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Survey and monitoring of opium poppy and wheat in Afghanistan: 2003 to 2009

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An integrated application of remote sensing technology was devised and applied in Afghanistan during 2003–2009 providing critical information on cereal and poppy cultivation, and poppy eradication. The results influenced UK and international policy and counter narcotics actions in Afghanistan.

1 Introduction

The annual production of opium in Afghanistan is said to exceed 90% of world production (UNODC, 2009) and to supply almost all of heroin consumption in the UK. The UK Government has a particular interest in counter narcotics (CN) and is a lead nation on policy formulation and action providing support and assistance to the Government of Afghanistan (GoA).

In 2003, there were serious deficiencies in the quantitative information on opium cultivation in Afghanistan which impeded both policy formulation and CN action. The key sources of estimates of quantity and trends in poppy cultivation were the independent annual opium surveys conducted by the US Government and, in collaboration with the GoA, the United Nations Office on Drugs and Crime (UNODC). The Surveys were providing different and often conflicting information late in the year severely limiting options for influencing the following season's crop. The information was also deficient in providing sufficient detail on the whereabouts of local concentrations of poppy cultivation and trends.

Part of the GoA's National Drug Control Strategy (NDCS) has included action to physically destroy the opium crop in the fields, by hand and/or mechanised means. The process included a scheme for compensating provincial governors for cost of eradication based on the area of crop eradicated. Thus there was also a requirement for verification of the eradicated area to assess the success of eradication and determine the size of the payments. This has had to take place against a background of insecurity, coercion and corruption rendering in-field verification unreliable.

Volatility of cereal prices in recent years and local shortages for food supply increased interest in the interaction between cereal and poppy cultivation in Afghanistan to see if encouraging farmers to grow cereals in designated Food Zones would reduce the cultivation of poppy. Current official cereal cultivation figures do not include objective field measurements instead they rely on farmer questionnaire surveys of unknown reliability, especially in the current circumstances.

2 Evolution of project work

Our initial role was to work with the US and UNODC Annual Opium Surveys to understand differences in survey figures and to recommend ways to improve consistency without prejudicing the independence of the Surveys' estimates. Both Surveys are science-based using remote sensing methods and detailed study of both revealed differences that could account for the inconsistency in results. Scientific trials were conducted to demonstrate benefits of recommended changes to Survey methodology; to encourage uptake and promote technical discussions between Survey teams. The trials evolved in 2006 into

independent remote sensing crop surveys in selected parts of Afghanistan conducted by us for the UK Government to provide poppy information and improved local detail earlier in the growing season than the US and UNODC Surveys. Cereal cultivation surveys were added from 2007 to investigate the interaction between cereal and poppy growing.

In 2003, there were gaps in generic knowledge concerning remote sensing of poppy, poppy yield and poppy eradication so in 2004 and 2005, because security issues prevented us from doing so in Afghanistan, we conducted field trials on crop grown commercially in the UK for the pharmaceutical industry.

By 2006, it was apparent that there was serious over claiming of poppy eradication and unclassified evidence for this was required. In 2007 we conducted aerial surveys using a commercial service with an Ultracam D Digital survey camera to facilitate photogrammetric measurement of eradicated poppy fields. The on-going security problems prevented the aircraft overflying important areas of claimed eradication so we successfully evolved alternative methodology using IKONOS satellite imagery and this was implemented through 2008 and 2009.

Afghanistan suffers a serious lack of trained technical personnel because of the persistent disruption of education during recent decades of war. The UNODC Survey team has set up a program of technical capacity-building for Afghan nationals and we have contributed key remote sensing training and mentoring to that program.

3 Overview of scientific trials and UK independent crop surveys

3.1 *UK field studies on poppy identification, eradication and yield estimation*

In 2004 we conducted multitemporal imagery trials. The optimum timing of imagery for discrimination of poppy from a range of other field crops was investigated and found to be around the flowering stage.

