Role of aerial photos in compiling a long-term remote sensing data set

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Abstract. Long-term data sets are important in the fields of ecology, hydrology, rangeland science, and geography. Remote sensing is an especially important component of such studies when spatial and temporal capabilities are important considerations. In many cases, satellite remote sensing is not adequate because of resolution or length of observation drawbacks. However, aerial photography, which extends back into the mid 1930s, is often overlooked. In order to find relevant imagery, considerable effort needs to be expended because the aerial photos over a particular study area can be scattered in a large number of archives across the country. Once the photos are assembled, digital scanning, proper documentation, storage, and a searchable data base are necessary to make easy and effective use of the aerial photos. The aerial photo data are of immense value to researchers, natural resource managers, students, and the general public.

Keywords: aerial photography, rangelands, ecology, historic landscape legacies, vegetation change.

1 INTRODUCTION

For ecological and rangeland analyses, long-term data of every kind, ranging from detailed ground observations to large area remote sensing images, are necessary in studies focusing on vegetation change, rangeland health, and evaluations of rangeland restoration projects. Although some ecosystem studies have used remote sensing data in the 1-4 km resolution range [Advanced Very High Resolution Radiometer (AVHRR) and Geostationary Operational Environmental Satellite (GOES)] [1,2], most projects need much higher resolution data. Using higher spatial resolution satellite data like 30m [Landsat Enhanced Thematic Mapper Plus (ETM+) (Landsat)], 10-20m [Satellite Pour l'Observation de la Terre (SPOT), and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)], and less than 5m (Ikonos, QuickBird), a variety of ecological and rangeland applications were evaluated [3-6]. Unsurprisingly, the highest spatial resolution data were preferred (e.g., QuickBird 60cm data) because large (>2m^2) individual shrubs and large clumps of grass were detected as well as other metrics such as vegetation cover and bare ground percentages, all valuable for rangeland health determinations [7].

Because field experiments, such as rangeland restoration treatments, often lack long-term continuing observational data, some sort of historical data are needed. This need for outside data occurs as investigators are transferred to other locations, become assigned to other projects, or retire. Contributing to this problem is the fact that most studies have relatively short-term durations because theses and dissertations are completed or funding is terminated. Individual researchers and even entire government agencies have been sidetracked by the

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outbreak of war [8,9]. Additionally, many rangeland restoration treatments are too large or remote to maintain the treatments or to continue to make the necessary measurements [10].

When the need for some type of continuous long-term remote sensing measurements over large rangeland and agricultural areas is realized, especially with a preferred high resolution of about 1-2m or even better, one existing, but frequently overlooked, data set can meet these needs. Acquisition of aerial photography, of about 25-100 cm spatial resolution, was started in rangeland and agricultural areas of the United States in the mid 1930s by various agencies of the U.S. Department of Agriculture (and their private company contractors) for conservation purposes [11]. In subsequent years, other agencies such as BLM, USGS, USFS and NASA (see list of agency acronyms in Table 1, section 3) have also been acquiring high resolution images from a variety of aircraft. One major drawback to assembling such a data base for a particular area is the fact that the historical aerial photos are scattered in different archives around the world. Originally the aerial photography was taken with black and white film, but in recent years color and color infrared photography has become more dominant.

The spatial resolution of 25 – 100cm of the photography makes it comparable to the QuickBird satellite resolution of 60cm. Even better resolution will be available from satellites in the future, but for now a researcher or manager must arrange for specific flights from aerial photogrammetry firms or alternatively obtain data from Unmanned Aerial Vehicles (UAVs) [12] flown at low elevation and able to provide spatial resolution of 5cm or better. Aerial photos can enhance point or plot data obtained by conventional ground measurements by allowing extrapolation of the ground measurements to provide a better understanding of conditions in the vicinity of the ground measurements and a landscape perspective of the detailed or plot-level study area.

The steps outlined in this paper can be used as a guide when a government agency or university department decides that a long-term historical remote sensing data base is desirable for research or operations over large areas. Assembling such a data base may lead to mounting more detailed remote sensing data acquisition for specific projects.

Aerial photos are excellent for locating treatment legacies left on the rangeland landscape. The photos are especially good for providing periodic updates of existing treatments [9]. In contrast to known treatment locations, the aerial photos are also well suited for locating lost treatments (lost because records for the experiments have disappeared or are inadequate). And surprisingly, they are excellent for discovering treatments we never knew existed [9]. Examples of such landscape legacies are undocumented experimental plots on U.S. Government lands which are not frequently visited because of inaccessibility and remote location (see Fig. 1) and treatments on public lands installed by private individuals not working with any governmental agencies (see Fig. 2). Figure 1 illustrates with aerial photographs, the presence of a pattern of treatment plots on the USDA-ARS Jornada Experimental Range (JER) in southern New Mexico that were never documented. The basic plot size is 25 x 100 ft. (7.6 x 30.5 m). Unknown treatments were performed on these plots. The only documents discovered were letters from the Soil Conservation Service to the JER proposing unspecified plot treatments in this particular area that were not subsequently approved because of a lack of funding. Figure 2a shows an undisturbed arroyo (Gilmore Draw) north of the JER before treatment with water retention dikes that were added in 1972 (indicated in 2a by solid straight lines). Figures 2b through 2f show the dikes right after installation and then in every decade thereafter. Figure 2c illustrates that because of natural water flow patterns in the arroyo, some dikes were more effective than others in retaining water and promoting vegetation growth.

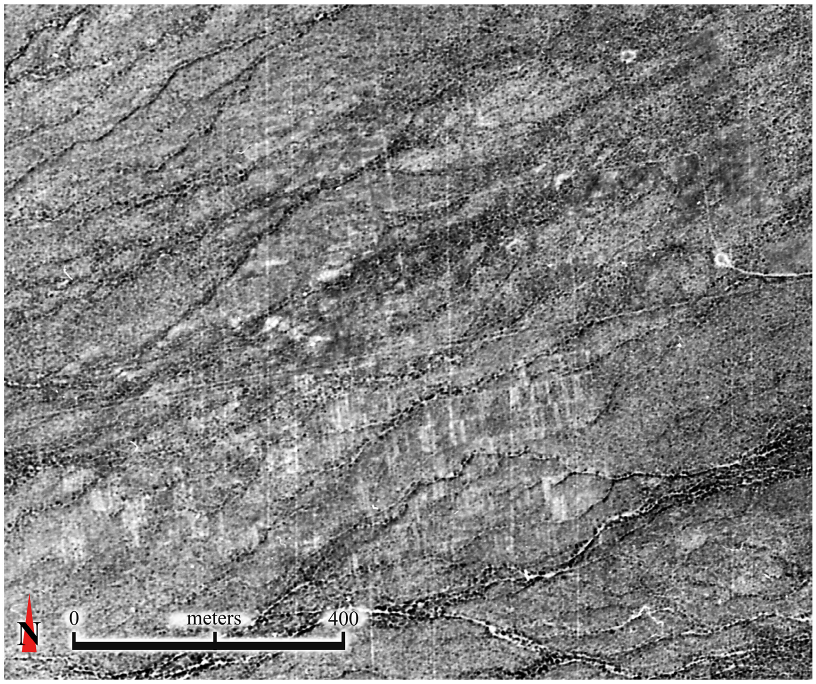

Fig. 1. Enhanced aerial photo of a network of undocumented rectangular plots (with unknown treatments) in JER Pasture 6 south and west of the Dona Ana Revegetation and Raingauge Exclosure taken on 11-14-74.

Documentation of rangeland treatments and condition can be provided through preservation of historical ground-based panoramic or landscape level photography. At the JER in southern New Mexico, ground-based photographs go back until 1905, prior to the formation of the JER in 1912. About 3,300 of these photographs are cataloged in the Rio Grande Historical Collections at New Mexico State University, in Las Cruces, New Mexico and the National Archives and Records Administration at College Park, Maryland. Additionally, rephotography has been used to document vegetation or landscape change with time. This approach requires historic ground photos documented with the exact location from which the photos were taken (preferably using a permanent marker that was established when the original photo was taken) and then photos taken in later years from the same spot. Classic studies of documenting vegetation change in the southwest U.S. using rephotography were published in 1965 [13] and then followed up later and published in 2003 [14]. Rephotography was also used in a study at the JER [10].

