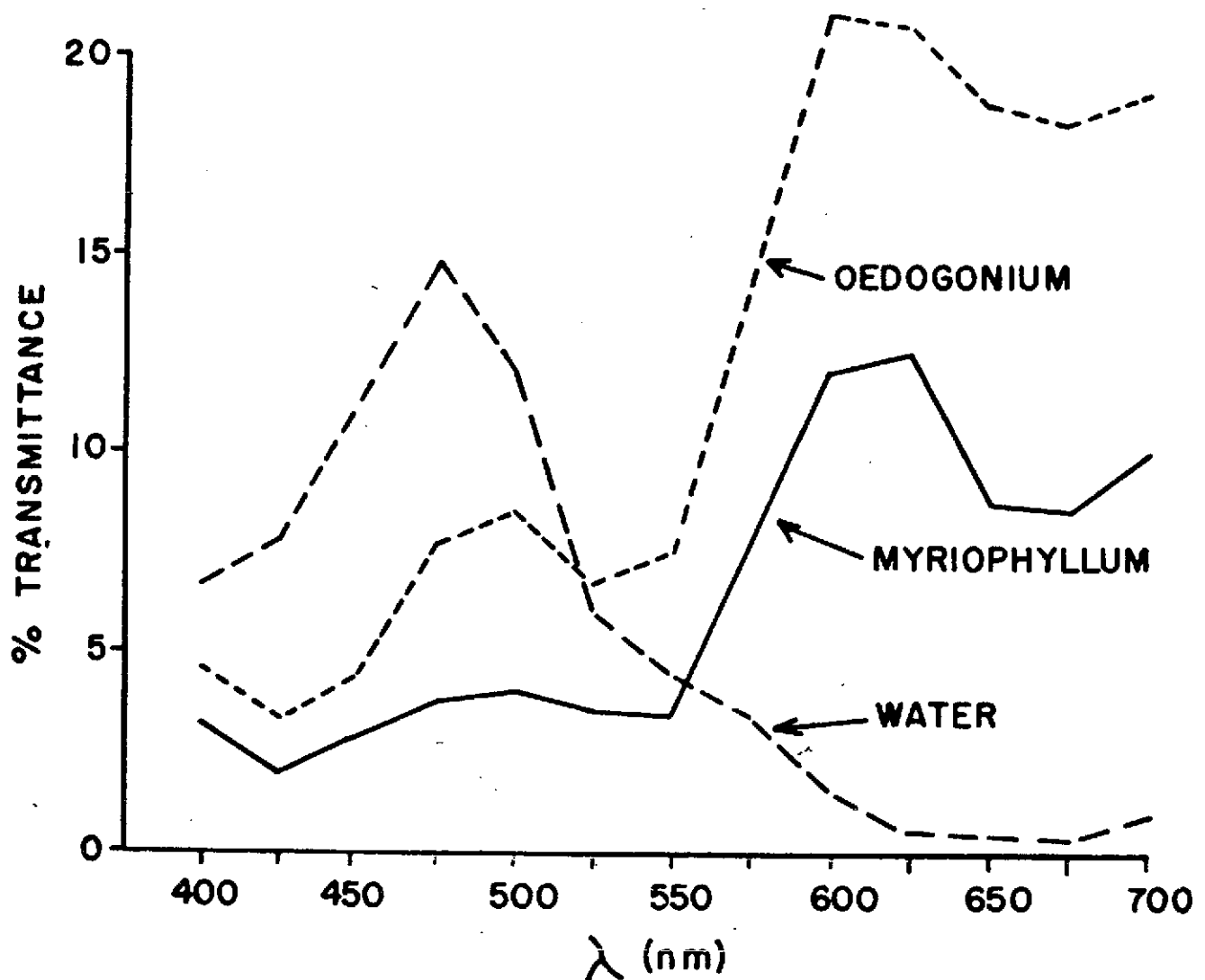


Figure 4. Spectral signatures on color infrared film of vegetation types that were investigated by photographic analysis.

TABLE 3

Test Stands of *Myriophyllum* Growth

Stand	Plant Density (stems·m ⁻²)	Stand Image Density (600 nm)	Water Image Density (600 nm)	Water Density/ Stand Density
1	255.8 ± 10.1	1.248	2.195	1.759.
2	226.6 ± 9.6	1.489	2.183	1.466
3	193.9 ± 15.8	1.713	2.155	1.258
4	189.3 ± 11.2	1.808	2.249	1.244
5	171.6 ± 6.3	1.852	2.261	1.221
6	202.5 ± 11.6	1.566	2.255	1.440

Harvest data and corresponding raw and standardized image density data that were used for verification and calibration of photoanalytic technique of estimating *Myriophyllum* biomass in Lake Wingra; 95% confidence limits are shown for mean stem densities.

Many variables affect the image characteristics used by quantitative densitometry, and standardization of the photography was prerequisite to successful photographic analysis. The effects of sun angle, sky condition, wave state, water turbidity, and film exposure or processing vary and can result in considerable error in image density measurements. This error was sufficient in some cases to obscure the quantitative information on the photograph. We tried several methods of standardizing the photography. A method in which white panels were located at or just below the lake surface was abandoned because of the large number required and because they rapidly became discolored. A series of open water density readings (at 600 nm for the *Myriophyllum*, 555 nm for the *Oedogonium*) and an additional density reading at the sampling point at 550 nm (*Myriophyllum* only) were compared for their ability to standardize the community readings by using density ratios. Linear regressions of the mean standardization densities as the dependent variable demonstrated that the method using open water reading (Figure 5) was superior to the method using two readings per sample point (Figure 6), and therefore was selected for subsequent analysis.

