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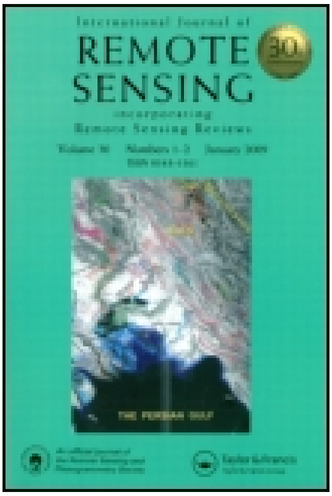

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Using multi-temporal Landsat ETM+ data to monitor the plague of oriental migratory locust

H. D. Tian [a c] , R. Ji [b] , B. Y. Xie [a] , X. H. Li [a] & D. M. Li [a]

[a] State Key Laboratory of Integrated Management of Pest Insects and Rodents , Institute of Zoology , Chinese Academy of Sciences , Beijing 100080, China

[b] Department of Biological Sciences , Xinjiang Normal University , Urumchi 830054, China

[c] Graduate University of Chinese Academy of Sciences , Chinese Academy of Sciences , Beijing 100049, China

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Using multi–temporal Landsat ETM+ data to monitor the plague of oriental migratory locust

H. D. TIAN†§, R. JI‡, B. Y. XIE*†, X. H. LI† and D. M. LI†
†State Key Laboratory of Integrated Management of Pest Insects and Rodents, Institute of Zoology, Chinese Academy of Sciences, Beijing 100080, China
‡Department of Biological Sciences, Xinjiang Normal University, Urumchi 830054, China
§Graduate University of Chinese Academy of Sciences, Chinese Academy of Sciences, Beijing 100049, China

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This paper aims to evaluate the effectiveness of using Landsat ETM+ data to identify the extent and severity of locust damage. Two cloud-free Landsat ETM+ images of the study area, taken before and after peak locust plague, were compared to determine the extent and severity of the 2002 locust plague according to the decrease of the Normalized Difference Vegetation Index (NDVI) derived from the two images. The results showed that the locust plague could be classified into heavy, moderate and light damage degrees based on the NDVI value decrease calculated by each pixel, which further evaluated its accuracy by extensive ground survey data. Locust plague can be identified with 98% and 92% accuracy for determining geographic extent and severity respectively using Landsat ETM+ data.

1. Introduction

The outbreak of oriental migratory locusts, *Locusta migratoria manilensis* (Meyen), has historically been a serious problem in China (Wu 1951). Between 707 BC and 2003, over 1000 locust plagues reportedly occurred (Zhu and Huang 2004). From the 1950s to the 1970s, improved locust control and land use practice virtually eliminated locust plagues in most parts of China (Ma 1960). However, since the 1980s, locust plague has become a serious problem once again, with a severity even greater than before (Zhu 1999). The annual total area affected by summer locusts in China were 1.06, 1.15 and 1.2 million ha. respectively from 2002 to 2004. These recent trends of heightened locust plagues have been mostly attributed to the increasingly dry climate in China (Zhu 2004). Another important factor is a shortage of adequate surveys to detect initial damage and plan appropriate control procedures (Chen 2000). Because of the large geographic scale of locust infestations, ground-based surveys rarely yield sufficient data to accurately analyse locust population dynamics and determine the optimum period for application of control measures (Ji *et al.* 2002).