There are many limitations when using rephotography. These include locating the exact historic photo point, using a camera with characteristics close to the original camera, the limited area covered by photos, obstruction of the original view in later years by vegetation growth or building construction, and inability to make quantitative vegetation measurements because of the oblique view angle of the photos. We can now start to use a similar approach with vertical aerial photography that started in the 1930s and 1940s described in this paper. It might be possible to use this new long-term aerial photo database in combination with the rephotography approach when photo dates coincide. The power of using historic photography in rangelands should be increased by adding the nadir views of the aerial photography to the oblique rephotography approach because the conclusions drawn in original rephotography studies can be confirmed, improved, or rejected using the large area, landscape perspective of the aerial photography.

1.1 History of aerial photography

Prior to the 1930s when regularly scheduled aerial photography was initiated, much work went on from a variety of platforms which included roofs of buildings, kites, balloons, airplanes, and even camera-carrying birds. The oldest existing aerial photo came from a tethered balloon at 1,200 ft (366m) over the city of Boston by James Wallace Black on October 13, 1860 [15]. The first aerial photo from a kite was by Arthur Batut in May 1888 over Labruguière, France. In 1906 Albert Maul used a compressed air rocket to acquire aerial photos from 2,600 ft (792.5 m) after which the camera returned to earth on a parachute [16]. In 1909 Wilbur Wright took the first aerial photo from an airplane over Centocelli, France [16]. Many of these early missions were dangerous to the point that help was sought from the famous Bavarian Pigeon Corps in 1903. Julius Neubronne patented a miniature camera weighing 70g that took automatic exposures every 30 seconds and could be breast-mounted on carrier pigeons [15]. The intelligence needs of opponents in World War I led to the need for more dependable aerial photography from the more stable airplane platform.

The need for advancing the technology on both sides led to improvements in the quality of the cameras and the photography. Many problems were identified with the aerial photography including distortion. In 1917, Sherman Fairchild developed an improved camera for producing vertical aerial photographs with minimal distortion for the U.S. military [17]. The Fairchild camera, with modifications, became the desired aerial photography camera for the next 50 years [15]. After World War I, Fairchild began to concentrate on non-military applications, and, by the 1930s, Fairchild Aerial Surveys was the most successful aerial photography company in the U.S. [15]. This period is also marked by many advances in the new science of photogrammetry which allowed for analysis of stereo photography [18].

It seems that throughout the history of aerial photography, the affinity for obtaining a view from above a particular area of interest was not limited to scientists and managers. Rather, non-scientists and lay people have shared the fascination for this aerial perspective. Their interpretation, although not always quantitative, reveals important insight not previously available. Such users value the aerial perspective and subconsciously use the same approach in analyzing an aerial photograph used by image analysis software, namely, distinguishing pattern, size, shape, shadow, surroundings, tone, texture, and color. Actually, asking those familiar with a particular area to "analyze" aerial photos is sometimes a necessary precursor to eventual employment of high resolution satellite data as well as even higher resolution aerial photography.

2 IDENTIFICATION OF AERIAL PHOTOS FOR SITES OF INTEREST

In the 1930s, the non-military applications of aerial photography were further advanced by the USDA in order to assist in agricultural programs set up to improve farm income following the Great Depression. These programs involved reducing acreage under cultivation to stabilize crop prices under a voluntary program that was coupled with attractive financial incentives for complying with the reduced planting. Aerial photography was used to provide accurate measurements of field sizes on a rapid basis. These aerial photos have provided a lasting legacy of data for other purposes such as soils mapping, land use classification, regional planning and geographic research [11]. This program quickly transitioned to a conservation program that paid farmers to switch from soil-depleting to soil-conserving crops. The coincidence of one of the worst droughts ever in the major agricultural areas of the U.S. in the mid 1930s further encouraged the move to more soil-conserving crops [11]. To assess the compliance by farmers, acquisition of the needed aerial photography was arranged

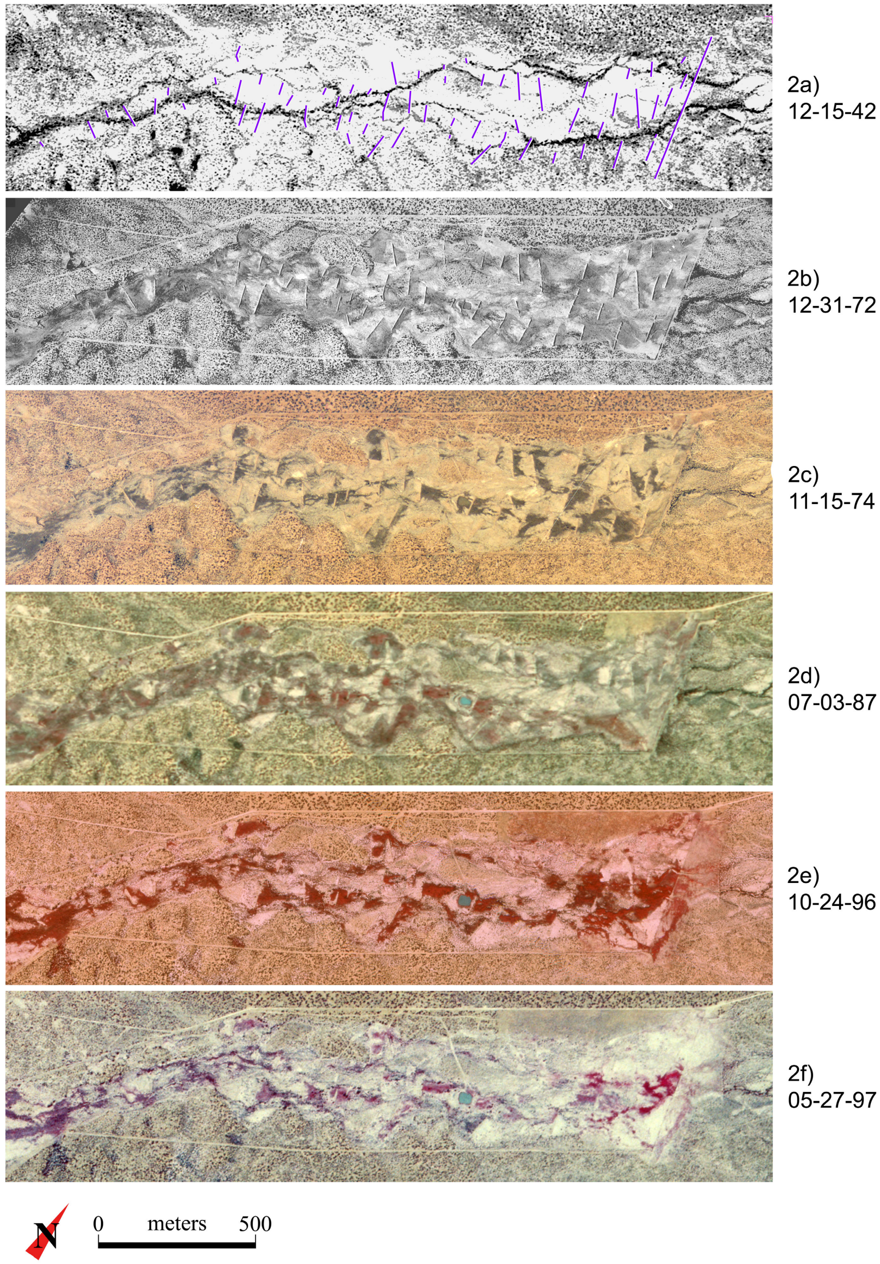

Fig. 2. Gilmore Draw rangeland remediation using water ponding dikes to increase soil moisture and vegetation growth. 2a) aerial photo on 12-15-42, before treatments with the locations of the dikes installed in 1972; 2b) aerial photo on 12-31-72, shortly after dikes were constructed; and 2c) through 2f) aerial photos in subsequent years.

primarily by the Agriculture Stabilization and Conservation Service (ASCS) and the Soil Service (SCS) of the USDA. Both cultivated fields as well as rangeland were covered by the aerial photography. Additionally, after World War II, the military flew photographic missions over selected areas for non-civilian applications to continually improve aerial photos for use in conflicts around the world. In 1972, various remote sensing military agencies were consolidated into the Defense Mapping Agency [17]. The job of completing widespread coverage in short periods of time was daunting for the U.S. government agencies and led to the employment of private aerial survey contractors to acquire a significant proportion of the aerial photography.