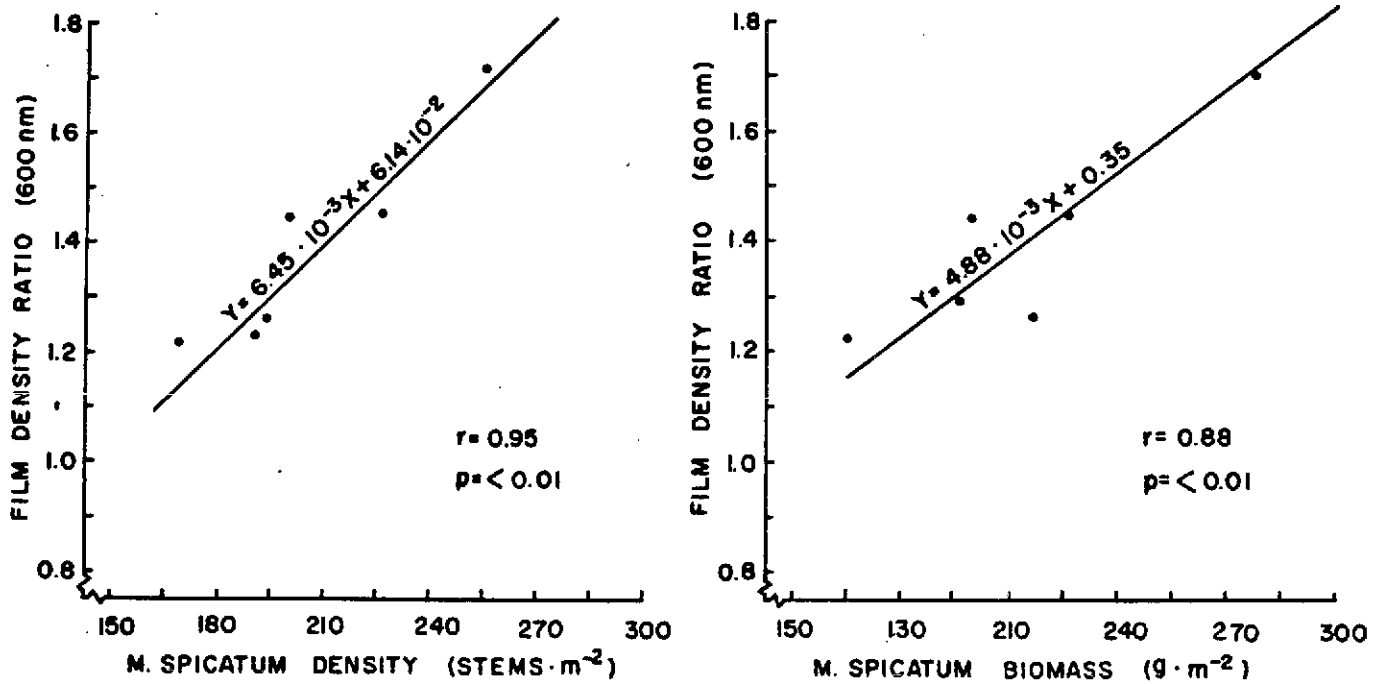


Figure 5. Regression analysis of *Myriophyllum* harvest data and film densities that were standardized by using readings from open water areas.

