Image Interpretation Keys for Validation of Global Land-Cover Data Sets

Melissa Kelly, John E. Estes, and Kevin A. Knight

Abstract

Photointerpretation keys originated from the need to efficiently train aerial photographic interpreters. Keys provide interpreters with a baseline of signature information that can be widely applied to images illustrating differing land covers, features, facilities, processes, and activities. Keys were produced for the International Geosphere Biosphere Programme Data Information Systems (IGBP-DIS) DISCover Validation effort. This effort had two objectives: to provide a prototype set of image interpretation keys that could be produced efficiently and cost effectively, and to create a foundation of enduring reference materials that could be refined and enlarged to facilitate the validation of future global land-cover products. The methodology of key development and production for this effort originated as an ideal, but has by necessity been shaped by pragmatic considerations. Factors including cost, time, and availability of imagery and ancillary data limited broad applicability of the keys developed. Research included determination of the most effective band combination, signature development and application, consistent implementation of a minimum mapping unit, use of signature elements in the evaluation of key use, and development of a product useful for cross applications. We continue to expand the present set of keys and develop a digital infrastructure for a global reference library of key materials. These materials will expedite future validation efforts and lead to greater confidence in the accuracy of future global land-cover products.

Introduction

Determining global scale changes in atmospheric, oceanic, and terrestrial systems requires establishing baseline parameters for variables such as gaseous exchange rates, and carbon sequestration in different broadly defined land-cover types (Walker and Steffen, 1997). Establishing a methodology for development and validation of a standardized land-cover product has set the stage for refined quantification and more strategic monitoring of global change parameters. The International Geosphere Biosphere Program Data and Information System (IGBP-DIS), global land-cover product, DISCover, was produced and validated to establish science-quality baseline data products for global change research. This article focuses on the development of image interpretation keys for use by the Expert Image Interpreters (EIIs) who were responsible for validation of DISCover using higher resolution Landsat Thematic Mapper (TM) and Systeme Probatoire de la Observation de la Terre (SPOT) imagery.

Interpretation keys have been used to facilitate the visual interpretation of aerial photography and remotely sensed imagery for more than half a century. Their use grew largely out of a need by the military and intelligence communities for efficient and effective training aids. Keys, used by both novice and expert interpreters, are verified examples of features of interest. Man-made facilities and their component elements, physiographic features and processes on the landscape, vegetative communities, and the terrain conditions indicative of such vegetation, are examples (U.S. Naval Photographic Intelligence Center, 1945; Zsilinsky, 1963 Loelke *et al.*, 1983; U.S. Defense Mapping Agency, 1996). The use of interpretation keys is considered to lead to more consistent and accurate identifications.

For the IGBP DISCover validation effort, EIIs were selected from remote sensing and mapping organizations around the globe. The criteria for their selection included considerable expertise in the analysis of the higher resolution image data for specific regions. This expertise would be expected to extend to analysis of both satellite imagery and aerial photography for one or more of the 13 IGBP global regions (Figure 1).

Image acquisition, enrollment of EIIs, development of a validation methodology, and key development activities were carried out at the Remote Sensing Research Unit (RSRU) at the University of California, Santa Barbara (UCSB). The material that follows provides additional background and assumptions underlying the validation effort. Many of the challenges and planning considerations, elements of key design, and an overview of key construction are discussed. The results of key use at the DISCover validation are followed by our conclusions and the benefits of continuing the interpretation key effort as a resource for future global validation work.

Background

Manual image interpretation, using imagery of higher resolution than that used to produce the data product, has been successfully used for regional scale validation efforts (De Boissezon *et al.*, 1993; Belward, 1996), so the IGBP Validation Working Group (VWG), with the agreement of the IGBP Land Cover Working Group (LCWG), decided that this state-of-the-practice methodology was the most practical means of proceeding in keeping with the "fast track" land-cover directive. Efforts were initiated to identify regional advisors, individuals with knowledge of remote sensing centers, institutes, laboratories, and individuals in specific areas of the globe (Belward *et al.*, 1999, in this issue). These regional advisors would then assist the VWG in the identification of three EIIs for each of the 13 IGBP validation regions.

Landsat TM and SPOT imagery, with near-global coverage and widely available, were the higher resolution imagery of choice for validation of the 1-km AVHRR DISCover data product.

Remote Sensing Research Unit, Department of Geography, University of California, Santa Barbara, CA 93106 (lis@geog.ucsb.edu).

Photogrammetric Engineering & Remote Sensing
Vol. 65, No. 9, September 1999, pp. 1041–1049.

0099-1112/99/6509–1041$3.00/0

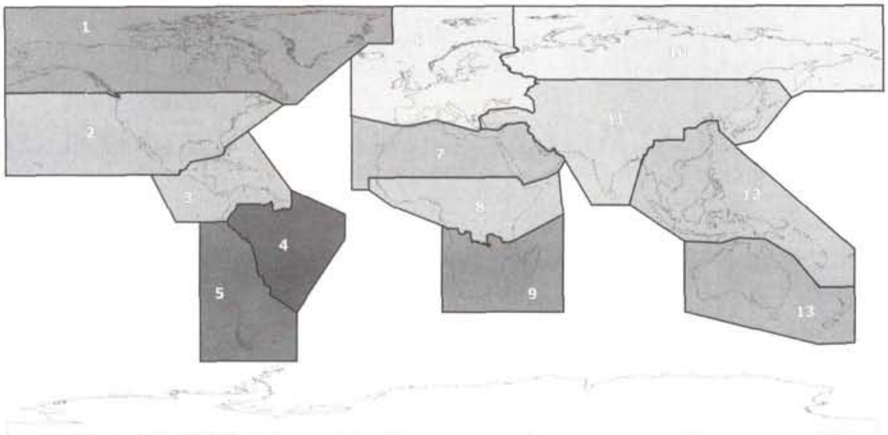

Figure 1. The IGBP DISCover validation regions.