While photography of specific areas was flown at irregular intervals, retention of these aerial photos for data analysis faced difficulties similar to retention of ground-based data associated with rangeland restoration treatments performed in the 1930s. Much of the restoration work was performed in the 1930s and early 1940s by the Civilian Conservation Corps (CCC) [19] at the direction of land management agencies like the Soil Conservation Service, Bureau of Reclamation, and the Forest Service. The CCC was disbanded at the onset of World War II which led to lost conventional data sets. Additionally, scientists involved went off to fight the war with some never returning to their pre-war work.

After World War II, the interest in the aerial photos over cultivated fields and rangeland declined. Fewer flights were made from 1950-1970, and there were challenges in locating the previously acquired images. Not only were the images scattered between archives, but some photos were also retained by the aerial survey firms. Accurate documentation of the location of aerial photos for areas of interest was lacking.

Certain procedures were in place to transfer aerial photos to major archives. All aerial photography recorded by the U.S. Government and its contractors prior to 1955 was supposed to be, and for the most part has been, transferred to the National Archives and Records Administration (NARA). There are exceptions to this, and NARA does not have some existing aerial photos before 1955. An example of the unplanned dispersal of aerial photos occurred in 1965 when Fairchild Aerial Surveys, Inc. was sold to Aero Services, Inc. which decided they had no use for most of the historical images obtained by Fairchild. Aero Services, Inc. made plans to quickly dispose of the aerial photos. Before they could do this, faculty at UCLA, California State University at Northridge, and Whittier College were afforded the opportunity to salvage many of the aerial photos at the last minute. This became the impetus for these colleges to set up their own photo archives [20]. The University of California at Santa Barbara also received images at a later date and set up an archive. As an example, some key aerial photography over Southern New Mexico, flown in 1948, covered the entire area of both the adjacent JER (783km^2) and the New Mexico State University Chihuahuan Desert Rangeland Research Center (CDRRC) (259km^2). Searches in NARA revealed that photography had never been delivered to NARA. Instead, it appears that the imagery was some of that rescued from the loading dock of Aero Services, Inc. by Whittier College personnel. At present the only archive possessing these key 1948 data is the Whittier College Fairchild Aerial Photography Collection (WCFAPC), albeit they usually just have mosaics and individual prints rather than archival transparencies.

2.1 Selected primary and secondary archives of historic aerial photographs

Other than early aerial photography (1930-1955) which has found its way to NARA, later aerial photography (and some old photography) can be obtained from primary archives like the USGS Eros Data Center (Sioux Fall, SD) and Earth Science Information Center (Reston, VA), the USDA Farm Service Agency, Aerial Photography Field Office (USDA-APFO) (Salt Lake City, UT) and the Bureau of Land Management, Aerial Photography Archive (Denver, CO). Several smaller archives with more limited holdings also exist, such as that at WCFAPC. There are also state-based or regional facilities that can assist users in locating and ordering aerial photo data from various archives. A good example is the Earth Data Analysis Center (EDAC) at the University of New Mexico in Albuquerque, NM. These types of facilities can not only provide data from their own photo archives or from major archives around the country, but can also assist the user by processing data as well as conducting studies using remote sensing data and geographic information systems.

Some data centers like those at USGS have online computer search capabilities and the possibility of ordering data once it has been selected. Other centers, like the USDA-APFO, have customer service telephone numbers that users can call to request computer searches of available data. At a small center like WCFAPC, they will provide searches for a fee, but it is probably best to visit in person, examine photo mosaics, and then actually view the individual aerial photos before ordering. The costs are usually lowest at the U.S. government agency archives, somewhat higher at facilities who assist the user or who use private contractors to produce the data, and highest at the small college archives. The cost for a black and white negative can vary from $3.00 up to $50.00 depending on the source of the data.

3 A LONG-TERM HISTORICAL AERIAL PHOTO DATA BASE: A CASE STUDY

The JER was established in southern New Mexico by the U.S. Department of Agriculture in 1912. Important grazing practices, rangeland treatments, climate measurements, and ecological and hydrological studies have been conducted at JER over the years. A similar set of studies on rangeland management practices have been conducted on the adjacent New Mexico State University CDRRC which was established in 1927. Up until 1977, no special requests were made for aerial photography, but many photos were taken over JER/CDRRC because of their proximity to the Rio Grande, agricultural lands, and military reservations. After 1977, routine aerial photo acquisitions were continued while several specific requests were made for aerial photos for research purposes. Agency research aircraft were used to fulfill these requests.

In the case of the JER/CDRRC historical aerial photography, the first indication of the extent of organized historic flights was found in the National Agricultural Library in Beltsville, MD which has bound photographic mosaics of individual aerial photos by state and county. After obtaining the individual photo frame identification numbers, visits were made to various archives to inspect the original imagery and order all cloud-free images covering JER/CDRRC land. Actual visits were required to see images at the National Archives and Records Administration in College Park, MD, the USGS in Reston, VA, WCFAPC in Whittier, CA, and EDAC in Albuquerque, NM. Web searching and ordering was possible for data from the USGS EROS Data Center in Sioux Falls, SD, whereas phone inquiries were sufficient for ordering from USDA-APFO in Salt Lake City, UT.

The products we prefer to use and order are transparencies, either b/w negatives or color positives. These products are used for scanning and archiving. One hard copy print is usually ordered for viewing or taking to the field. In rare instances when only a print is available, we then use the print for scanning and archiving. Most data facilities also can provide scanned products at additional cost, but we prefer to do the scanning in our own shop because it is much less expensive than sending the images out for contract scanning. When we have flown our own aerial photo missions, we obtain the original transparency film roll which is the best product to work with. When ordering, most archives have a working film roll that is a copy of the original. Sometimes, two different archives will have working rolls of the same flight, but one will have the original or first copy and the other will have a later generation copy. This often happens in the two major archives – the USDA-APFO and the USGS-EROS data centers. If ordering in such situations, it behooves the user to inquire about who has the closest to original working roll as the quality of your ordered product can vary.

A set of aerial photographs can sometimes be found at the study location such as JER/CDRRC, but without metadata. Unfortunately, one problem that can result in these cases is that there often is no legend or photogrammetric marks to identify date of acquisition, aerial platform, camera used, etc. These images are not useful unless partially installed treatments with a known treatment date can be identified to provide a rough estimate of time of acquisition or unless we can acquire metadata to go with the photos. Aside from these unidentified images, we have now acquired over 5,000 aerial photos from piloted aircraft for the 1042 km^2 joint research area at JER/CDRRC (we have also obtained 5,145 additional UAV aerial photos at 5cm resolution). Table 1 is a listing of the piloted aerial photo data base that has been acquired over the JER/CDRRC area. We are in the final stages of cataloging, scanning, and storing the images for use by researchers at JER/CDRRC. The primary users for such a long-term aerial photo database include U.S. government and university research scientists, National Science Foundation (NSF) Long-Term Ecological Research scientists and graduate students, U.S. State and local government agency personnel, K-12 school students and teachers, and educational outreach and local non-profit organizations like the Chihuahuan Desert Nature Park.