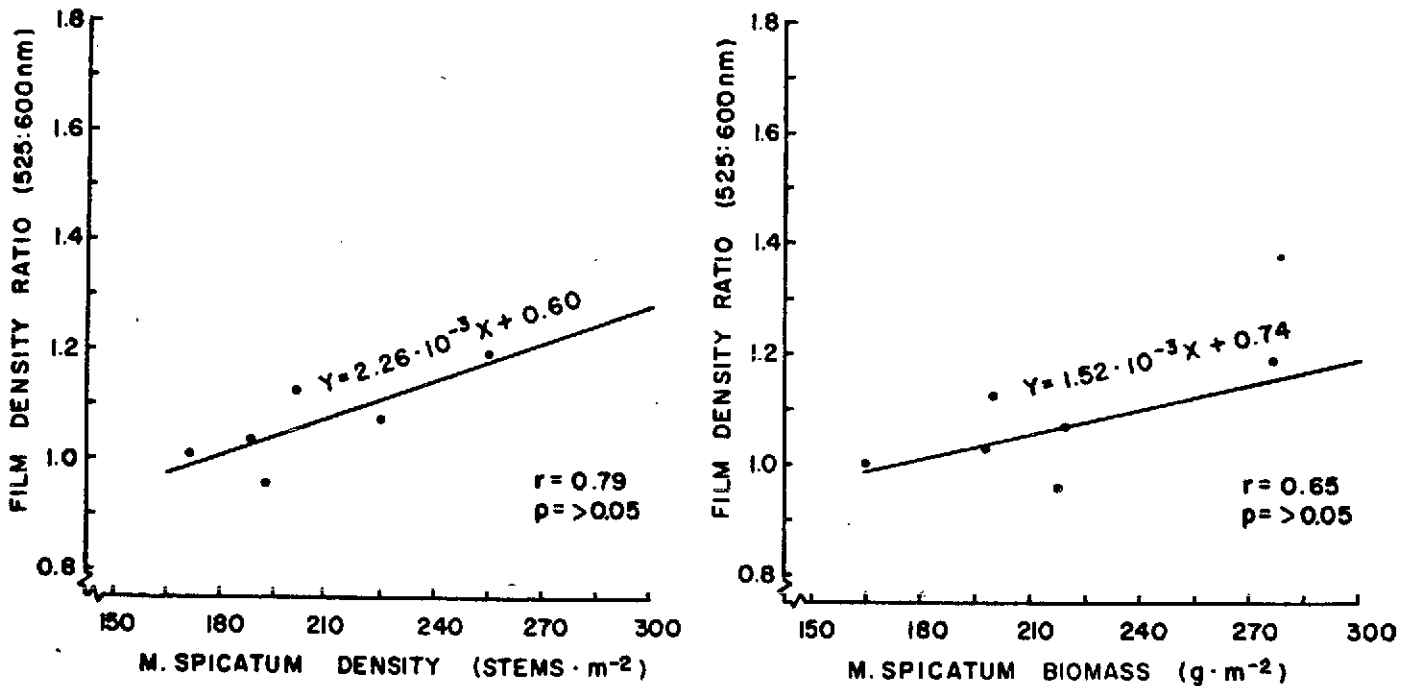


Figure 6. Regression analysis of harvest data and film densities standardized by the use of a ratio of film densities at 525 and 600 nm from each sampling point within the *Myriophyllum* community.

Photo-analysis methods were not used to make biomass estimates for the *Oedogonium* mats but were tested for their potential use in future seasons. The harvest biomass data and standardized film densities were tested by linear regression (Figure 7). Ideally, better *Oedogonium* biomass estimates than those of Table 4 would have been used for calibration purposes but the difficulty of processing the harvested material limited the number of samples collected. Our assumption that the choice of 555 nm allowed the *Oedogonium* to be shown in contrast against a uniform background of *Myriophyllum* and water was slightly in error. The theoretical value for the standardized density of the south stand in late season, 1972 (*Oedogonium* mat was not present) is 1.000, but the measured value (Table 4) was 1.051. We consider that the marl and diatoms found in abundance on the *Myriophyllum* in late summer are probably responsible for the increased reflection which we observed.

TABLE 4

Oedogonium Harvest Data and Corresponding Raw and Standardized Film Densities That Were Used to Test Photographic Analysis as a Sampling Technique of Estimating Algal Mat Biomass

Stand and Date	Biomass (g·0.1 m ⁻²)	Image Density of Alga (555 nm)	Image Density of Water (555 nm)	Water Density/ Alga Density
West 8/10/71	8.72 ± 1.9	0.674	1.223	1.815
West 8/24/71	4.24 ± 1.8	0.330	0.418	1.267
West 7/24/72	5.70 ± 1.2	0.962	1.508	1.567
West 9/6/72	5.90 ± 2.7	0.835	1.193	1.429
East 9/6/72	8.03 ± 2.1	0.703	1.057	1.504
South 9/6/72	0.00 -	1.116	1.173	1.051

95% confidence limits are shown for mean stand biomass

The mean standardized densities were converted to a stem density value using the regression formula. Total stems were obtained by multiplying by total area sampled (found by Planimetry) then converted to biomass with the appropriate factor (mean weight per stem for that time of season). For the purpose of comparison, both photographic methods were used to independently estimate the total *Myriophyllum* biomass at selected times during the three years of study (Table 5). However, we concluded that the photoanalytic approach yielded the superior estimates and so the results obtained by that method were used to characterize the spatial and temporal distribution of *Myriophyllum* in the lake.

We conducted a program of limited field sampling of *Myriophyllum* during the 1971-72 growing seasons to verify the applicability of the photographic methods to those seasons.

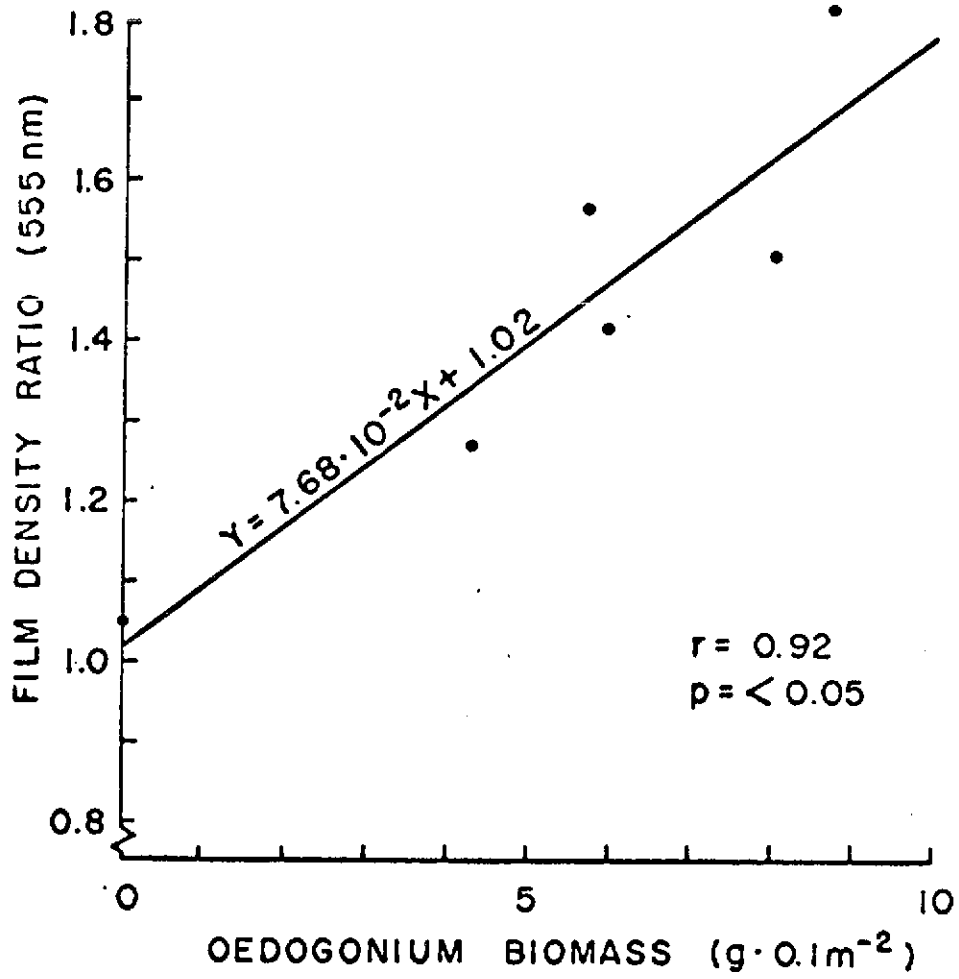


Figure 7. Regression analysis of *Oedogonium* harvest data and film densities.