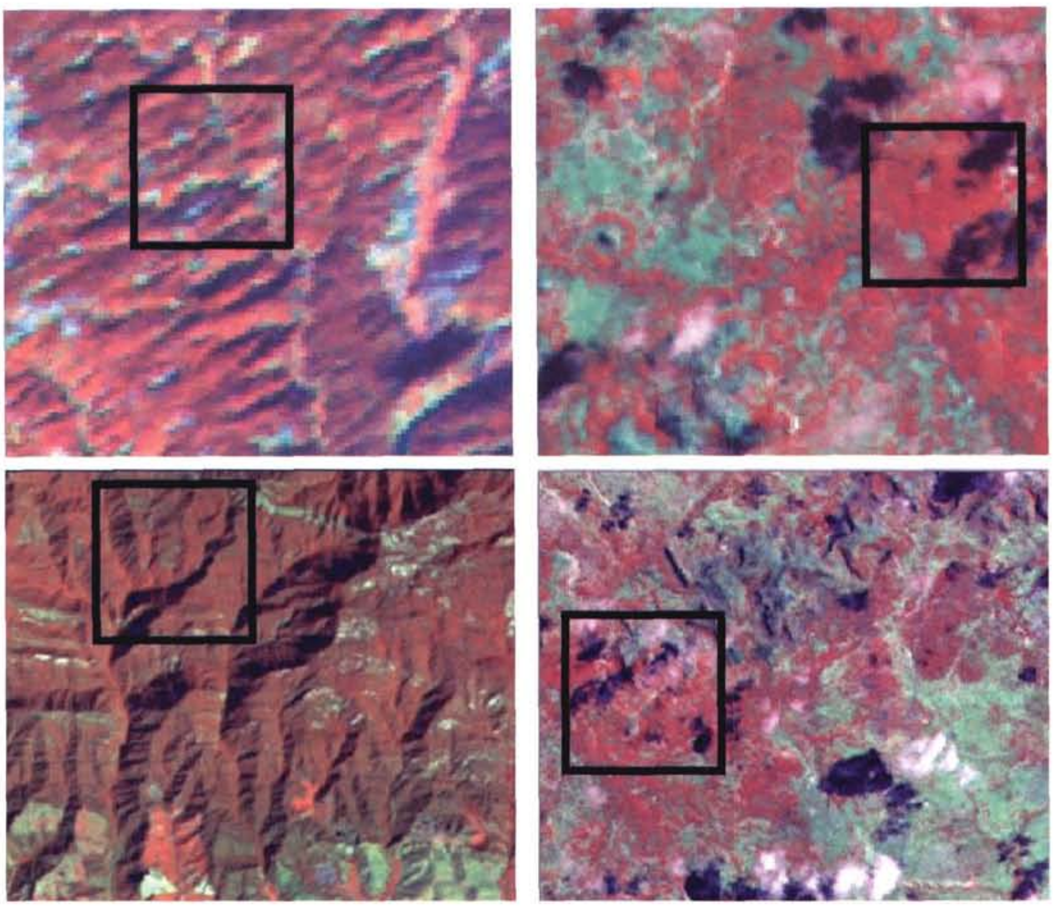

Plate 1. Examples of inter-regional signature variation. Closed shrubland as it appears on Landsat TM imagery around the world and in different seasons. Upper left: Portugal, Region 6, December 1990. Lower left: California, Region 2, July 1992. Upper right: Brazil, Region 4, August 1992. Lower right: Ethiopia, Region 8, March 1992. These images are the same scale.

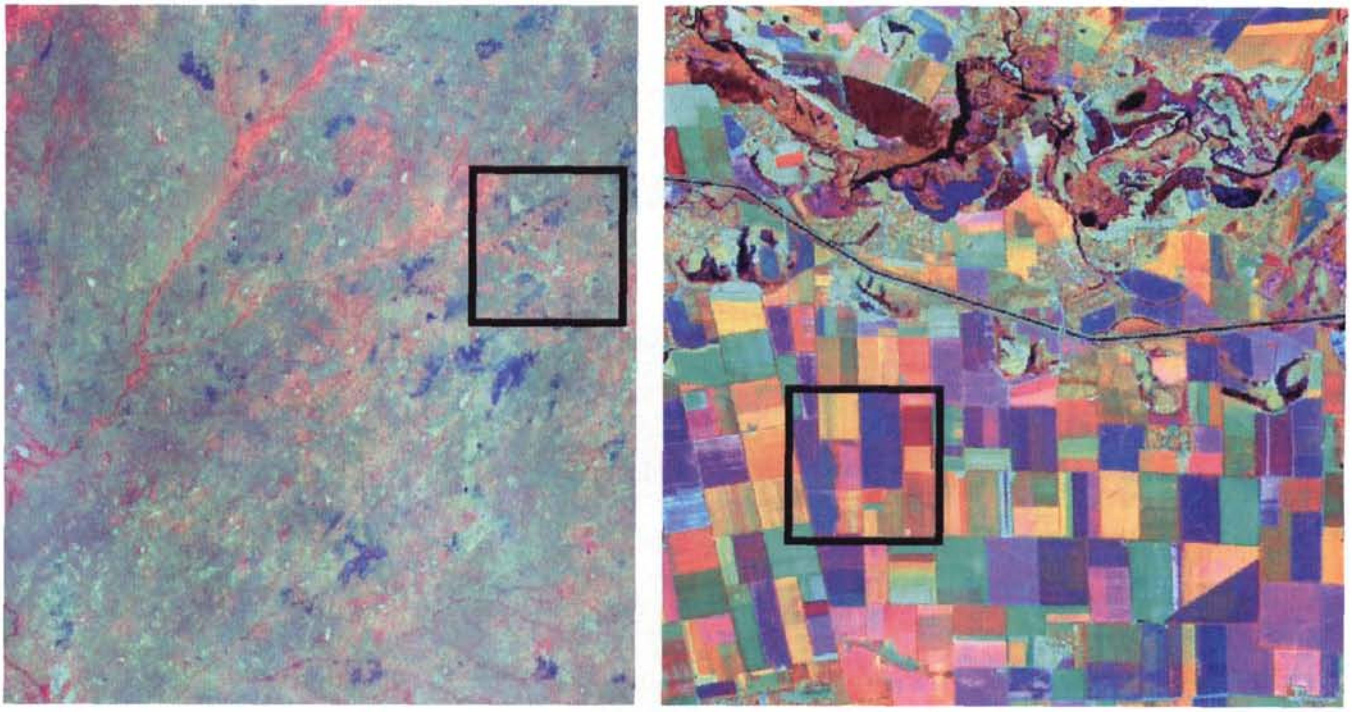

Plate 2. Inter-regional signature variation. Comparison of agricultural patterns in Landsat TM imagery. Left Region 8, central Africa, west Togo; 10 Jan 1991; TM Bands 4,5,3; Right Region 6, Europe, north Ukraine; 01, July 1990; TM Bands 4,5,3. The images have the same scale. It is the different agricultural methods in practice at different scales which makes these cropland signatures so different. Compared to the large checkerboard pattern of croplands in the Ukraine, the tiny cleared fields in western Togo could be easily overlooked.