The UNODC estimates opium yield from capsule measurements within 1m square quadrats and then estimates average yield from a sample of locations (UNDCP, 2001). Security constraints limit access for sampling and so prejudice accurate yield estimation. We adapted methodology developed for precision farming of cereals using minimal ground sampling (Taylor *et al.*, 1997b; Wood *et al.*, 2003) to investigate improvement of poppy yield estimation. There was a high correlation between NDVI and opium yield estimated by the UNODC method. This points to a role for remote sensing in improvement of opium yield surveys with reduced reliance on ground sampling but lack of resources prevented us taking it further.

In 2005 a randomised block field trial was conducted to investigate the efficacy of hand and mechanised poppy eradication and its interpretation on imagery. Mechanised methods of poppy eradication created distinctive patterns in the eradicated crop that could be recognised on imagery. Eradication at early growth stages allowed time for significant crop recovery that could also be recognised on later images. Later eradication was more efficient.

3.2 *Application of MODIS imagery for wide area crop information*

Afghanistan is a large, sparsely populated country famously inaccessible because of extreme terrain and poor infrastructure. Much of the country is characterised by small-scale irrigated cropping along high narrow valleys emanating from the Hindu Kush but the main irrigated agriculture is along the larger river systems such as in Helmand, Kandahar and Nangarhar provinces.

A time-series of 250 m resolution MODIS imagery from February 2000 was downloaded from the NASA archive and used to generate NDVI profiles at any location in Afghanistan. As illustrated in figure 1, the large range in altitude plus differences in latitude creates big variations in the timing of crop cycles depicted by the NDVI profiles. Also large areas, particularly in the north, are prone to drought which creates large annual variations in the productivity of dryland agriculture and the associated NDVI responses.

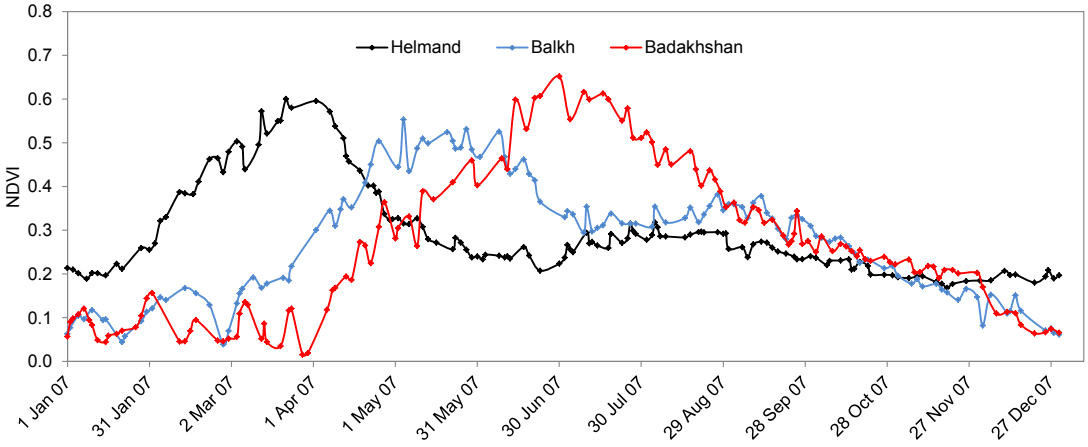


Figure 1: NDVI profiles from MODIS imagery at agricultural locations in Helmand (altitude 741 m, latitude 31.43° N), Balkh (altitude 1463 m. latitude 35.80° N) and Badakhshan (altitude 2502 m, latitude 36.31° N).

NDVI profiles were calibrated for crop growth stages at a sample of locations using ground photography taken by the UNODC. Profiles were then used to guide the acquisition timing of high and intermediate resolution imagery across the country for optimal discrimination of poppy around the flowering stage. In cases where weather conditions prevented optimal imagery acquisition, the timing on the MODIS profiles assisted interpretation of the high resolution imagery by informing the interpreters as to the likely crop types and growth stages present.