TABLE 5

Total *Myriophyllum* biomass (Kg, ash-free) in Lake Wingra
at the Times When Usable Aerial Photography was Obtained

	<u>Photointerpretive Method</u>		
	<u>1970</u>	<u>1971</u>	<u>1972</u>
22 May			49,643 ± 14,602
8 June	46,785 ± 13,850		66,677 ± 19,950
23 June	52,974 ± 16,028		
14 July		27,832 ± 7282	
21-23 July	53,868 ± 14,543		73,644 ± 12,792
3 Aug	53,618 ± 13,531		
10-17 Aug	49,483 ± 8000	52,756 ± 9541	
6-8 Sept	74,542 ± 9551		82,158 ± 15,158
21 Sept			80,579 ± 10,680
	<u>Photoanalytic Method</u>		
	<u>1970</u>	<u>1971</u>	<u>1972</u>
22 May			50,803 ± 9601
8 June	52,324 ± 9414		60,939 ± 11,456
23 June	61,820 ± 11,685		
14 July		37,154 ± 7394	
21-23 July	50,717 ± 10,140		92,321 ± 13,848
3 Aug	52,440 ± 10,488		
10-17 Aug	41,982 ± 8414	52,213 ± 10,495	
6-8 Sept	63,710 ± 12,740		87,134 ± 17,427
21 Sept			80,408 ± 16,886

Results of both photographic methods are shown with 95% confidence limits.

RESULTS AND DISCUSSION

PHOTOGRAPHIC METHODS

The *Myriophyllum* community has some important features in common with the salt marsh and grassland communities where quantitative photographic methods have been successfully used. The latter communities seem rather well suited for the application of photographic techniques because of the nearly pure stands and the uniform relationships between cover, plant densities, and standing crop biomass. Successful quantitative photography depends first on the technique's capability to provide sufficient contrast between the plant material and the background, in order that cover can be correlated with photographic response. The growth form of the plants must be such that cover is correlated with standing crop. Thus, in the ideal situation, fairly large variations in cover would be the result of small changes in standing crop. Little, if any, information could be obtained photographically if the cover exceeded 100 percent.

In the case of *Myriophyllum* in Lake Wingra the near infrared region may provide the greatest optical contrast because of the absorptive properties of the background water and the strong reflectance of this waveband by plant tissues. This contrast possibly results in the dramatic image on color infrared film where the weeds appear orange against the blue of the water. The growth habit of *Myriophyllum* places the bulk of the stem leaves near the surface where they often form a dense canopy that may help reduce competition from slower growing species. In the instances of the most robust growth, sufficient stems may be present to produce a completely closed canopy just below the surface. Changes in total *Myriophyllum* biomass in the lake are mainly the result of an increased area of colonization and greater plant concentration within the community. At certain times of the year stem elongation should also be a factor in increased standing crop. Extent of colonization is easily measured with photogrammetry. Both the increased stem concentration and elongation results in a greater quantity of plant material near the surface, and in greater infrared reflection (which will register as a change in the photographic image). We concluded that an aerial photographic technique was reasonably included as one of the methods useful for the study of the Lake Wingra ecosystem.

The photointerpretive method should ideally use more than two image classes in order to yield the best results. Subjective segregation of an image into classes required by this method was found too difficult when we attempted separation into many classes. In addition, the maps became exceedingly complex and reliable calibration was not possible with the harvest data available. By using two image classes the separation was sharp and easy to use but the technique is probably not sufficiently sensitive to give consistently good results. Possibly, a situation where the variation in plant density was sufficiently complex that no patterns of growth could be visually discerned would render methods of this type unusable. In this situation

the most that the photographs could be expected to supply visually would be presence or phenological data. When the total biomass estimates obtained with the interpretative method were compared with those from film analysis (Table 5) the results were generally in close agreement, suggesting that the use of photographic interpretation combined with limited harvest sampling may be a suitable alternative to conventional harvest methods.

The photoanalytic method, tested for use in analysis of *Myriophyllum* growth but also shown useful for measuring the biomass of algal mats, has an advantage of the capability to detect many levels of community vigor. Various "quadrat" sizes and sampling techniques can be used in the analysis of the film image and a large number of samples can be collected with little effort. Biomass and stem density estimates can be made often and with precision. Our results suggested, however, that the method as it is used here may be insensitive to differences at the extremes of plant concentration. Figure 8 shows the suspected response of this system which is based on the theoretical minimum standardization density of 1.0, the results of linear regression, and maximum harvest and standardized density values. The insensitivity at the lower stem density levels is not only the result of the low stem concentration but the weak growth and insufficient biomass near the surface to form a distinctive image on the film. Areas of Lake Wingra characterized by minimum growth were eliminated from the analysis. The insensitivity at the higher stem densities is probably the result of cover values approaching or exceeding 100%. Only a few of the harvest quadrats contained stem counts or biomass values of this magnitude so it was not considered to be an important source of error. The characteristics of this photographic response curve would be expected to change when using different photographic scales and film-filter combinations.