The estimated cost of assembling a historical aerial photography data base like that in Table 1 is shown in Table 2. The assumptions for this estimate are that about 5,000 images would be purchased, visits to three major archives in the Washington, D.C. area and at least one small archive would be required, a technician's salary would be required for processing and scanning, and that some equipment would need to be purchased. The total cost would be $226,500 although this number could be reduced to $151,500 by only purchasing one product of each image frame, namely, a transparency. It should be pointed out that this cost estimate pertains to the combined area of the JER/CDRRC which is approximately 1042 km^2. Areas of interest that are smaller or larger will cost a lesser or greater amount proportionate to the difference in relative sizes.

Table 1. Listing of piloted long-term aerial photography data base acquired over the JER / CDRRC study area

Date	**Flight Sponsor**	**Archive Source**	**Spectral Type**	**Approx. Scale**	**Number of Images**	**GPS Center**	**Scanned**
May 1935	Unknown	WCFA-PC	B&W	1:24,000	4	no	yes
Dec 1936	SCS	NARA	B&W	1:31,680	27	yes	yes
Mar 1937	SCS	NARA	B&W	1:31,680	95	partial	yes
Dec 1942	US Army	USGS	B&W	1:50,000	105	yes	yes
Jan 1943	US Army	USGS	B&W	1:50,000	15	yes	yes
Oct 1946	US Army	DIA	B&W	1:30,000	27	yes	yes
Jan 1947	US Army	DIA	B&W	1:30,000	13	yes	yes
Oct 1948	US Army	DIA	B&W	1:30,000	65	yes	yes
Oct-Dec 1947	ASCS	NARA	B&W	1:10,560	90	yes	yes
Sep-Oct 1948	US Army	WCFA-PC	B&W	1:30,000	95	no	yes
Apr 1949	US Army	DIA	B&W	1:50,000	10	yes	no
Jun 1955	ASCS	APFO	B&W	1:10,000	25	yes	yes
Nov 1960	ASCS	APFO	B&W	1:20,000	19	yes	yes
Dec 1963	US Army	WSMR	B&W	1:31,320	44	yes	no
Mar 1967	ASCS	APFO	B&W	1:20,000	15	yes	yes
Dec 1972	USGS	USGS	B&W	1:29,000	43	yes	yes
Jan 1973	USGS	USGS	B&W	1:33,100	105	yes	yes
Feb-Mar 1974	ASCS	APFO	B&W	1:40,000	83	yes	yes
Nov 1974	BLM	EDAC	Color	1:31,680	107	yes	yes
May 1975	BLM	EDAC	Color	1:31,680	15	partial	yes

Table 1. (Continued) Listing of piloted long-term aerial photography data base acquired over the JER / CDRRC study area

Date	Flight Sponsor	Archive Source	Spectral Type	Approx. Scale	Number of Images	GPS Center	Scanned
Sep 1977	ARS (Weslaco)	JER	B&W	1:30,600	170	partial	yes
Sep 1977	ARS (Weslaco)	JER	CIR		645	partial	yes
Sep-Oct 1978	US Air Force	USGS	B&W/ Color	1:25,000	140	partial	partial
Sep 1980	USGS	USGS	B&W	1:80,000	8	yes	yes
Oct-Dec 1980	BLM	EDAC	Color	1:31,680	156	yes	yes
Jun 1982	NASA	NASA	Color		21	no	yes
May 1984	NASA	USGS/ APFO	CIR	1:55,064	6	yes	yes
May-Sep 1986	NHAP	USGS/ APFO	B&W/CIR	1:58,000	141	yes	yes
Jul 1987	NHAP	USGS/ APFO	B&W/CIR	1:58,000	12	yes	yes
Sep 1988			CIR		210	no	no
Sep 1989	ARS (Weslaco)	JER	CIR	1:6,000	58	no	yes
Sep-Oct 1989	BLM	EDAC	Color	1:24,000	99	yes	yes
May-Jun 1991	BLM	EDAC	Color	1:24,000	29	yes	yes
Jul-Sep 1991	USGS	USGS	Color	1:24,000	34	yes	yes
Sep 1994	EPA	EPA	CIR	1:18,890	449	no	no
Sep-Oct 1996	NAPP	USGS	B&W/CIR	1:40,000	181	partial	yes
May 1997	NASA	NASA	CIR	1:65,000	47	partial	yes
May 1998	NASA	NASA	CIR	1:65,000	48	no	yes
Jun 1998	NAPP	APFO	CIR	1:44,373	5	yes	yes
Sep.13, 1998	NASA	NASA	CIR	1:65,000	66	no	yes
Sep.17, 1998	NASA	NASA	CIR	1:65,000	47	no	yes
Oct 1998	NAPP	APFO	CIR	1:44,373	40	yes	yes
Jun 1999	NASA/ Master	NASA	CIR	1:30,000	156	partial	partial
Sep 1999	NASA/ASP	NASA	CIR		48	no	yes
Jun 2000	NASA/ASP	NASA	CIR	1:60,851	77	partial	yes
Jun 2000	NASA/ Master	NASA	CIR	1:65,000	63	partial	yes
Sep 2000	NASA	NASA	CIR	1:65,000	62	partial	yes
May 2002	NASA	NASA	CIR	1:30,000	90	yes	yes
Mar 2003	NAPP	APFO	CIR	1:43,171	90	yes	yes

Table 1. (Continued) Listing of piloted long-term aerial photography data base acquired over the JER / CDRRC study area

Date	Flight Sponsor	Archive Source	Spectral Type	Approx. Scale	Number of Images	GPS Center	Scanned
May 2003	ARS (Weslaco)	JER	CIR	1:10,000	215	partial	yes
May 2004	ARS (Weslaco)	JER	CIR	1:10,713	128	yes	yes
Nov 2004	ARS (Weslaco)	JER	CIR	1:10,176	182	yes	yes
Jun 2005	ARS (Weslaco)	JER	CIR	1:12,266	161	yes	yes
Oct 2006	ARS (Weslaco)	JER	CIR	1:10,449	413	yes	no

ACRONYMS

APFO=Aerial Photography Field Office (USDA)
ARS=Agricultural Research Service
ASCS=Agricultural Stabilization and Conservation Service
ASP=Airborne Sensor Program
BLM=Bureau of Land Management
CDRRC= Chihuahuan Desert Rangeland Research Center
DIA=Defense Intelligence Agency
EDAC=Earth Data Analysis Center
EPA=Environmental Protection Agency
JER=Jornada Experimental Range
NAPP=National Aerial Photography Program
NARA=National Archives and Records Administration
NASA=National Aeronautics and Space Administration
NHAP=National High Altitude Photography
SCS=Soil Conservation Service
USGS=US Geological Survey
WCFAPC=Whittier College Fairchild Aerial Photography Collection
WSMR=White Sands Missile Range

B&W = black and white
CIR = color infrared

Table 2. Estimate of cost to assemble a long-term aerial photography similar to that in Table 1.

Steps	Cost
Purchase of 5,000 images (1 print, 1 transparency) (90% from large archives, 10% from small archives)	$ 170,500‡
Travel to visit archives	$ 2,500
Per Diem expenses at archives	$ 3,500
Processing and scanning by technician	$ 35,000†
Scanner and server	$ 15,000†
Total	$ 226,500*

* Note that total cost could be reduced to $151,500 by purchasing only transparencies and then making prints in-house after scanning for use in field work.
† May not be needed because of existing infrastructure
‡ Some aerial photos may already exists at research facility and need not be purchased.

3.1 Scanning of JER/CDRRC aerial photos

When scanned prints are compared to scanned transparencies, the scanned print always contains less detail than the scanned transparency [21]. This is because the print is usually at least one generation removed from the transparency. Our images are scanned at 1200 dpi with an Epson 1640XL large-format flatbed scanner. We felt that by scanning at this rate, we would avoid having to come back to re-scan certain images where the investigator would like to improve the resolution, and we have noticed that, in images with linear features, the 1200 dpi provides the best continuity of these features. We also recommend using a digital scanner with a large bed [ours is 12.2 in (31.0 cm) by 17.2 in. (43.7cm)], so that we do not have to cut any images to fit on the normally available, but smaller, scanner beds. For photogrammetric work, it is imperative that the fiducial marks are included in the scans. By scanning in-house, we always follow the exact procedure for processing all the photography. After scanning, we determine the center point coordinate of each frame using Digital Ortho Quarter Quads of the same area. Some recent images from the National Aerial Photography Program (NAPP) after 2003 have included this center point in the header information of each photo.