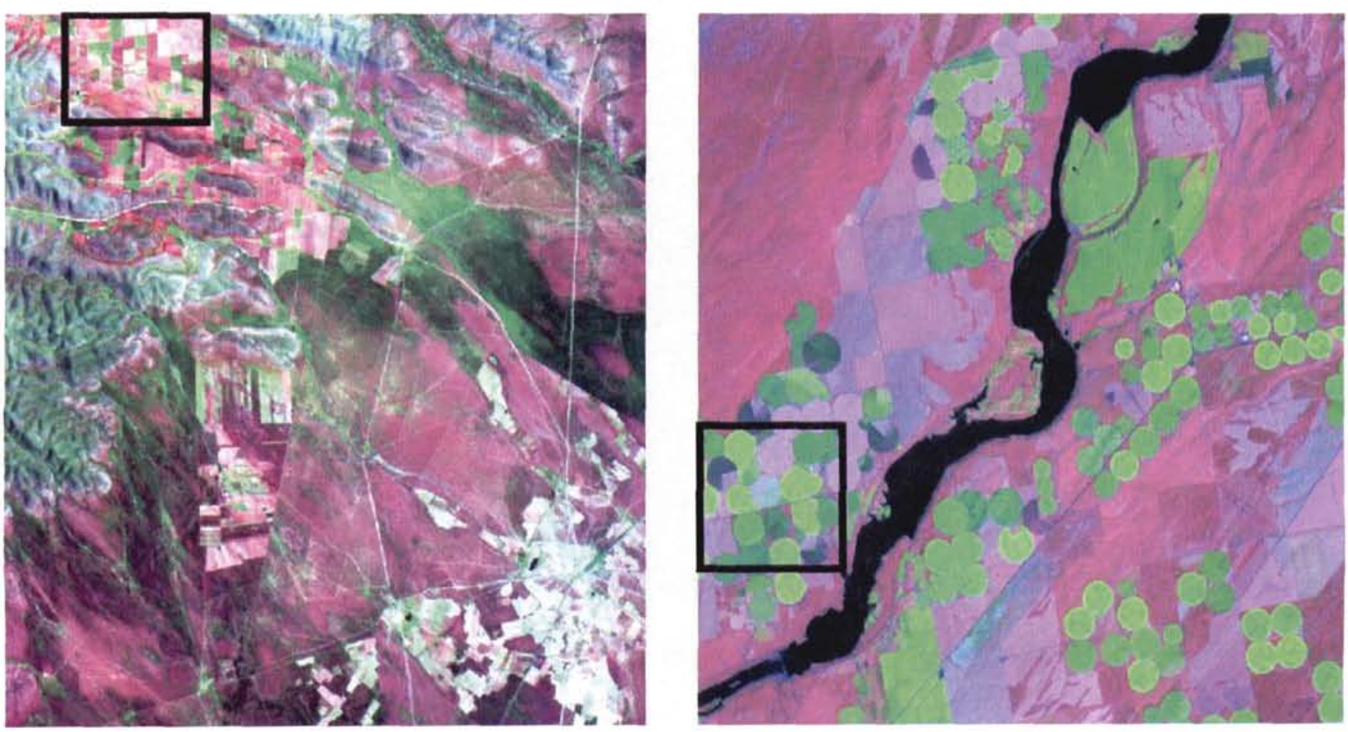

Plate 3. Landsat TM (bands 5,4,3) intra-regional signature variation: croplands. Left: Region 2, La Paz, Mexico. Right: Region 2, southcentral Washington.

Following classic manual image interpretation procedures (Estes *et al.*, 1983), sources of necessary ancillary data that could be made available to the EIIs were documented. Ancillary data included, among others, thematic maps, atlases, textbooks, and existing photo and image interpretation keys. It was quickly determined, however, that image interpretation keys did not exist for the diversity of environments where the land-cover classes to be validated are found.

Assumptions

Anticipating the need to provide a common framework for interpreters, we began with the premise that image interpretation keys would facilitate interpretation accuracy and thereby improve overall validation accuracy. It was also our hope that the successful use of keys for DISCover would set an important precedent for validation of future global data sets, and the establishment of a mechanism to provide access to a global image reference library. Our primary goal, however, was to improve the accuracy of the validation sample interpretations.

Some of the assumptions which directed the process of establishing a pragmatic methodology for use of keys in the DISCover validation exercise included that

- The land-cover classes were equally interpretable,
- A characteristic image signature could be identified for each of the IGBP land-cover classes,
- Suitable high resolution imagery representing both geographic and phenologic variation of each class could be obtained, and
- Keys would prove cost-effective by improving interpreter consistency.

Challenges and Planning Considerations

In working towards the development of image interpretation keys, researchers faced a number of challenges. From the literature review, it was determined that there was no precedent for production of interpretation keys on such a large scale. Indeed, very little information is available in the recent professional and academic literature on image interpretation keys.

Our goal in the validation setting was to provide the image interpreter with user-friendly access to the digital radiometrically and geometrically corrected Landsat and SPOT data for the manipulation which is essential for spectral comparison. Metadata and ancillary location-specific information were available on the Validation Worksheets on which each EII recorded land-cover interpretations and associated notes. Hardcopy keys annotated with critical site data provided a convenient in-hand reference for comparison and discussion among the EIIs.

Both theory and practice tell us that there are components of the ecosystem affecting irradiance or spectral reflectance that will vary in every image. For example, soil moisture, atmospheric moisture, and direction and intensity of the lighting change continuously and can dramatically effect the appearance of a particular feature or an entire landscape in a given image. The challenge is to adequately capture the spectral, spatial, and temporal variation inherent in the IGBP land-cover classes.

The IGBP land-cover classification scheme (Belward, 1996) consists of 17 land-cover classes. It was unnecessary to develop keys for the classes of water bodies and snow and ice because they were not validated. Of the remaining 15 classes, all have substantial variation both between and within each of the 13 IGBP regions. Many have significant seasonal variation. The lack of available imagery has so far limited the objective to demonstrate a range of seasonal variation.

To further illustrate the challenges of global land-cover key development associated with this activity, a rough estimate for a minimum number of keys might be calculated as follows: 15 (land-cover classes) $\times$ 13 (IGBP regions) $\times$ 4 (seasons) = potentially 780 images necessary to demonstrate variation within the primary 15 IGBP global land-cover classes. However, not all classes will exhibit variation for all four seasons. For example, grasslands often have a season of higher moisture availability and a season of low moisture availability, but the spatial signature in terms of tone, texture, and pattern appear fairly similar all over the globe. Thus, grasslands may require as few as two keys per region if variation from region to region actually proves to be minimal. On the other hand, classes such as open and closed shrub land can vary dramatically in height, tone, texture, and reflectance and may require several keys to demonstrate an adequate range of their variation (Plate 1). Agricultural practices around the world vary significantly in field size, field configuration, crops planted, management practices, and crop phenology. The signature of croplands in western Togo of West Africa may not be recognizable to an interpreter with experience in only European agriculture patterns and practices (Plate 2). Even within a single region, these may vary enough to produce significantly different signatures (Plate 3).