Remote sensing techniques can greatly facilitate monitoring locust population dynamics on a large geographic scale. The application of such techniques has two

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*Corresponding author. Email: xieby@ioz.ac.cn

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main objectives: (a) early warning, i.e. forecasting regions most likely to be infested; and (b) damage assessment, including identification of the extent and severity of damage. Such information is vital for the implementation of targeted control operations as opposed to the traditional, less effective blanket approach (Ji *et al.* 2002). Remote sensing techniques have been used in locust plague studies since the 1970s. Pedgley first tested the feasibility of detecting locust breeding sites using satellite remote sensing in 1973. Hielkema (1977, 1980) applied Landsat MSS data to a desert locust survey to assess the ecological conditions for desert locust population development. McCulloch and Hunter (1983) used Landsat MSS data to identify and monitor Australian plague locust habitats based on vegetation greenness. Tucker *et al.* (1985) suggested that Landsat MSS and NOAA AVHRR data could offer unique and unprecedented possibilities for examining the ecological conditions of desert locust recession areas. The studies of Bryceson (1984, 1986) and Bryceson and Wright (1989) showed that it was feasible to use Landsat MSS data to detect areas suitable for locust breeding and ovi-positing by monitoring changes in vegetation conditions. Shi *et al.* (2003) used MODIS data to determine the occurrence and extent of locust plague in reed marshes, and used NDVI to evaluate the most optimum areas for locust hatching. Ji *et al.* (2002) used MODIS data to map and classify the areas affected by oriental migratory locust into light, moderate, and heavy damage categories with 88.8% accuracy. Ma *et al.* (2005) studied the spectra of field reeds and the relationship between reed biomass and the Leaf Area Index (LAI) to evaluate the feasibility of using Landsat ETM+ to monitor locust damage.

The remote sensing data used for monitoring locust plagues is mainly from Landsat MSS, MODIS, NOAA-AVHRR. These sensors have a spatial resolution of 78 m, 250 m, 1100 m respectively and temporal resolution of 18 days, 1–2 days, 1 day with 0.6, 6.25 and 121 ha. of each pixel area respectively. Landsat MSS has a high spatial resolution, but its temporal resolution is too low to effectively monitor locust population dynamics. Contrary to Landsat MSS, spatial resolutions of MODIS and NOAA-AVHRR, though being of a higher temporal resolution, are too low to accurately describe locust damage on a local scale. Landsat ETM+/TM have higher spatial and temporal resolutions than Landsat MSS with 30 m, 16-day of spatial and temporal resolutions respectively. Therefore, we can use different Landsat ETM+/TM images to accurately detect the geographic extent of locust damage on a local scale, because the duration from first hoppers to adults is about one month.

The main objective of this study was to evaluate the feasibility of using Landsat ETM+ data to identify the extent and severity of locust damage. The delineation and quantitative estimation of locust damage is based on the vegetation index change. Different vegetation indexes have been used to monitor forest damage caused by insect pests (Nelson 1983, Williams *et al.* 1985, Rock *et al.* 1986, Mukai *et al.* 1987, Vogelmann and Rock 1989). Among those vegetation indexes, the NDVI is the most used for a variety of remote sensing applications because of its high positive correlation with plant biomass, especially for areas with vegetation coverage less than 80% (Kriegler *et al.* 1969, Rouse *et al.* 1973, Lyon *et al.* 1998, Zhao 2004). Ground survey data was also used to verify the reliability of results.

2. Study area description

The study area (38°28.04′ N–38°31.67′ N and 117°28.33′ E–117°31.33′ E), located in Nandagang State Farm, Hebei Province, China is a dry reservoir close to the Bo Sea (see figure 1).