When aerial photos are acquired, it is recommended that they only be rejected for excessive cloud cover. Differences in image resolution or perceived low quality should not be a basis for rejecting an image because many different users will be using the long-term data base. The information content of an image may be acceptable for one application and unacceptable for another. Users familiar with the area can often interpret meaningful information from even poor quality images. In compiling this long-term data set, we archived all nadir view photos, and only excluded the more difficult-to-interpret oblique air photos because we had enough nadir views at approximately the same time.

We have found that there are software packages that can be used to reduce certain image quality issues. Photoshop, ERDAS, ENVI, and PCI can perform contrast enhancement, color balancing, histogram matching, and frequency domain filtering. Image information can also be increased by transforming the images from red, green, and blue (RGB) color space into the intensity, hue, and saturation (IHS) color space. Manual work with Photoshop can adjust contrast and correct colors to make them easier to interpret visually. Whenever automated image-to-image comparisons are to be made, then the images will need to orthorectified or at least transformed to approximate orthorectification.

3.2 Accessibility of the aerial photo data base to researchers

In order for researchers and other users to access the aerial photo products, certain tools are needed. Particularly, an interactive search engine is needed in order for the user to locate and then view thumbnails or full frames of their area of interest. Our search engine allows the user to search by geographic coordinates, date, pasture number, and other identifying features. Once the scenes of interest have been identified, the user can download the scanned file for further use. The archived original transparencies are never accessed, but users can check out the hard-copy prints for inspection in the lab or for use in the field.

3.3 Applications of a long-term aerial photo data base

The establishment of the time of the actual installation of various treatments is sometimes possible using aerial photos. Figure 3 shows a sequence of before, during, and after installation of experimental plowing patterns in JER's Pasture 6. The 1980 image, taken on November 9, 1980 indicates that plots were installed in November 1980. There was no documented evidence of when these plots were installed before the aerial photos were examined. Remediation of unproductive rangeland using simple water ponding dikes constructed in the mid 1970s is shown in the sequence of photos in Fig. 4. The grass response to increased soil moisture behind the dikes did not begin for about 15 years, probably due to the normal sporadic nature of rainfall events in the Southwest.

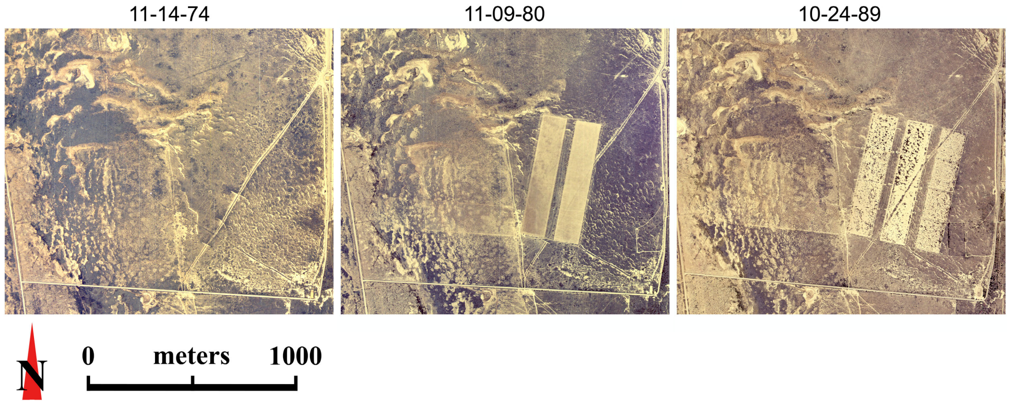

Fig. 3. BLM natural color aerial photos used to determine the time that plots were installed to evaluate the effect of radar return by different furrow patterns. 3a) aerial photo on 11-14-74, before plowing; 3b) aerial photo on 11-9-80, during construction of the plowed plots showing only 2 of the 3 strips installed; and 3c) aerial photo on 10-29-89, showing complete set of 3 strips consisting of 12 plots.

Once the grass response started, however, it has continued despite the fact that the shallow dikes (7-30cm in height) had received no maintenance and had been breached. Just the slowing down of the surface runoff, however, was enough to allow an island of increased soil moisture and biotic productivity to form where ponding took place. In response to the increased soil moisture behind the dikes, increased vegetation growth and cover was promoted.

The reverse application of this temporal monitoring is also possible, namely, determining the length of time that a remediation treatment remains effective. The longevity of effectiveness of contour terraces, brush spreaders, grubbed strips, and exclosures was documented using aerial photography [9].

For a particular research facility, national park, or wildlife refuge, a historical aerial photo data base can serve to document past treatments or land cover changes and provide a template for use in deciding upon future research site locations and for assistance in deciding between different management approaches.

Figure 5 shows portions of JER Pastures 6, 7, and 17. In these aerial photos, several different vegetation types (creosote, tarbush, tobosa grass) can be seen along with various attempts at remediation and surface treatments such as fields plowed to evaluate radar reflectivity, root plowing treatments, and irrigated fields. On this photo, past treatments, both documented and undocumented, are delineated so that future research sites can be selected.

Some past treatments will necessarily be avoided, while other areas may be selected for future study. The historical remote sensing data base can also be used to monitor vegetation change over time as shown in Fig. 6 which shows the increase of shrubs and decrease of grass [7]. Another use is to monitor rangeland remediation treatments over time to estimate temporal effectiveness [9] as shown in Fig. 7 for over 70 years in shrub removal strip images. Associated with this monitoring, images in the historical data base can reveal undocumented treatments that have left a legacy on the landscape requiring further study (e.g., see Figures 1 and 2) [9]. Upon assembly of a searchable, historic aerial photo data base, many applications are possible over arid and semi-arid areas like the JER. Such applications have been documented in [9] and [22]. For continuing research studies and management needs, additional aerial photos, QuickBird satellite images, or UAV coverage can be justified, and strongly supported. Such imagery will also serve to increase the long-term aerial photo data base for future studies. The availability of the data base to university graduate students can be quite useful because they would have access to a continually evolving long-term data set rather than each spending their valuable time compiling their own data base. They can spend a limited time getting familiar with the data base and study area characteristics and then develop scientific hypotheses and start analysis soon after.

Hyperspatial aerial photos with about 5 cm resolution are required for rangeland health assessments [12] that are the responsibility of land management agencies like the BLM and the Natural Resources Conservation Service. These aerial photos could be acquired from improved camera systems in piloted aircraft or from Unmanned Aerial Vehicles (UAVs) flying at an altitude of about 700 ft (213 m). The value of these data for rangeland health lies in the hyperspatial capability (i.e., the resolution of imagery is finer than the objects of interest) of the data to measure patch size and gaps in vegetation, bare soil, and the difference in vegetation types.

Figure 8 shows the capability of the hyperspatial data to display bare soil gaps between small vegetation patches in a comparison of different remote sensing data types. Future applications will increase as miniaturized multispectral and hyperspectral instruments are developed to complement hyperspatial capabilities of small payload UAVs.

4 DISCUSSION

There are many planners and scientists who have a need for remote sensing data, especially of a long-term nature. Satellites are typically considered but found to be lacking in important features such as resolution, period of record, simplicity, or ease of use. Aerial photos are certainly a useful candidate as an alternative remote sensing data source. They serve as a way to extract timely information but also prepare users for the transition to more sophisticated types of remote sensing data.

Many times only one or two photos can be initially identified, but there is a large body of data that can be uncovered with thorough searching. It is possible to obtain coverage over study areas of interest at least once a decade and sometimes even more frequently. Many times the resolution is much better than with available satellite coverage. With the growing capabilities of UAVs, this is even more the case.

If historical aerial photography seems useful for any research or application you are involved in, you will need to set aside the time to acquire it. Some searching and acquisition can be done using the internet. But, in order to assemble a complete data base, you need to be persistent which sometime means personal visits to specific archives. Not all the data that exists are easy to locate.