It is also important to note that other variables such as elevation, slope, and aspect significantly affect the signatures of some classes. While every attempt was made to use the available imagery to illustrate regional and phenologic variation for each land-cover class, this was not achieved for all classes. The regional expertise of the interpreters helped somewhat to reduce reliance on the keys. However, based upon comments from the EIIs at the validation, the keys were helpful and the lack of keys in some areas was a disappointment (Scepan *et al.*, in this issue 1999).

No less challenging are the cost of producing new keys, and the difficulty of finding and obtaining existing keys. These issues have not been addressed in the literature. Because of their specialized nature, the initial cost of keys can be high. Besides the initial investment in imagery, there are additional costs for acquisition and compilation of ancillary data, specialized interpretation, synthesis of ancillary graphics with the imagery, and the development and maintenance of a database. In this case, there is also development, structuring, and coordination of the online data directory.

Despite this, the enduring value of keys cannot be overstated, and their persistent use in universities, corporations, and government agencies speaks strongly to their long-term cost effectiveness (Chisnell and Cole, 1958; Choate, 1957; Colwell, 1946; Loelke *et al.*, 1983; Madden *et al.*, 1999, U.S. Naval Photographic Intelligence Center, 1945). Additionally, despite their production for so many projects (U.S. Defense Mapping Agency, 1995; U.S. Environmental Protection Agency, 1994; HRB-Singer, 1978; U.S. Naval Reconnaissance and Technical Support Center, 1967; U.S. War Department, 1942; Zsilinszky, 1963), they exist as gray literature and are not publicized, or proprietary usage restricts access to them. The difficulty of finding appropriate keys for use is a strong argument for the creation of a virtual global library of reference images where duplication of effort is minimized and the entire user community has access.

Elements of Key Design

Logistical considerations aside, the more interesting aspects of key design/production involved signature characterization. In traditional photo interpretation, a signature is a representative photo rendition of a feature, i.e., a characteristic example. Image tone/color, pattern, texture, shape, size, context, and association combine to form characteristic image signatures for given features. As remote sensing has developed finer spectral resolution, the concept of signature has been, in a sense, deconstructed. What was once a spatial visual concept, now frequently refers to statistical irradiance parameters, which characterize a specific class of training data. Signature now more often refers to the measured irradiance characteristics of an object or a feature. Objects or features are frequently exemplified as a unique spectral measure read from a hand-held spectrometer, or as a graphic probability model generated from digital image data by image processing software. The two concepts of signature suggest complementary elements of interpretation keys, because they both represent characteristic examples of specific features. The spatial signature on the image and the spectral signature for that spatial area are equally useful to the interpreter in demonstrating the range of signature variation which is so critical in training interpreters to a common reference.

Signature characterization for the IGBP interpretation keys, then, is an attempt to adequately capture and display the spatial and temporal variation of the spectral signature of a given land-cover class. Signature characterization assumes that, for each class in each region, adequate object-to-background contrast exists. That is, the land-cover class of interest can be spectrally differentiated from all other classes in the image being analyzed. Signature characterization is critical for assimilating diverse interpreter perspectives into a common spatial interpretation framework.

The subjective element inherent in image interpretation leaves the practice open to much criticism. As a result, the nature and extent of interpreter variation is often conveniently ignored. Although numerous projects have applied image interpretation as a part of their methodology or as a part of a validation, such as Gap Analysis (Eve and Merchant, 1998) and Coastal Change Analysis Project (U.S. National Oceanic and Atmospheric Administration, 1998), published references to interpreter variation or the consideration of interpretation keys are scarce (Madden *et al.*, 1999).

Another important consideration in the design of the interpretation keys associated with this effort is the consistent application of a minimum mapping unit (MMU) for all the keys. The IGBP MMU is 1 km^2. At the smaller MMU of TM, 28.5 m, classes which were agglomerated at the larger MMU of AVHRR will be separated. In consideration of these affects on interpretation, all keys have been constructed with a standard dimension of approximately 400 by 400 TM pixels, and interpretation guidelines were to maintain a 1 km^2 area of interpretation.

Image selection criteria play a significant part in key design and development. Selection of an inadequate or misrepresentative signature example, interpreted and verified as containing the specific signatures required, can greatly influence how an interpreter will analyze subsequent images. Some images were selected in part for their clear, unambiguous representation of an IGBP DISCover land-cover class, others because of their complexity. The primary imagery selection criteria were

- The image must clearly show examples of the IGBP land-cover features,
- Images must be of adequate resolution and clarity to distinguish the land-cover classes at the desired scale,
- The image must have an identifiable location on the globe,
- Recognizable landmarks must be present on the image and on readily available reference maps, and
- Images must show both variation of the signature of a class and variation in the context in which the signature of the class is found.

Because the DISCover classification was based on AVHRR data, higher resolution TM and SPOT imagery were acquired for the sample points. Standard image processing of the Landsat TM and SPOT imagery minimized both radiometric and geometric distortions. The image corresponding to a particular region was evaluated for content. Areas were selected that demonstrated significant variation within a particular land-cover class. Variation between different classes was also a consideration because this allows for better contrast between other land-cover types within the area of interpretation. To facilitate identification of the numerous scenes selected, an ArcView database containing the scene center and areal extent of each TM image was developed. Ancillary data such as country names, major cities, rivers, and lakes of the world were keyed to each scene using the Microsoft Expedia Maps web site (**http://www.expediamaps.com**).

By querying the database, a list of landmarks in the area of each image could be used to more quickly orient a map location to a particular scene. The selected key images were cropped from the larger image to the prescribed 400- by 400-pixel size and an exported graphic template of necessary annotations was applied. The core validation image represented a 40- by 40-km area. The key sub-image was sized to maintain high resolution in print on a letter-sized document with accompanying text. Text associated with the image was placed in the lower section of the key. Information included the location of the image, a description of landmarks visible in the image, the TM bands shown, the database file name, and the date. Keys were designed to be concise and simple in order to allow interpreters who are not native English speakers to easily understand the text (Plate 4).