The NDVI profiles revealed a wide range of timings and growing patterns that, tempered with scientific judgement regarding MODIS pixel size and its orthorectification accuracy, were relatable on high resolution imagery to: identifiable crop mixes; agricultural practices such as crop rotations; and, evolution of new agricultural areas.

The time series of NDVI profiles also revealed the year-on-year variations in cropping patterns that were used to map reliability of cropping and to monitor drought onset and map affected areas.

3.3 *Poppy and cereal cultivation surveys*

Several alternative approaches to estimation of crop area using remote sensing were investigated. These were: the regression estimator as implemented by the EU MARS Project, described by Taylor *et al.* (1997a); object-oriented image analysis as implemented through eCognition (Definiens Imaging GmbH, 2003); sub-pixel analysis as developed by Applied Analysis Inc (Huguenin *et al.*, 1997; Applied Analysis Inc., 2003); and Frame Sampling Analysis as implemented in ERDAS Imagine™.

We based our cultivation surveys on the Frame Sampling Analysis because it could be adapted for use alongside the UNODC Survey and there was already US experience in its application in Afghanistan reported by Luders *et al.* (2004). Our survey methodology was

streamlined to bring forward the delivery of results to earlier in the crop season. This was achieved by the following: 1) syncronising imagery acquisition around poppy flowering; 2) reducing the sample size; and 3) reducing the size of the sampling frame by mapping only the area actively growing crops during the poppy season. The last was achieved by timing the acquisition of DMC imagery at poppy flowering which as greatly facilitated by the frequent coverage by the DMC constellation of satellites.

High resolution satellite (IKONOS) or aerial (Ultracam D) imagery was visually interpreted to map poppy and cereal fields by photogrammetry at the sample locations. Reliable interpretation keys for this were developed by cross referencing imagery with ground observations including ground photography and GPS coordinates for individual fields. The sample information was then combined with full coverage intermediate resolution DMC satellite imagery to make the poppy and cereal cultivation area estimates and to create map products of poppy and cereal distribution. All imagery preparation such as orthorectification and pan sharpening was carried out in-house to speed up delivery of imagery from suppliers and to facilitate quality control alongside speed of processing. Images were orthorectified using a high resolution controlled image base. Comparisons showed that the bulk processed products from suppliers were not consistently accurate.

Surveys of poppy cultivation area were carried out in up to nine selected provinces each year from 2005 through 2009. Surveys of cereal cultivation in Helmand and Nangarhar provinces were added from 2007. The results included: 1) the cultivated areas and annual trends for the provinces, districts and the Helmand Food Zone (as designated by the provincial governor in 2008); 2) maps indicating the probable crop distributions and changes in the area of agriculture actively growing crops during the poppy season; and, 3) details of natural events such as drought or flooding that could have influenced crop production. Figure 2, for example, shows the dramatic reduction of poppy cultivation in Nangarhar between 2007 and 2008 depicted in the probability distribution maps. The accuracy of our provincial area estimates for poppy and cereals was measured by the 90% confidence interval determined by using the bootstrap method. Confidence intervals were generally between $\pm$ 6 and $\pm$ 15 % for province estimates.

3.4 *Verification of poppy eradication*

Eradication verification was carried out in support of the UNODC and included training their staff in the verification methodology and in the systematic presentation of results for use as evidence.

Claimed areas of eradicated poppy fields were independently verified by photogrammetry on aerial photography from Ultracam D camera and IKONOS imagery. High accuracy of orthorectification was critical to ensure correct identification of eradicated fields when cross referenced with the GPS coordinates and ground photography provided by eradication teams otherwise the combination of small field sizes and the GPS error could lead to inconclusive or incorrect field identification. Comparisons between our bespoke process and commercially supplied products again showed the latter not having consistently high enough accuracy for verification of eradication. Eradicated poppy fields were revisited on later imagery to assess poppy recovery or replanting into other crops. The example Ultracam photography in figure 3 shows eradication patterns in partially recovered poppy fields following eradication at very early growth stages.