A variety of applications can be served by the same long-term aerial photo data set once it is assembled. Important applications exist in the fields of ecology, hydrology, rangeland science and remediation, geography, soils and natural resources modeling. If justification for assembling the data base is needed, strong multifaceted applications support can be obtained from scientists in the above fields.

In planning for the data base, some thought should be given to the computer expertise needed for analysis and hardware necessary for storage of the large data set. This becomes even more of a problem as higher and higher resolution aerial photos, e.g. many individual photos from UAVs or higher resolution satellite data over large areas are acquired. A lot of data can be acquired in a short time period which can take an extremely long time to process and analyze and can require significant server capacity to store the raw and analyzed data. We currently estimate that a storage capability of 52 terabytes will be required for the Jornada aerial photography collection based on existing data and estimated future acquisitions of aerial photographs from all platforms.

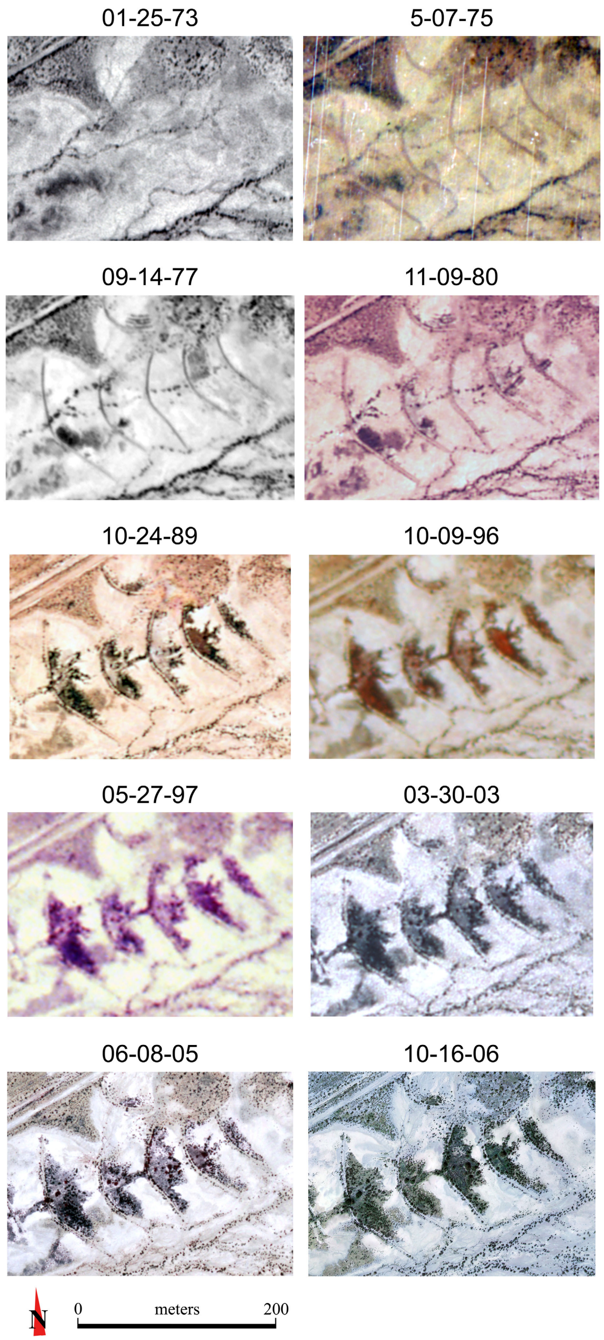

Fig. 4. Aerial photo sequence of the Ace Tank water ponding dikes from before installation (1973) during installation (1975) and in subsequent years through 2006. Minimal vegetation growth occurred in the first 15 years, but in 20 years, the vegetation behind the dikes had strong growth. A lack of maintenance since 1975 has not seemed to affect the vegetation response.

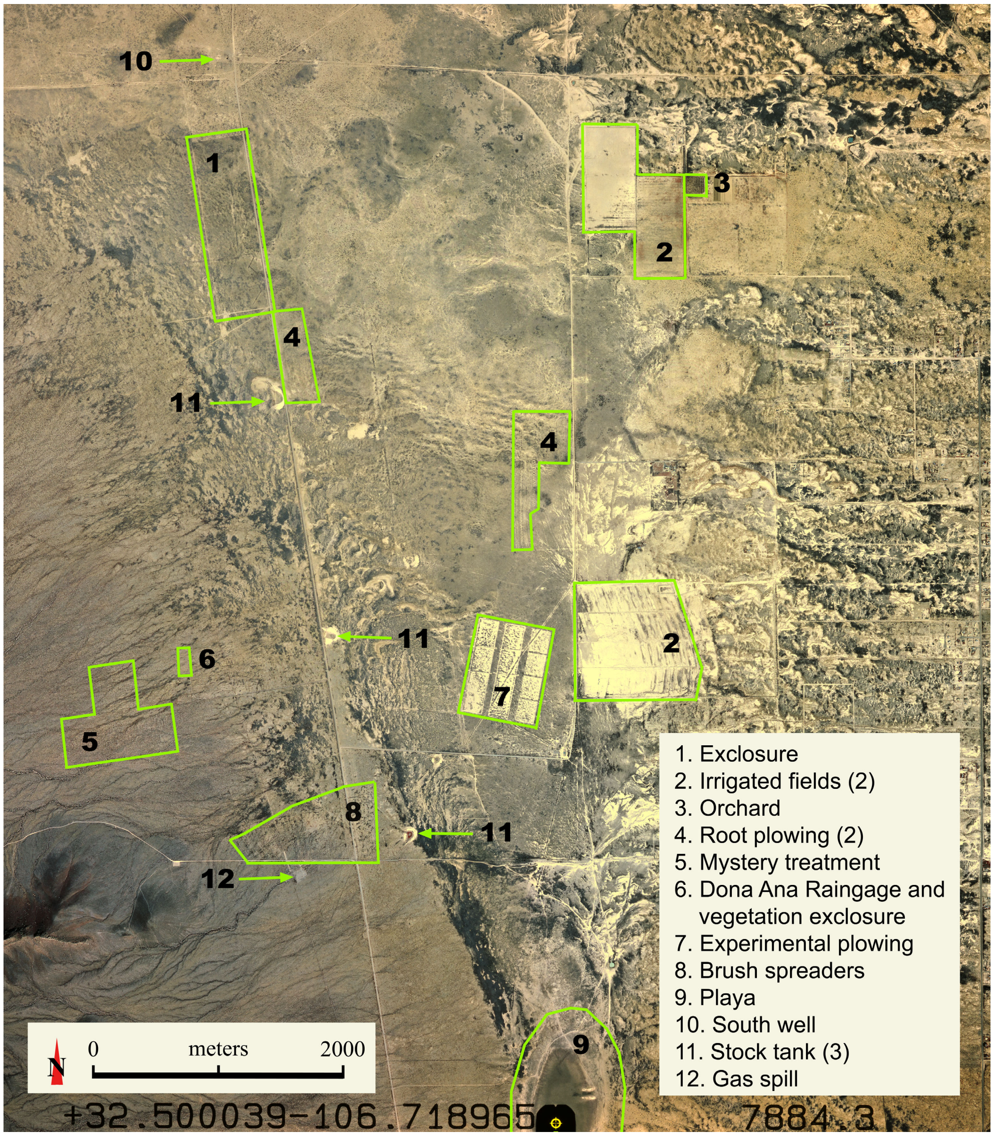

Fig. 5. Aerial photo taken on 3-30-03 covering portions of JER Pastures 6, 7, and 17 showing various research treatments and operational land cover manipulations that can be used as a template to guide selection of future research sites. The numbers on the aerial photo refer to the treatments listed in the lower right corner.