For hardcopy keys used during the validation, a Landsat TM band combination of 5,4,3 was used based on the consensus of the VWG interpreters present at the North America methods text held in 1998 (Scepan, 1999, in this issue). During the actual validation workshop, interpreters were given the validation image in digital format with radiometric and geometric corrections applied. All of the TM and SPOT bands were available for display and analysis using ERDAS Imagine software. This gave the interpreters a full range of the image processing options. These capabilities were available for the validation scenes during the DISCover validation, but ideally this would also be available for a digital Key. Important capabilities included data scaling, several methods of image stretching, histogram and spectral signature manipulation, application of several filters, and recombination of any three selected bands for enhancement of specific features as they desired. Spectral differences in the features portrayed in an image can vary significantly. Image processing tools can often be critical to identification of features (Plate 5). Table 1 shows the number of different band combinations by land-cover class, used by interpreters during the DISCover validation. While not validated, water bodies are included in Table 1 because of one case where a registration error placed the sample point incorrectly into water. From Table 1, it is evident that different interpreters approach the land-cover classes from many different perspectives. This underscores the necessity for keys in a digital format so that interpreters can manipulate the image data for feature enhancement.

A schematic view of the hardcopy and digital keys as they are presently envisioned is provided in Figure 2. The hardcopy images would benefit from being in a larger image size and might occur as several pages. The digital format could be accessible in the schematic format via a web page with explanatory text. For the IGBP DISCover validation, a reasonable directory structure organized keys first by region and then by land-cover class. In future validations it remains to be seen whether such an organization will continue to be most appropriate.

Results

Initially it was hoped that a full set of interpretation keys could be developed to assist the EIIs. Key development was complicated by a shortage of imagery for some classes, and an inadequate representation of class phenology.

Governed largely by funding constraints and time schedules, the keys produced were derived from imagery readily available at UCSB. Sixty keys were developed. All of these keys

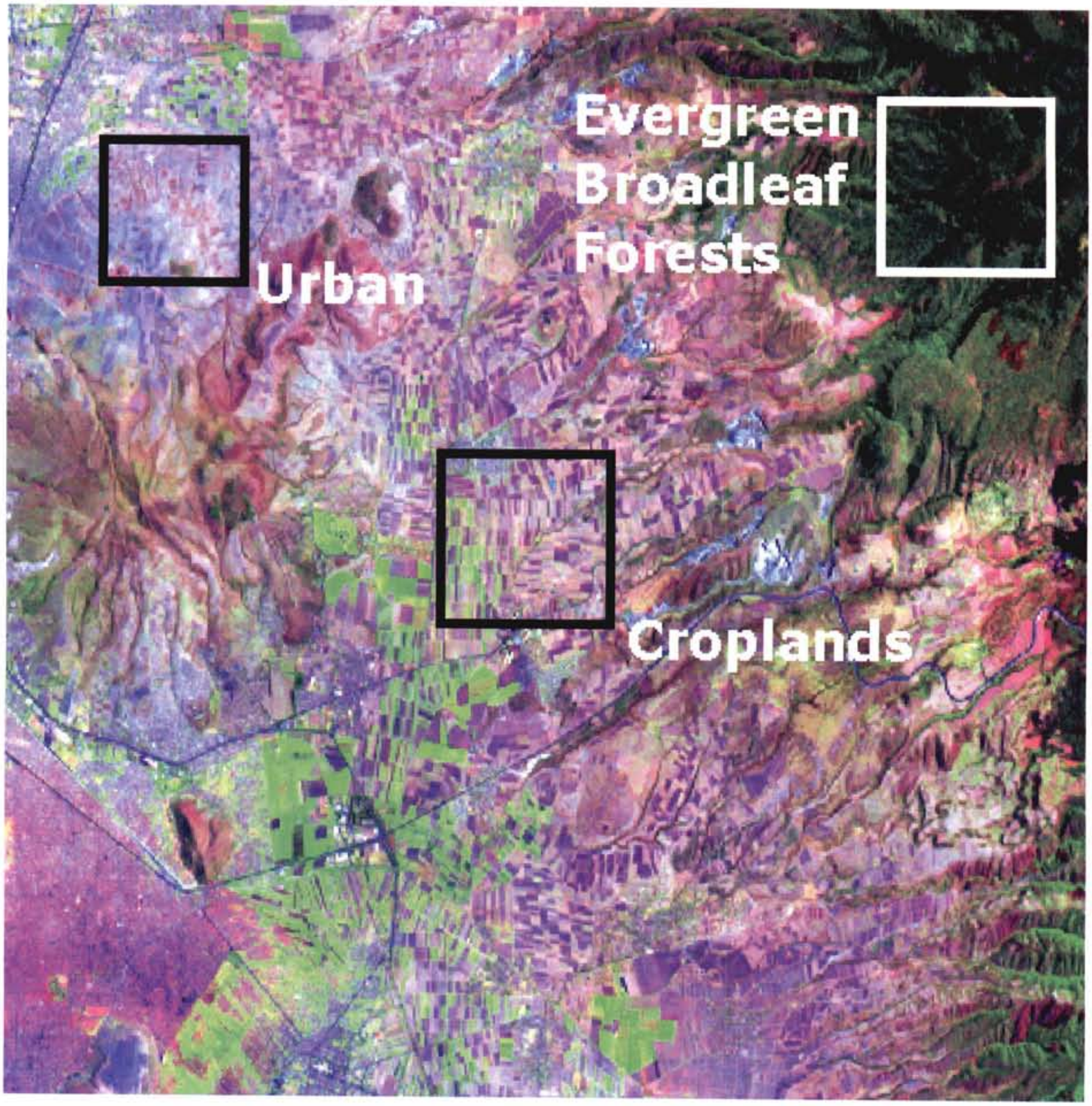

Plate 4. Example of a hardcopy interpretation key. Region/Class: IGBP Region 2, land-cover classes savanna, croplands, urban, evergreen broadleaf. Location: Mexico, Mexico State, Neovolcanic Plateau, Amecameca. 98° 55′ 13.″45 W, 19° 24′ 37.″44 N. Image Date: 24 May 91. Scale: 1 inch = ~2.3km. Sensor: Thematic Mapper; Bands 5,4,3. Source: Landsat TM, USGS EROS Data Center.

were derived from Landsat imagery. The U.S. Geological Survey EROS Data Center was very generous in supplying Landsat TM data for the validation activity. Complex coordination of funding for SPOT data resulted in its delayed arrival to the RSRU team until shortly before the validation workshop. As a result, the keys produced and used at the Validation were from Landsat TM data, and included images from only ten of the 13 global regions. For three regions of the globe, the only available imagery was SPOT data, and so these were without keys (Region 3-Central America, Region 7-North Africa and the Middle East, and Region 13-Australia and New Zealand).