We observed marked effects of extensive periphyton growth on the results of photographic analysis. When the *Oedogonium* mat was in its early stages, information about the *Myriophyllum* could be reliably obtained. During maximum mat development the *Myriophyllum* growth was effectively obscured in a few areas and little data was obtained by photographic methods.

The advantages of using the 35mm format for preliminary work are the low cost, availability of equipment, and ease of handling. The small coverage was found to restrict the photographic scales to those that were greater than optimum for this type of analysis and so future investigations will utilize the mapping camera formats.

COMPARISON OF METHODS

Myriophyllum biomass estimates for 1970 were found to differ sharply with previous estimates made with the use of harvest data alone (Nichols 1971; Adams, unpublished). The estimate of maximum biomass using only the harvest data was 117,868 kg (ash-free) for the 31 August—3 September period. The maximum estimate using photographic analysis occurred also in early September but was only 67,710 kg (ash-free). Since it was necessary to confine the random sampling to only those general areas where plants were found

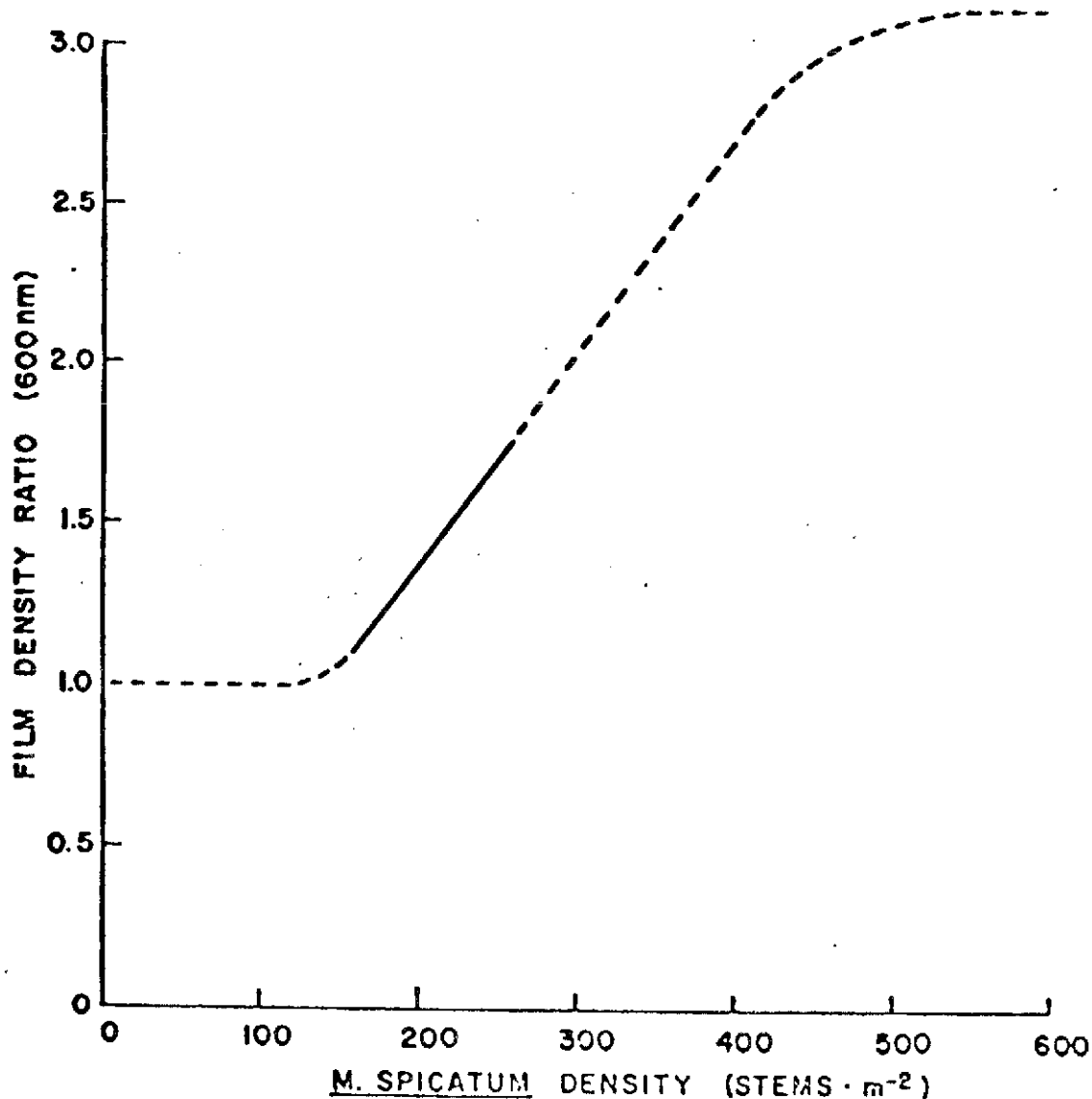


Figure 8. Suspected response of standardized film density to stem densities in photographic analysis of color infrared film. Regions of nonlinearity are discussed in text.

growing while using the harvest method, it was difficult to calculate the actual area sampled during each period. By using hydrographic data the area of the lake within a depth class of 0-240 cm (the range within which rooted plants are normally found growing) was estimated as 53 ha. A photogrammetric analysis of plant growth, however, demonstrated that the growth of rooted plants covered a maximum of only 43 ha that year. The growth area of *Myriophyllum* (Figure 9) reached a maximum of 28.6 ha and varied considerably during the season. A second reason for the higher estimates obtained by the

harvest method is the absence of the shallow-water (less than 40 cm) component of *Myriophyllum* growth in the results of the photographic methods. Photographic analysis and interpretation was difficult in these areas because of the bottom reflection, heterogenous species mix, and weak plant growth. We estimated that these areas contained less than 5 percent of the total *Myriophyllum* biomass and so not of great importance in the total analysis. Another contrast between the harvest and photographic methods is their statistical reliability. Because of variation and insufficient sample size, the standard errors of the harvest data are 10% to 40% of \bar{x} while the standard errors of the photographic data are well below 10% of \bar{x} . Because of compounded error from the calibration data the 95% confidence limits about the total biomass estimates from photoanalysis are as high as 20% of the estimate. These are still far better than the 95% confidence limits of the harvest results which are as high as 58% of the estimate.