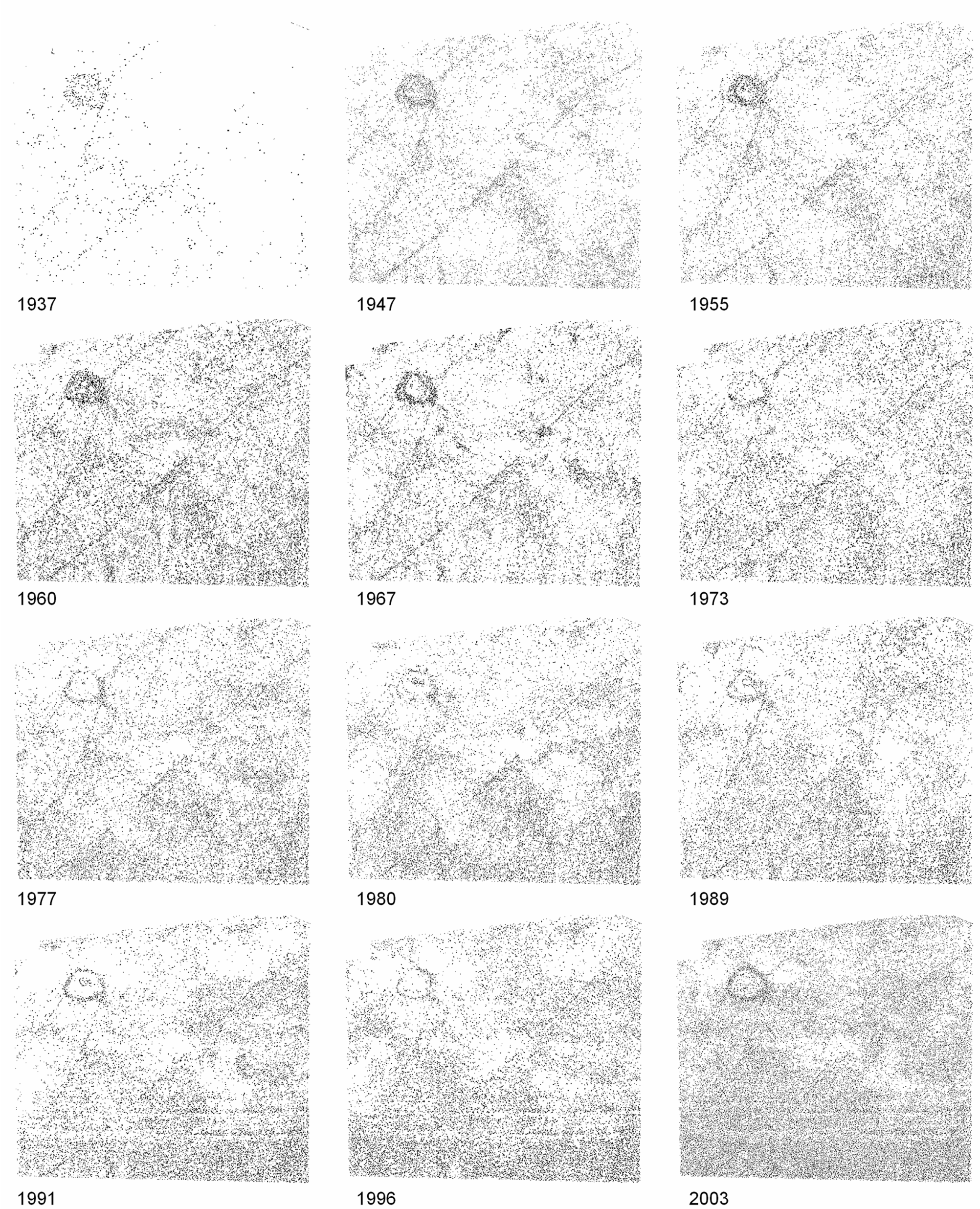

Fig. 6a. Shrub cover change from 1937 to 2003 based on results from object-based classification of aerial photos (1937-1996) and a QuickBird image (2003) over Pasture 2 of the CDRRC north of Las Cruces, NM [7].

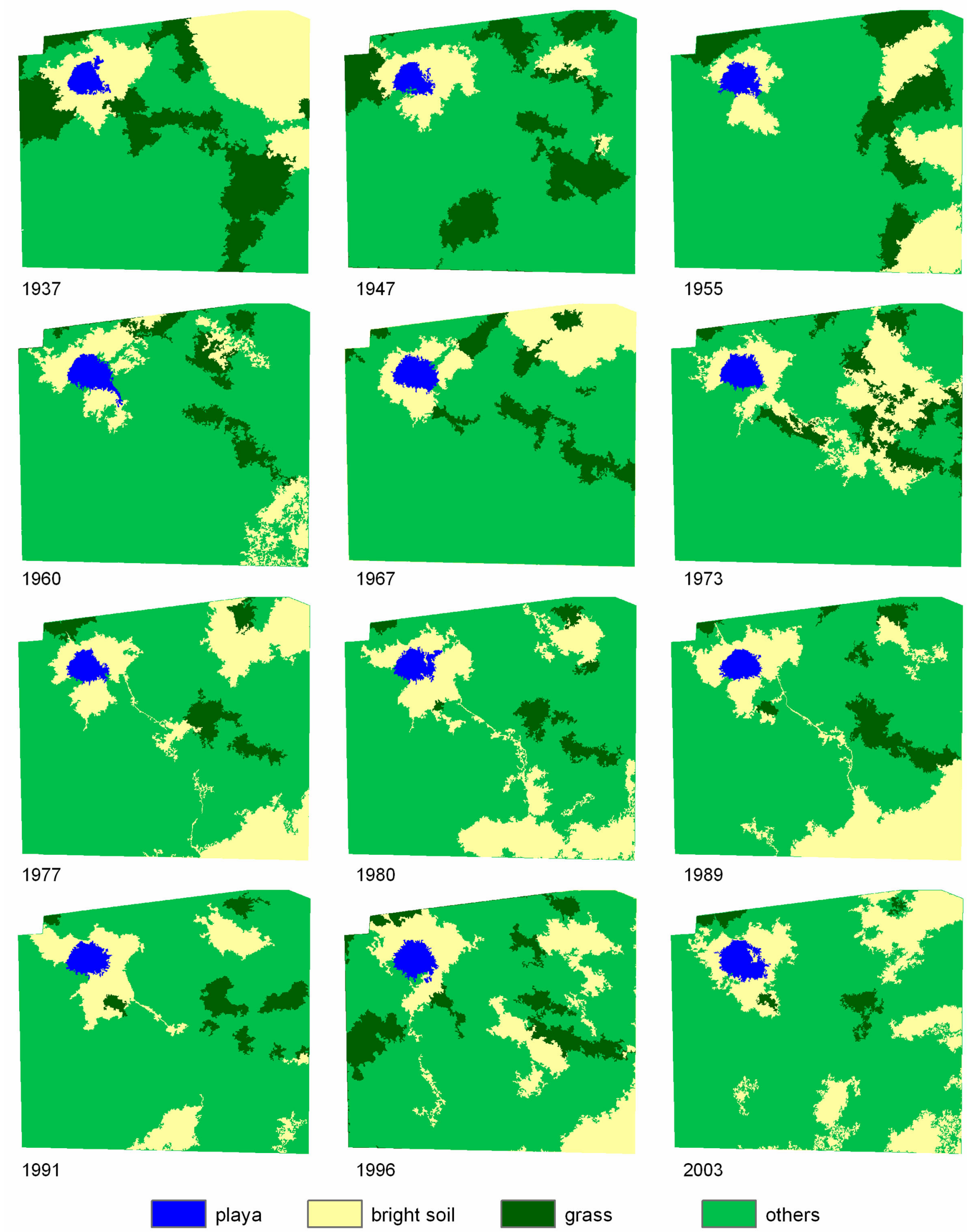

Fig. 6b. Grass and other vegetation cover change from 1937 to 2003 based on results from object-based classification of aerial photos (1937-1996) and a QuickBird image (2003) over Pasture 2 of the CDRRC north of Las Cruces, NM [7].