A major aspect of the use of image interpretation keys was the desire to develop a referential background that was consistent between interpreters. The more image interpretation experience an analyst/interpreter has, the better interpreter he/she becomes. The EIIs were from 16 different countries and perhaps as many different disciplinary specializations (Figure 3). While image interpretation by EIIs with a diversity of discipline backgrounds and experience can be accommodated in the validation process, their diversity of backgrounds and experiences can lead to an unwieldy array of perspectives. We believed these diverse perspectives could benefit from cross cultural communication as much as from standardization, and toward this goal, EIIs were encouraged and engaged in various discussions between groups during the validation.

Discussion

We are continuing to create this virtual reference library of land-cover keys and ancillary information by expanding our activities along the following lines:

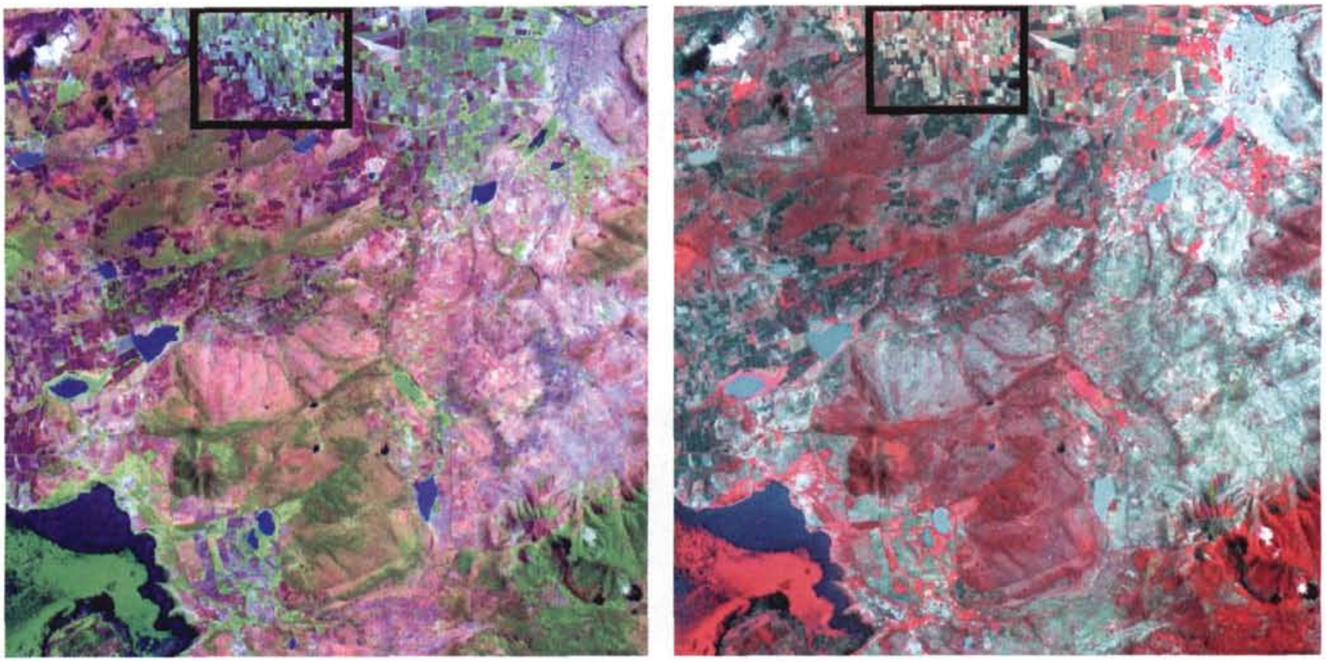

Plate 5. Feature enhancement. Left: TM Bands 5,4,3. Right: TM Bands 4,3,2. Michoacan, Mexico, agricultural fields. Different band combinations emphasize different feature characteristics and are critical to identification in many instances.

Table 1. Total Number of Band Combinations Used for Interpretation of Each Land-Cover Class by EIIs at the IGBP DISCover Validation

Class	Class Name	# Band Combinations Used by each Interpreter
1	Evergreen Needleleaf Forests	8
2	Evergreen Broadleaf Forests	6
3	Deciduous Needleleaf Forests	5
4	Deciduous Broadleaf Forests	7
5	Mixed Forests	8
6	Closed Shrublands	6
7	Open Shrublands	6
8	Woody Savannas	5
9	Savannas	5
10	Grasslands	5
11	Permanent Wetlands	8
12	Cropland	8
13	Urban and Built-up	6
14	Cropland/Natural Vegetation Mosaics	6
15	Snow & Ice	not interpreted
16	Barren	5
17	Water Bodies	3

- Broaden and refine descriptions of land-cover classes to include local, or regionally based land-cover types. Many land-cover researchers are most familiar with local or regional habitat descriptions, which are translated into a global description only with experience. A cross-walking table would seem to be an important inclusion to the processes of both class description and class determination during a validation.
- The IGBP validation somewhat arbitrarily delineated 13 global regions in an attempt to satisfy both administrative and biogeographic requirements. It could prove more beneficial for terrestrial parameterization to ascribe to a more strictly ecoregional partitioning based on input from regional experts and global change modelers.
- Increase the number of images representing each class to include a ground view, and an intermediate scale air photo (Figure 2).

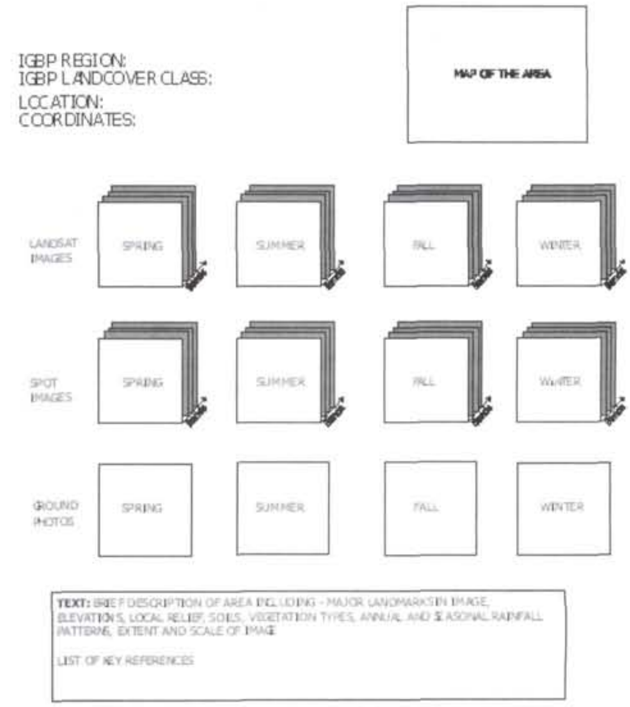

Figure 2. Idealized digital interpretation key directory structure. The envisioned digital key consists of a medium scale air photo, a small scale satellite image, and a large scale ground photo, as well as separate files for each photo, each satellite image band, and one for ancillary and metadata relating to the imagery.