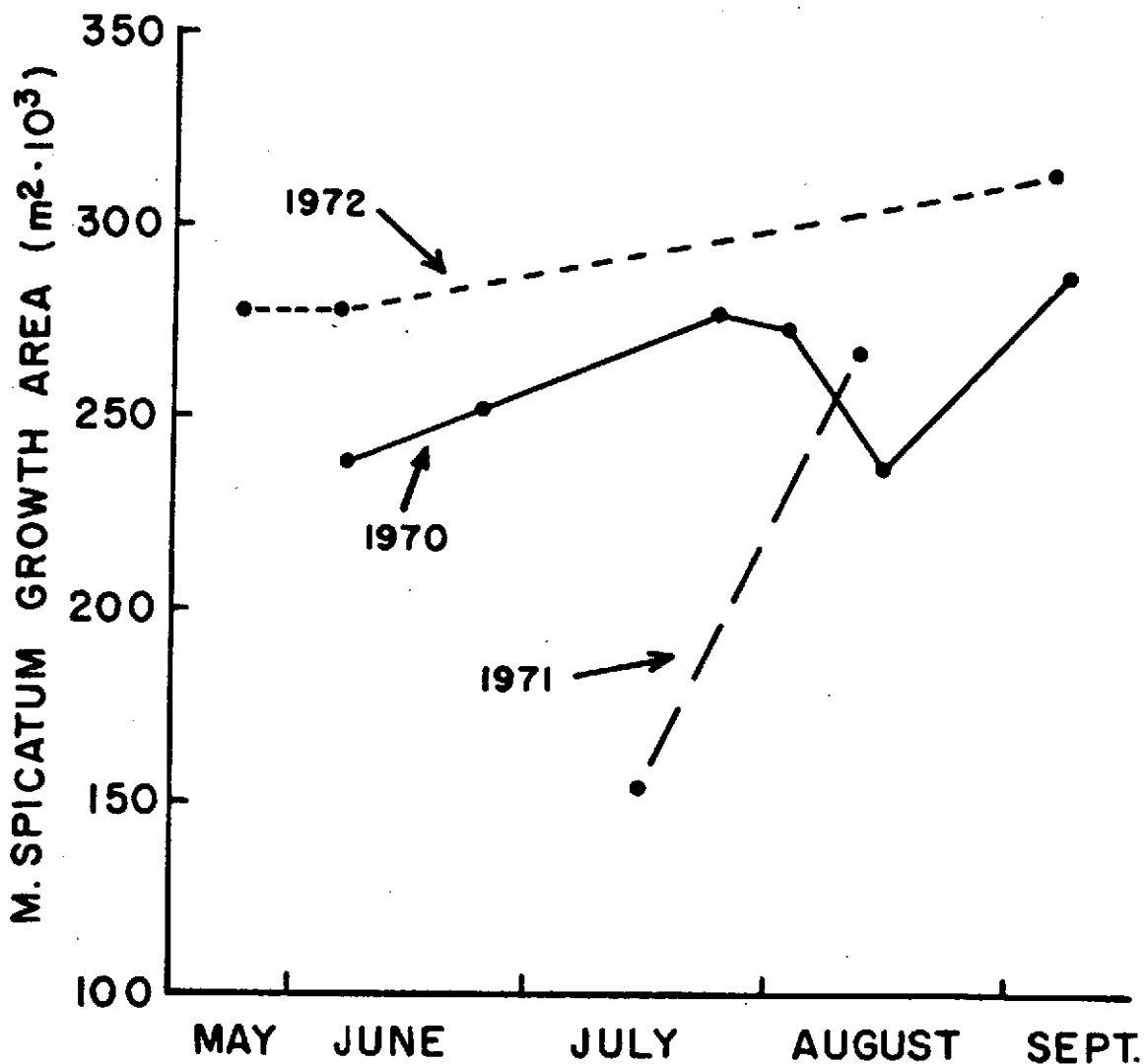


Figure 9. Area of *Myriophyllum* growth in Lake Wingra. Results were obtained by photogrammetric analysis of aerial photography.

The main advantage in the use of photographic methods is their efficiency. The harvest method with its sample processing requires about 250 hours to make a single biomass estimate, while photographic analysis can be accomplished in as few as 10 to 15 hours. Short term changes that are obscured because of the days or weeks required to collect the necessary number of samples can be monitored by photography. Photographic methods also have the advantage of being non-destructive.