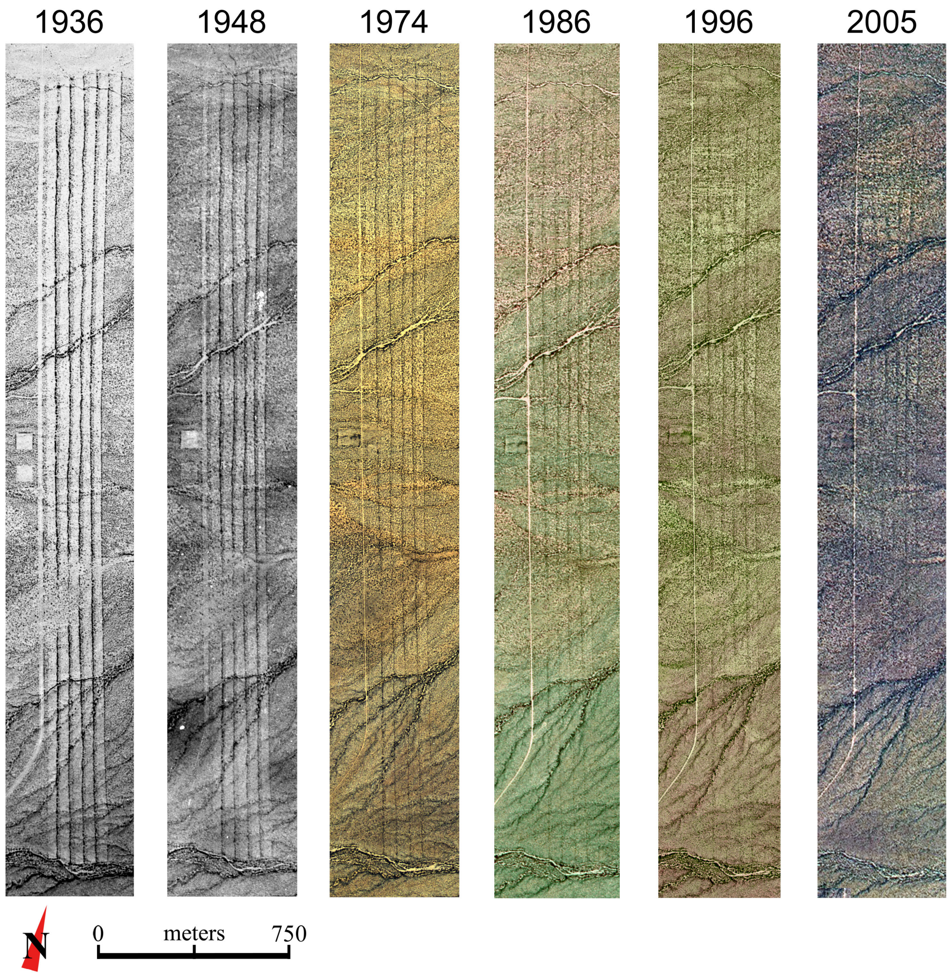

Fig. 7. Temporal sequence of 1936, 1948, 1974, 1986, 1996, and 2005 aerial photos of alternating grubbed and ungrubbed straight line strips in CDRRC Pasture 10. At the west end of the ungrubbed strips, brush from the grubbed strips was piled.

Although the assembly and analysis of the historical data base will take a major amount of time, it is really only a start. You must then make plans to extend the data set from the last image acquisition into the future. Several options are possible. If money is not a limiting factor, one may elect to purchase high resolution satellite data like QuickBird with 60 cm resolution (for panchromatic data; 2.4 m for multispectral) which is comparable to some current aerial photography (especially when the latest and improved QuickBird data are released). The cost of QuickBird data is $5,445 for one standard frame (272.25 km^2). These data have been acquired since 2001 by the Digital Globe Company. Aerial photography providing similar or even better resolutions can be contracted from private companies or arranged through various governmental agencies such as the USDA, Farm Service Agency, Aerial Photo Field Office in Salt Lake City, UT, USA. The cost for these flights is extremely variable and total cost may be offset by grants from research and operational natural resources agencies. In the not-too-distant-future, aerial photography may be carried out by Unmanned Aerial Vehicles (UAVs), if Federal Aviation Administration (FAA) regulations permit. Some very promising results have been obtained with low elevation UAVs indicating that such aerial photography provides excellent data for natural resources at very reasonable cost [23]. In addition to the required favorable FAA regulations, development of miniaturized digital multispectral aerial photography cameras needs to be advanced. With coincident development of FAA regulations and the improved sensors, aerial photography from small UAVs could be very affordable for research and operations. Additionally, other instrumentation (e.g. thermal imagers) could be flown on small UAVs to complement visible and near infrared aerial photography. This would most likely require purchase of small UAVs and instrumentation by specific agencies for use in their areas of interest. If successful, the UAV approach could be transferred to larger, high performance UAVs with more sophisticated instrumentation that could cover much more extensive areas at high altitude similar to the National High Altitude Photography efforts by USGS using manned aircraft. In this case, the interested agencies could apply to a central facility for data instead of purchasing their own UAV and remote sensing system.

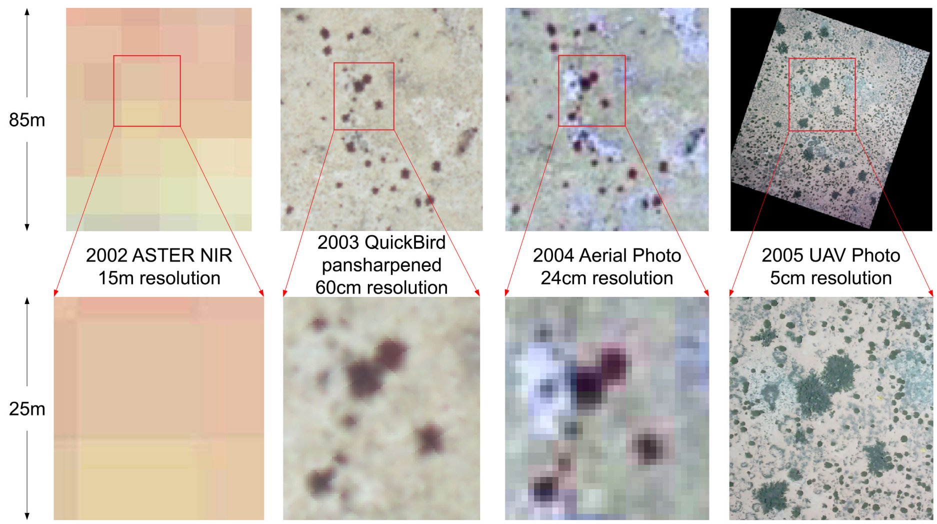

Fig. 8. Comparison of satellite, piloted aircraft, and UAV imagery on the Jornada Experimental Range over the same area to illustrate detection of different patterns, patches, and gaps at different scales.

The use of recently developed object-based software, Definiens Professional [24], has made the use of single, broad-band or mosaicked aerial photos more effective for classification than with other classification software which had limited use with the aerial photos.

When long-term analysis is attempted, for example, for vegetation and ecosystem change, the areal coverage value of aerial photography should not be overlooked. This capability can add value to long-term plot or point measurements that may exist in some long-term research study sites through extrapolation to much more extensive areas.

5 CONCLUSIONS

Aerial photography is useful in the development of long-term data bases that could be used for assessment of vegetation or land cover changes after the initial changes have been noticed or as a remote sensing part of ongoing long-term studies. The reason aerial photography can be used after the fact is that image collection started in the mid 1930s and continues through to the present. This continuity of data collection makes it extremely useful for recently begun long-term studies such as Long-Term Ecological Research projects. Although certain restoration projects have lapsed because of lack of funding, personnel reassignment, or a change in priorities, these projects can always be revisited and evaluated with current aerial photos along with coordinated ground measurements. In order to find the relevant historical photos, a large number of aerial photo data bases must be searched in order to assemble a comprehensive data set. Digital scanning, documentation of the photos, storage of the data, and a searchable data base are necessary to allow easy use of the historical aerial photos. Once assembled, these data are invaluable for use by a wide variety of researchers and managers.

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