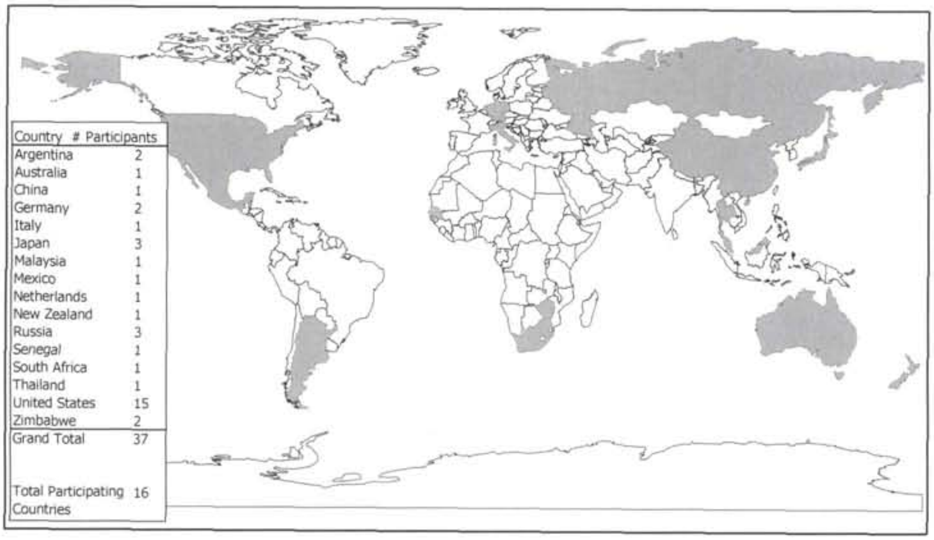

Figure 3. Countries with EIIs at the IGBP DISCover validation.

Enlarge existing keys, for each class, to more adequately demonstrate phenologic and regional signature variation at different scales. This will extend their potential applications as well as further elucidating the interpreters understanding of variation within each land-cover class.

- Expand existing keys to employ data from a variety of different sensor systems would also increase their usefulness and versatility. As new sensors are launched, it is inevitable that requirements for new signature characterizations will develop with the addition of new information from new sensors.
- Perform tests designed to determine if the keys that are developed actually do increase interpreter consistency. Comparative tests between experienced and novice interpreters and their interpretation accuracy before and after exposure to keys could provide quantitative evidence and perhaps even a cost-benefit model of the value of keys for validation.
- Continue to establish and maintain relationships with organizations and individuals with land-cover and image interpretation expertise around the globe, and enlist their cooperation and contributions towards the global reference image library. Management and quality control would be centralized, while participation and input of data could come from many sources. Based upon discussions among the EIIs at the validation workshop, implementation of this type of key development concept has wide support.
- Set up a web page directory structure organized by region and land-cover class, which allows for presentation and selection of reference images by class, phenology, and location.

We believe that there is a real and pressing need for image interpretation keys in support of future large-scale land-cover validation efforts. Because the validation process demonstrated that the assumption that all of the DISCover land-cover classes are equally interpretable does not hold; sampling frames must be recalculated. We must give more attention to keys of those problem classes. Another assumption that did not fully hold was that we could obtain imagery of the geographic and phenologic variation of each IGBP class. Because of imagery costs and availability, we were not able to do this. This makes it even more important that an international cooperative key development effort continue so that we have such data for future validation exercises.

Conclusions

Key development associated with the validation of the IGBP-DIS Global 1-km^2 land-cover product DISCover was a large and a complex undertaking. When we initially conceived this key development effort, it was in somewhat naïve terms. Once we actually began to seriously consider what would be involved in the development of such keys, we quickly realized that full development was well beyond the scope of this effort. Because of limitations on time, availability, and cost of imagery, key materials produced to date for ten of the IGBP regions still inadequately represent the phenologic variation of the IGBP land-cover classes for those areas.

However, we did demonstrate the range of activities that such a key development would entail. Based upon EII comments, we also demonstrated that keys were of value in the validation process. Feedback from the EIIs was very positive; additionally, there was consensus that all users would benefit from completion of the keys. The majority of EIIs expressed a need for more keys with additional descriptive text and supportive land-cover verification input from local land-cover experts. Many have volunteered their own expertise. Indeed, growing largely out of comments from the EIIs and their enthusiastic support and encouragement, we are carrying forward our key development activities.

We see the global image interpretation keys developed and used in IGBP DISCover validation as a building block resource for an international library of validation materials that can be used in global change research. Use of the global image interpretation keys in this effort contributed to the consistency and the accuracy of validation interpretations. Continued development of the keys is critical to improving the newly established global land-cover accuracy standard. With the planned launch of MODIS in 1999, the opportunity to do this may begin very soon. A quarterly schedule of production and validation of MODIS land products, such as vegetation cover conversion and land-use/land-cover change (Strahler *et al.*, 1995; Wharton and Myers, 1997). The keys developed as part of this ongoing effort will, we hope, prove useful to MODIS investigators.

Collections of on-line global land-cover images have already been initiated by groups of ecologists, cartographers, and remote sensing scientists. A list of the DISCover EIIs is available at **http://rsrunt.geog.ucsb.edu/IGBP/sept-val.html**. Most notably among the volunteer interpreters, Dr. Koji Kajiwara, a lecturer at the Center for Environmental Remote Sensing at the University of Chiba, Japan, has initiated a Global Image Network Database. This database contains ground and aerial photos of Mongolian land-cover images (Kajiwara, personal communication). It was created to establish confidence site biometrics for sensor calibration. These images are invaluable for validation of land-cover mapping and key development as well. Sharing these data via the Internet with other land-cover researchers is an inspirational gesture. Other researchers and organizations also already have images on line, which could contribute to land-cover validation. Coordinating and standardizing existing efforts and allowing further contributions would seem a natural extension of a process that is slowly gathering momentum. If effectively integrated and organized, the beginning of a virtual reference library of land-cover keys and ancillary information, in essence, a set of signature representations for global land-cover types, could become reality.