MYRIOPHYLLUM BIOMASS

We found that the results of photogrammetric analysis alone indicate that the "typical" season for the growth of *Myriophyllum* in Lake Wingra doesn't exist (Figure 9). The 1970 and 1972 seasons have a similar pattern of early expansion of growth area. The total area colonized was greatest in 1972 and reached 34.6 ha by late August. This large proportion of the littoral zone occupied by nearly pure stands of *Myriophyllum* (up to 80%) are an expression of its ability to dominate those areas suitable for growth. The mid-August reduction in area noted in 1970, was probably non-existent or much reduced in 1972. The area of growth in mid-July of the 1971 season (only two sets of usable photographs were obtained for that season) was in contrast to the area of growth during the same period of the other two seasons. In that year the early growth occurred mainly in the western end of the lake where the most robust beds normally occur. Extensive growth was later observed in most areas of the littoral zone where early season growth was usually observed.

The midsummer reduction in total biomass observed in 1970 (Figure 10) was also indicated by the results of the harvest method. We consider this to be the result of post flowering auto-fragmentation and a reduction in the area of colonization. A second biomass peak occurred in late August 1970, and was associated with the fall flowering period. This midsummer decrease was not observed in other years and may, in part, reflect the nutrient availability during that season.

The minimum biomass observed during the three years of study was 37,154 kg and occurred in mid-July of 1971. It is interesting to note that at this time the average biomass in the community was 240 g.m^{-2} indicating that it was growing very well in those areas where it was able to grow. By early August 1971 it had spread into additional areas and total lake biomass was greater than that observed during the same period of 1970.

We observed the most vigorous growth of *Myriophyllum* during the 1972 season. The maximum standing crop of 92,321 kg (66 g.m^{-2} lake) occurred in mid-July. At this time the average biomass within the *Myriophyllum* community also reached a maximum of 292 g.m^{-2} , which is greater than the peak *Myriophyllum* standing crop of 240 g.m^{-2} observed by Forsberg (1959) in Lake Osby, Sweden or the 175 g.m^{-2} observed by Lind and Cottam (1969) in University Bay of Lake Mendota. The range of biomass values observed for the three years was 180-292 g.m^{-2} and generally agrees with the 253 g.m^{-2} reported for Lake Wingra in 1969 (Nichols and Mori 1971).

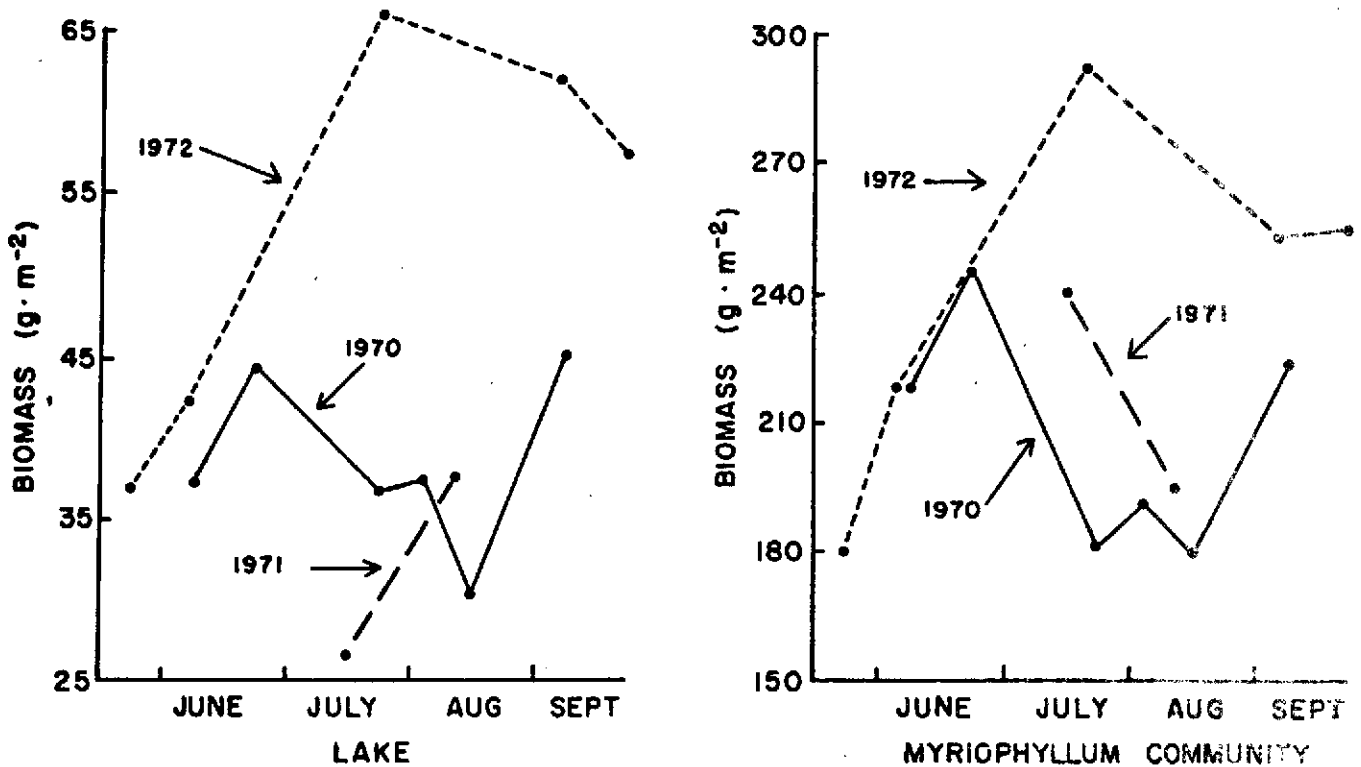


Figure 10. *Myriophyllum spicatum* biomass (ash-free) in Lake Wingra. Estimates for the three seasons are compared by the mean biomass for the weed bed community and for the entire lake.