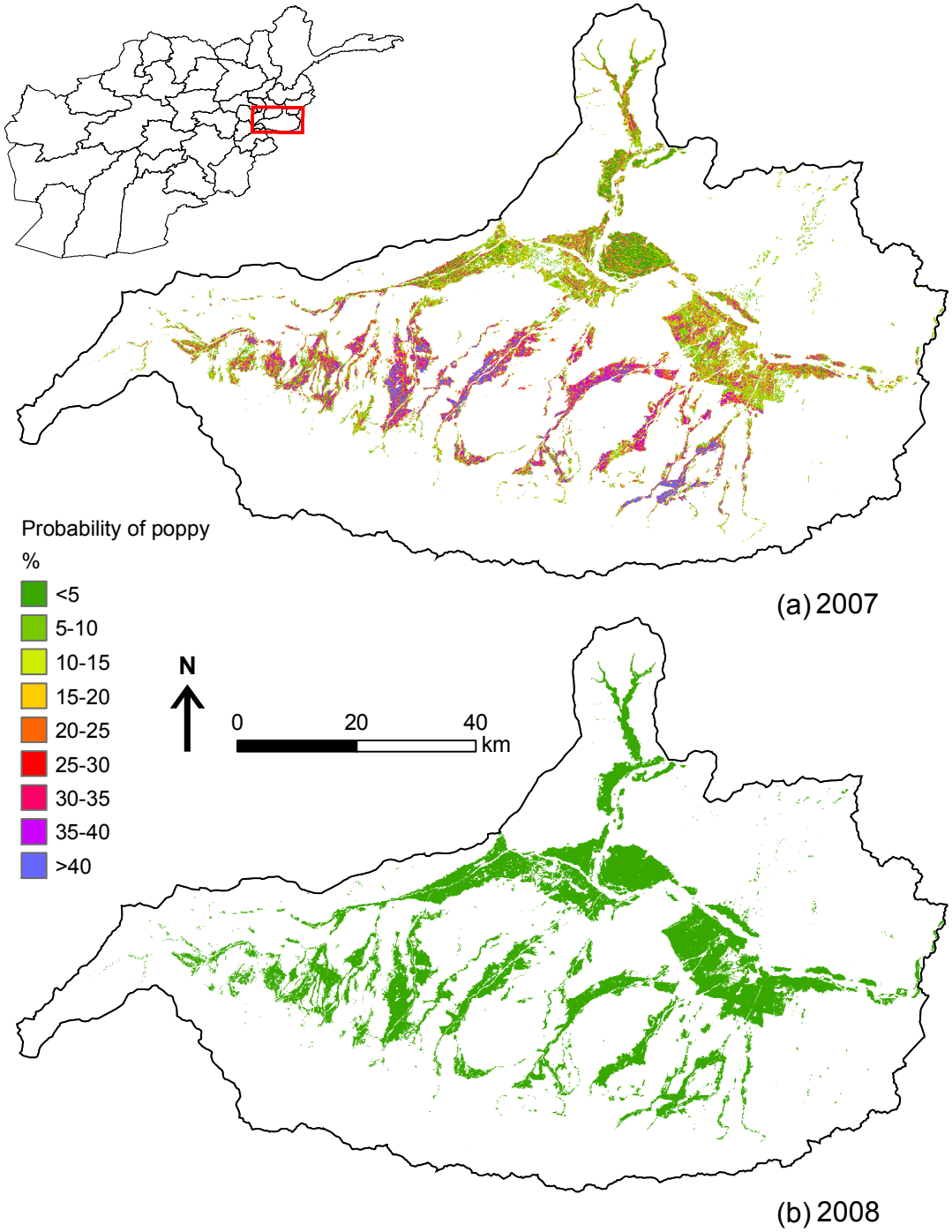


Figure 2: Probability of finding poppy in Nangarhar in *(a)* 2007 and *(b)* 2008.