Accurate land-cover information is critical in evaluating global environmental parameters, but there are many other applications as well. Predictive modeling of species distributions and Optimization Modeling of Reserve Site Selection are being explored currently with unvalidated regional scale land-cover maps (Davis and Stoms, 1996; Davis *et al.*, 1996). Eventually, these applications will extend to the global scale. Applications for determining the status of wetlands, forestry, agriculture, and land-use changes seem endless. Future validation efforts are critical. We will not be able to determine or monitor changes of given land-cover classes unless future validation activities are carried forward. Toward this goal, we would like to invite the land-cover community to participate in a volunteer key development activity. Everyone would have access to the material produced and it could be used at the discretion of the users. Issues of quality control and long-term maintenance will need to be addressed, as will issues of harmonization of metadata. At some point, we would hope that some appropriate organization, with sufficient resources, would see the value of the keys developed and that this organization would then take over the key development coordination and maintenance.

References

Belward, A.S., (editor), 1996. IGBP-DIS Working Paper #13: *The IGBP-DIS Global 1 km Land Cover Data Set (DISCOVER), Proposal and Implementation Plans*, Report of the Land Cover Working Group of IGBP-DIS, IGBP Data and Information System Office.

Belward, A.S., J.E. Estes, and K.D. Kline, 1999. The IGBP-DIS global 1 km land cover data set DIScover. A project overview, *Photogrammetric Engineering & Remote Sensing*, 65(9):1013–1020.

Chisnell, T.C., and G.E. Cole, 1958. Industrial Components: A photo-interpretation key on industry, *Photogrammetric Engineering*, 24:590–602.

Choate, G. A., 1957. A selected annotated bibliography of aerial photo-interpretation keys to forests and other natural vegetation, *Journal of Forestry*, 55:513–555.

Colwell, R.N., 1946. The estimation of ground conditions from aerial photographic interpretation of vegetation types, *Photogrammetric Engineering*, 12(2):151–161.

Davis, F.W., and D.M. Stoms, 1996. A spatial analytical hierarchy for GAP analysis, *GAP Analysis: A Landscape Approach to Biodiversity Planning* (M. Scott, T. Tear, and F. Davis, editors), American Society for Photogrammetry and Remote Sensing; Bethesda, Maryland.

Davis, F. W., D. M. Stoms, R. L. Church, W. J. Okin, and K. N. Johnson, 1996. Selecting biodiversity management areas, *Sierra Nevada Ecosystem Project: Final Report to Congress, Vol. II, Assessments and Scientific Basis for Management Options*, University of California. Centers for Water and Wildlands Resources, Davis, California.

De Boissezon, H., G. Gonzales, B. Pous, and M. Sharman, 1993. Rapid estimates of crop acreage and production at a european scale using high resolution imagery: Operational review, *Proceedings of the International Symposium on Operationalization of Remote Sensing*, International Institute for Aerospace Survey And Earth Sciences, Enschede, The Netherlands, 2:94–105.

Estes, J.E., E.J. Hajic, and L.R. Tinney, 1983. Fundamentals of image analysis: Analysis of visible and thermal infrared data, *Manual of Remote Sensing*, American Society of Photogrammetric Engineering and Remote Sensing, Falls Church, Virginia, 1:987–1124.

Eve, M.D., and J.W. Merchant, 1998. *GAP Land Cover Mapping Protocols, A National Survey of Land Cover Mapping Protocols Used in the GAP Analysis Program*, Final Report, internet site **http://www.calmit.unl.edu/gapmap/** 13 June 1999.

HRB-Singer, Inc., 1978. *Interpretation Manual for Color and Color Infrared Aerial Photography for Surface Coal Mines*, Bureau of Mines, United States Department of the Interior, Prepared for Division of Environment by HRB Singer, Inc.

Loelke, G.L., Jr., G.E. Howard, Jr., E.L. Schwertz, Jr., P.D. Lampert, and S.W. Miller, 1983. *Land Use/Land Cover and Environmental Photointerpretation Keys*, U.S. Geological Survey Bulletin 1600, U. S. Government Printing Office, Washington, D.C.

Madden, M., D. Jones, and L. Vilchek, 1999. Photointerpretation key for the Everglades vegetation classification system, *Photogrammetric Engineering & Remote Sensing*, 65(2):171–177.

Scepan, J., 1999. Thematic validation of high resolution global land-cover data sets, *Photogrammetric Engineering & Remote Sensing*, 65(9):1051–1060.

Strahler, A., A. Moody, and E. Lambin, 1995. Land Cover and Land Cover Change from MODIS, *Proc. 15th Int. Geosci. and Remote Sensing Symp.*, Florence, Italy, 10–14 July, 2:1535–1537.

U.S. Defense Mapping Agency, 1995. *Photo Interpretation Student Handbook, Module 2: Buildings, Transportation, Industries, Communications and Electronics, Cultural Areas; Module 3: Hydrography; Module 4: Cropland, Rangeland, Woodland, Wetlands; Module 5: Landforms and Exposed Surface Materials*, Defense Mapping Agency, U.S. Government Printing Office, Washington, D.C.

U.S. Environmental Protection Agency, 1994. *Landscape Monitoring and Assessment Research Plan*, 620/R94/009, United States Environmental Protection Agency, Office of Research and Development, Washington, D.C.

U.S. National Oceanic and Atmospheric Administration, 1998. *Coastal Change Analysis Program (C-CAP)*, Coastal Services Center, (internet site **http://www.csc.noaa.gov/ccap/**).

U.S. Naval Photographic Intelligence Center, 1945. *A Guide to Pacific Landforms and Vegetation for Use in Photographic Interpretation*, OPNAV-16-VP107. Air Intelligence Group, Division of Naval Intelligence, Office of the Chief of Naval Operations, Navy Department, Washington, D.C.

U.S. Naval Reconnaissance and Technical Support Center, 1967. *Image Interpretation Handbook, Vol. I.*, NAVAIR 10-35-685, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C.

U.S. War Department, 1942. *Interpretation of Aerial Photographs*, Technical Manual TM 5-246, U. S. Government Printing Office, 1943. Washington, D.C.

Walker, B., and W. Steffen, (editors), 1997. *The Terrestrial Biosphere and Global Change: Implications for Natural and Managed Ecosystems; A Synthesis of GCTE and Related Research*, The International Geosphere-Biosphere Programme: A Study of Global Change of the International Council of Scientific Unions, Stockholm, Sweden.

Wharton, S.W., and M.F. Myers, (editors), 1997. *MTPE EOS Data Products Handbook, Volume 1, TRMM & AM-1*, Mission to Planet Earth (MTPE), Earth Observing System (EOS), National Aeronautics and Space Administration (NASA), Goddard Space Flight Center, Greenbelt, Maryland.

Zsilinszky, V.G., 1963. Photographic Interpretation of Tree Species in Ontario, Department of Lands and Forests, Timber Branch, Ontario, Canada.