Peak seasonal standing crop was always found to occur in the west end of the lake and reached values as high as 400 g·m⁻². This area always experienced an early biomass peak whereas maximum growth occurred during late summer in the other parts of the lake. Most of the storm sewers enter the lake at the west end and this area of the littoral zone has a bottom composed of thick organic "ooze". Substrate and nutrient factors are suspected to be important factors contributing to this vigorous spring growth. A general increase in the growth of *Myriophyllum* and periphyton has been correlated with increased precipitation and nutrient input during the 1972 season (McCracken et al., manuscript submitted for publication). The reduction in biomass that is characteristic of the western end of the lake for the period of July through September could be related to the abundance of *Oedogonium* which forms dense mats in some parts of this section each season.

REFERENCES

- Aldred, A.H., and F.W. Kippen. 1967. Plot volumes from large-scale 70mm air photographs. *Forest Sci.* 13: 419-426.
- Anderson, R.R. 1971. Multispectral analysis of aquatic ecosystems in the Chesapeake Bay. *Proc. 7th Symp., Remote Sensing of Environment*, pp 2217-2230.
- Anderson, R.R., and F.J. Wobber. 1972. Wetlands mapping in New Jersey. *Proc. 38th Ann. meeting, Am. Soc. of Photogrammetry*, pp 530-536.
- Avery, T.E. 1968. *Interpretation of aerial photographs*. Burgess Publishing Co. 324 pp.
- Bressette, W.E. 1973. The use of near infrared photography for aerial observation of phytoplankton blooms. 2nd Ann. Remote Sensing of Earth Resources Conference. Univ. of Tennessee, Tullahoma.
- Carter, V.P., and R.R. Anderson. 1972. Interpretation of wetlands imagery based on spectral reflectance characteristics of selected plant species. *Proc. 38th Ann. meeting, Am. Soc. of Photogrammetry*, pp 580-595.
- Clarke, G.L., G.C. Ewing, and C.J. Lorenzen. 1970. Spectra of back-scattered light from the sea obtained from aircraft as a measure of chlorophyll concentration. *Science* 167: 1119-1121.
- Driscoll, R.S., P.O. Currie, and M.J. Morris. 1972. Estimates of herbaceous standing crop by microdensitometry. *Proc. 38th Ann. meeting, Am. Soc. of Photogrammetry*, pp 358-364.
- Forsberg, C. 1959. Quantitative sampling of subaquatic vegetation. *Oikos* 10: 233-240.
- Gallagher, J.L., R.J. Reimold, and D.E. Thompson. 1972. Remote sensing and salt marsh productivity. *Proc. 38th Ann. meeting, Am. Soc. of Photogrammetry*, pp 338-348.
- Kelly, M.G., and A. Conrod. 1969. Aerial photographic studies of shallow-water benthic ecology, pp 173-184. *In* P.L. Johnson (ed), *Remote Sensing in Ecology*. Univ. of Georgia Press, Athens.
- Klooster, S.A., and J.P. Scherz. 1973. Water quality determination by photographic analysis. *Proc. 2nd Ann. Remote Sensing of Earth Resources Conference*. Univ. of Tennessee, Tullahoma. Also published as Report 21, Univ. of Wis. Inst. for Env. Std., Remote Sensing Program, Madison.
- Knipling, E.B. 1969. Leaf reflectance and image formation on color infrared film, pp. 17-29. *In* P.L. Johnson (ed), *Remote Sensing in Ecology*, Univ. of Georgia Press, Athens.

- Lind, C.T., and G. Cottam. 1969. The submerged aquatics of University Bay: A study of eutrophication. *Amer. Mid. Nat.* 81(2): 353-369.
- Lukens, J.E. 1968. Color aerial photography for aquatic vegetation surveys. *Proc. 5th Symp. Remote Sensing of Environment*, pp 441-446. Univ. Michigan, Ann Arbor.
- McCracken, M.D., T.D. Gustafson, and M.S. Adams. The productivity of *Oedogonium* in Lake Wingra. (Manuscript submitted for publication.)
- Miller, L.D., and R.L. Pearson. 1970. Remote sensing of the productivity of the shortgrass-prairie as input into biosystem models. *Proc. 7th Symp., Remote Sensing of Environment*, pp 165-199. Univ. Michigan, Ann Arbor.
- Nichols, S.A. 1971. The distribution and control of macrophyte biomass in Lake Wingra. Final Completion Report Project No. OWRR B-019-Wis. Water Resources Center. Univ. of Wisconsin, Madison.
- Nichols, S., and S. Mori. 1971. The littoral macrophyte vegetation of Lake Wingra. *Trans. Wis. Acad. Sci. Arts Lett.* 59: 107-119.
- Rinehardt, G.L., and J.P. Scherz. 1972. A 35mm aerial photographic system. *Proc. 38th Ann. meeting, Am. Soc. of Photogrammetry*, pp 571-579.
- Scherz, J.P. 1972. Final report on infrared photography applied research program. Report no. 12, Univ. of Wis. Ins. for Env. Std., Remote Sensing Program, Madison, Wisconsin.
- Spooner, D.L. 1969. Spectral reflectance of aquarium plants and other underwater materials. *Proc. 6th Symp., Remote Sensing of Environment*, pp 1003-1011. Univ. Michigan, Ann Arbor.
- Steel, R.G.D., and J.H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Publishing Co. P. 108.
- VonSteen, D.H., R.W. Leamer, and A.H. Gerbermann. 1969. Relationship of film optical density to yield indicators. *Proc. 6th Symp., Remote Sensing of Environment*, pp 1115-1125. Univ. Michigan, Ann Arbor.
- Westlake, D.F. 1964. Light extinction, standing crop and photosynthesis within weedbeds. *Verh. Inter. Verin. Limnol.* 15: 415-425.