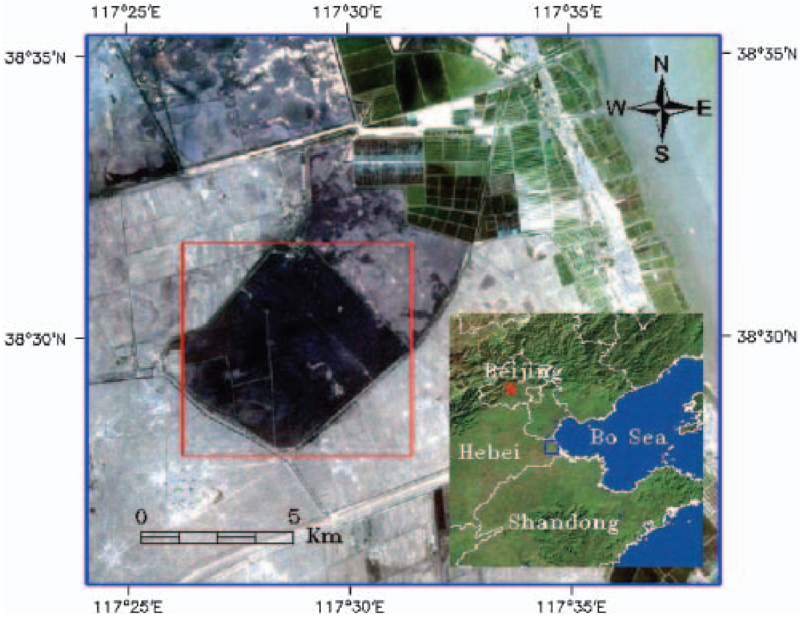

Figure 1. The map of study area (included in red quadrangle).

Apart from low-lying areas during the rainy season, it has been dry since the 1980s. At the time of our study, the average vegetation coverage in areas studied was less than 70%. Natural reeds *P. communis* are the dominant species (more than 99% of the total biomass), interspersed with *Suaeda salsa* (L.) Pall, *S. glauca* (Bunge) Bunge, *M. sacchariflorus* and *Setaria viridis* (L.) Beauv (Ji *et al.* 2002). The state farm has been heavily infested with oriental migratory locusts since the 1980s and is a priority region for locust control and management (Zhu 1999). The densities of gregarious hoppers reached 8000 individuals m^{-2} in 2002, and the area infested approached 2000 ha. which accounted for 68% of the entire reservoir (Ji and Xie 2004).

Oriental migratory locusts have two generations a year in the study area, the first from May to July (called the summer locust), and the second from July to October (called the fall locust) (Ma 1965). Summer hoppers need only about one month to complete their development. Oriental migratory locusts usually have five instars (growth stages). Young hoppers (during the first three instars) remain feeding locally for several days before dispersing to further locations. The more devastating damage is often caused by the 4th and 5th instar gregarious hoppers called bands, and gregarious adults called swarms. By the end of May, 2002, hoppers in the study area were mostly still in the 3rd instar, causing slight damage to the reeds. On 7 June, the hoppers, now in the 5th instar, began causing serious damage to the reeds, and the local government applied a chemical spray to control the plague that day. Many locusts survived however, so a second crop-dusting was applied on 15 June.

3. Materials and pre-processing

Two cloud-free Landsat ETM+ images of the study area before (31 May) and after (16 June) peak damage were acquired to detect changes in vegetation conditions. The two images were first geometrically and atmospherically corrected.

3.1 *Geometric correction*

The image on May 31 (M_1) was rectified to the image on June 16 (M_2) using more than 20 homologous ground control points (GCPs) including road intersections, corners and so on. The image rectification procedure is based on first-order polynomial transformation with an error of <0.04 pixel (1.2 m). After rectification, image M_1 was radiometrically resampled at its initial spatial resolution using cubic convolution re-sampling procedures.

3.2 *Atmospheric correction*

The first step in atmospheric corrections was converting digital numbers (DN) to at-sensor radiance L_{sat}, using the gains and offsets given in image header files (Landsat-7 Science Data User's Handbook 2004). Then, L_{sat} was calibrated to scaled surface reflectance by atmospheric corrections using the Dark Object Subtraction (DOS) approach (Song *et al.* 2001, Soudani *et al.* 2006). We preferred to use the DOS approach, as shown in previous studies, rather than radiative transfer models (such as FLAASH, 6S) because the performance of radiative transfer models is not guaranteed in the absence of aerosol and water vapour content measurements describing the atmospheric conditions simultaneously to the image acquisitions (Teillet and Fedosejevs 1995, Brivio *et al.* 2001, Wang *et al.* 2004, Soudani *et al.* 2006).