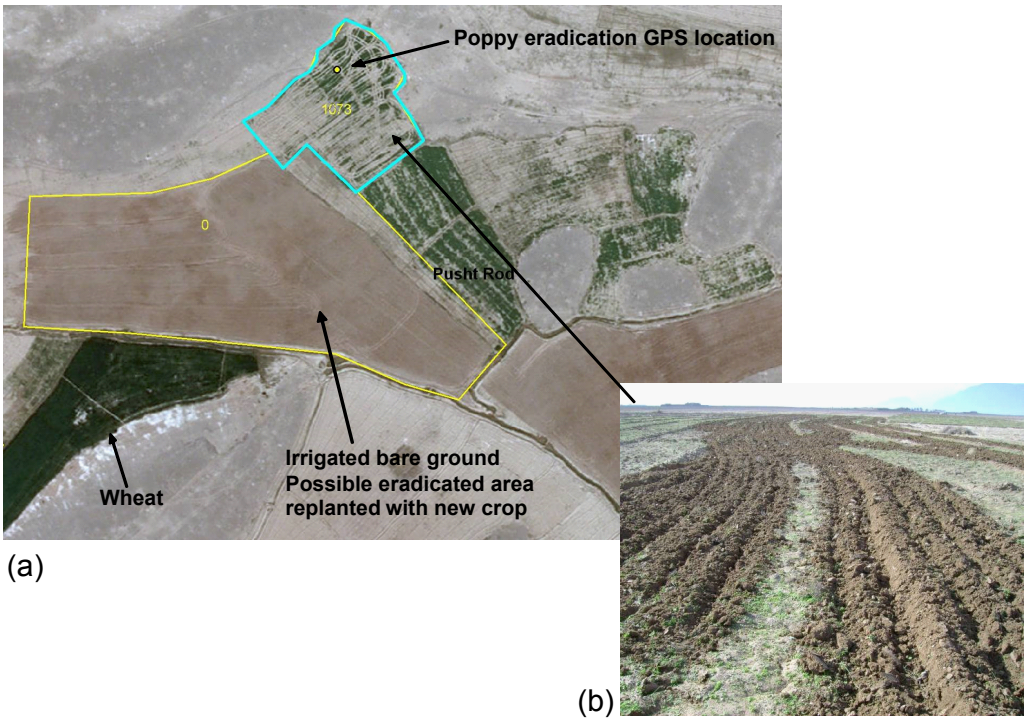


Figure 3: Natural colour Ultracam D imagery *(a)*, acquired 1 March 2007, showing poppy field No.1073 in Farah, which was incompletely eradicated on 17 December 2006 at very early growth stage, as seen in UNODC ground photograph *(b)*, and re-grown at the time of imagery. Ultracam Imagery ©BRITSH CROWN COPYRIGHT.

4 Commentary

An integrated application of remote sensing technology using high, medium and coarse spatial resolution imagery was devised and applied to provide critical information on cereal and poppy cultivation in Afghanistan.

Photointerpretation of sample sites, stimulated by this work, became a common feature of US, UNODC and our surveys and was frequently shared and compared by the Survey teams at overlapping sample locations generally confirming and promoting remarkable consistency in the identification of poppy fields. There were systematic differences between teams in the level of detail carried forward in the mapping of field boundaries. This systematic removal or inclusion of bare patches and field level infrastructure accounted for some differences between figures produced by the different Surveys, however, in general there was improved consistency between the main poppy cultivation estimates and trends from 2005.

The streamlined survey methodology, enabled us to provide cultivation figures several months earlier and with better detail at district level than the US and UNODC Surveys; as early as mid-May in Helmand; by mid-June in other Southern and Eastern provinces and by mid-July in the North.

At times, the results of this project have been highly controversial and unwelcome news but the science-based approach has created confidence in them and ensured they have been taken seriously. The work has influenced actions on CN in Afghanistan, and national and international policies. Results have been used and quoted by both the British Prime Minister and the Executive Director of the UNODC.

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