3.3 *Ground survey data*

After the second crop-dusting, we recorded the damaged site coordinates using the Global Positioning System (GPS) in an irregular sampling method. The distance between two recording sites varied from 50 m to 100 m and the damaged areas varied from $<100\,\mathrm{m}^2$ to $>3000\,\mathrm{m}^2$. It is hard to record all damaged sites using small intervals (50 m), yet using large intervals (100 m) sometimes misses the more slightly damaged sites. During ground surveys, damaged sites were classified into three categories: (a) heavy damage (70–100% of reed foliage removed and damaged plants clumped at the sampling points); (b) moderate damage (40–70% of reed foliage removed and damaged plants clumped at the sampling points); (c) light damage (10–40% of reed foliage removed and damaged plants clumped at the sampling points).

4. Analysis and results

The extent and severity of locust damage was extracted by comparing the two NDVI images. NDVI is calculated using the following formula:

$$NDVI = \frac{(\rho_{\mathrm{nir}} - \rho_{\mathrm{red}})}{(\rho_{\mathrm{nir}} + \rho_{\mathrm{red}})} \tag{1}$$

where ρ_{nir}, and ρ_{red} are surface reflectance in near infrared and red band of sun spectra, respectively. This formula yields a value that ranges from -1 (usually water) to $+1$ (strongest vegetative growth).

To evaluate the extent and severity of locust plagues based on changes in NDVI values, some factors such as the change of vegetation conditions and the variation of soil moisture during the 16 day period should also be taken into account. Because the study area is a nature reserve, oriental migratory locusts were estimated as the only damage to the reeds. Therefore, the biomass reduction of reeds was attributed only to the locust plagues. Because the NDVI is sensitive to background soil moisture, soil moisture of several sites was measured in the study area on 31 May and 16 June. Results showed that soil moisture had no significant difference between the two days, so the impact of the variation of earth moisture on NDVI values could be dismissed in the study.

The change in vegetation conditions was acquired by subtracting the NDVI image of 31 May from the NDVI image of 16 June pixel by pixel. Positive results indicate that reeds have grown and were not damaged by locusts; while negative results indicate that reed biomass decreased: the more the biomass decreases, the more serious the damage. Figure 2 showed the results, where dark regions were areas damaged by locusts, the more dark, the more serious the damage.

Using ground survey data, the accuracy of the results was evaluated by the extent and severity of locust damaged areas. Figure 2 was classified into three categories according ground survey data (see figure 3):

Heavy damage areas: pixel value $<=-0.1339$.
Moderate damage areas: pixel value from -0.1339 to -0.0716.
Light damage areas: pixel value from -0.0716 to 0.

Comparing the categories and ground survey data, only three sites out of the total 191 ground survey sites fell outside the extent of locust plague derived from this technique, 15 points were classified into the three categories in error. The accuracy for extent and severity of locust damaged areas are 97% and 90%, respectively.

All the above image processing and calculations were carried out with ENVI TM 4.2 software (Research System Inc. Boulder, CO, USA.)

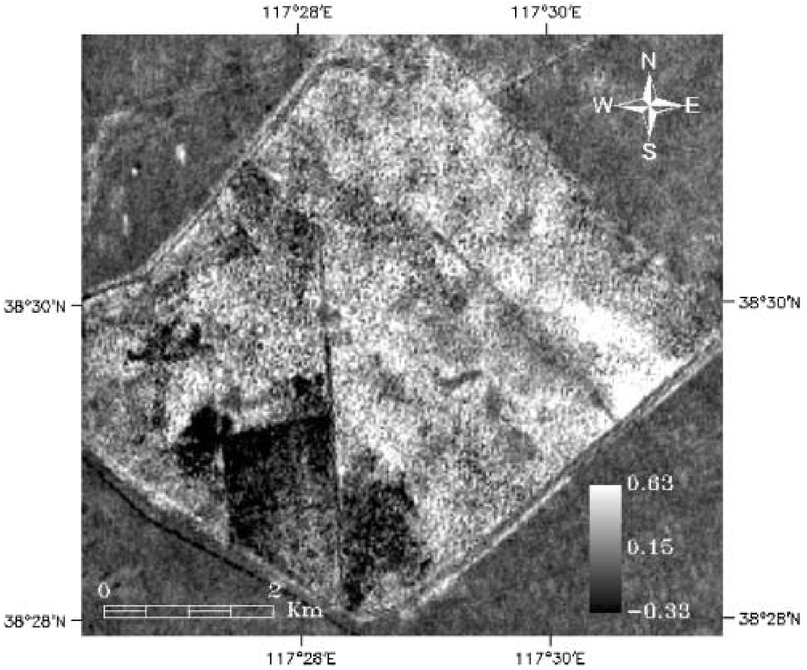

Figure 2. Decrease of NDVI from 31 May to 16 June.

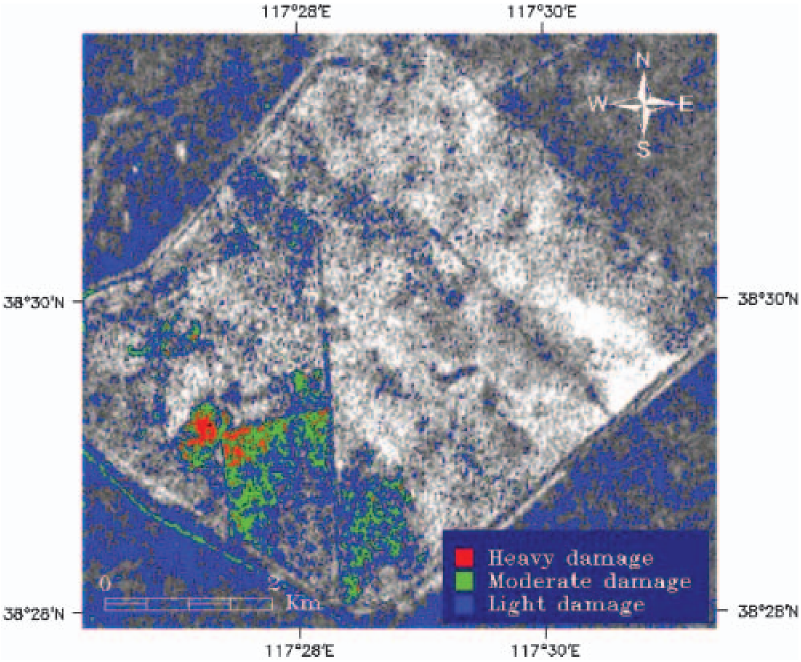

Figure 3. Three categories in locust damaged area. Red for heavily damaged region; Green for moderately damaged region; Blue for light damaged region.

5. Conclusions

The only alternative to remote sensing techniques for monitoring locust plagues is to conduct ground surveys, which being labour-intensive and time-consuming, generally cannot be collected quickly enough for effective control operations (Ji and Xie 2004). The results of this study showed that using Landsat ETM+ data to monitor the plague of oriental migratory locusts could obtain higher accuracy (>90%) in extent and severity compared with the results of previous studies.

6. Discussion

With the development of remote sensing techniques, a number of new remote sensing satellites using high spatial and temporal resolution such as IKONOS, QUICKBIRD, IRS-P6 and SPOT-5 have been launched, creating the potential to improve monitoring accuracy in real-time. However, images acquired by these satellites are affected by weather conditions to a large extent. Radar imagery has all-weather, day–night capability enabling it to overcome above limitations. Still, radar imagery has high spatial and temporal resolutions (such as RADARSAT-1, ENVISAT-1). By improving resolutions of satellites, remote sensing techniques can quickly be used to identify damaged areas and precisely estimate the extent and severity of locust damage. Also, the delineation of breeding grounds of locusts should be attempted so that the same may be used for forecasting regions most likely to be damaged by locust populations.

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