Journal of Environmental Management xxx (2016) 1–14

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Timely monitoring of Asian Migratory locust habitats in the Amudarya delta, Uzbekistan using time series of satellite remote sensing vegetation index

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A R T I C L E I N F O

Article history:
Received 21 March 2016
Received in revised form
20 August 2016
Accepted 1 September 2016
Available online xxx

Keywords:
Aral Sea
Land cover change
Locust management
MODIS
Random forest
Reeds
Satellite earth observation

A B S T R A C T

The Asian Migratory locust (*Locusta migratoria* migratoria L.) is a pest that continuously threatens crops in the Amudarya River delta near the Aral Sea in Uzbekistan, Central Asia. Its development coincides with the growing period of its main food plant, a tall reed grass (Phragmites australis), which represents the predominant vegetation in the delta and which cover vast areas of the former Aral Sea, which is desiccating since the 1960s. Current locust survey methods and control practices would tremendously benefit from accurate and timely spatially explicit information on the potential locust habitat distribution. To that aim, satellite observation from the MODIS Terra/Aqua satellites and in-situ observations were combined to monitor potential locust habitats according to their corresponding risk of infestations along the growing season. A Random Forest (RF) algorithm was applied for classifying time series of MODIS enhanced vegetation index (EVI) from 2003 to 2014 at an 8-day interval. Based on an independent ground truth data set, classification accuracies of reeds posing a medium or high risk of locust infestation exceeded 89% on average. For the 12-year period covered in this study, an average of 7504 km^2 (28% of the observed area) was flagged as potential locust habitat and 5% represents a permanent high risk of locust infestation. Results are instrumental for predicting potential locust outbreaks and developing well-targeted management plans. The method offers positive perspectives for locust management and treatment of infested sites because it is able to deliver risk maps in near real time, with an accuracy of 80% in April-May which coincides with both locust hatching and the first control surveys. Such maps could help in rapid decision-making regarding control interventions against the initial locust congregations, and thus the efficiency of survey teams and the chemical treatments could be increased, thus potentially reducing environmental pollution while avoiding areas where treatments are most likely to cause environmental degradation.

1. Introduction

Locusts are one of the most devastating agricultural pests in the countries of the former Soviet Union, particularly Russia, Kazakhstan (Latchininsky, 2000), and Uzbekistan (Sivanpillai and Latchininsky, 2007). They represent a major threat for agricultural production such as cotton and wheat, and have caused substantial monetary damages in the past. In Kazakhstan for instance, a locust outbreak in 1999 resulted in the destruction of 2200 km^2 of grain crops at an estimated cost of USD 15 million (Latchininsky, 2013).

The breeding habitat of the Asian migratory locust *Locusta migratoria migratoria* (LMI), the main locust species in that region, are stands of the common reed (*Phragmites australis*). They can be found along rivers such as Volga, Amudarya, Syrdarya, Ural, and Ili

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http://dx.doi.org/10.1016/j.jenvman.2016.09.001
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and around vast lakes such as the former Aral Sea, Balkhash, Alakol, and Zaisan (Tsyplenkov, 1970). Outbreaks are usually preceded by abnormally dry years and as larger breeding areas, i.e. reeds are not flooded, the suitable habitats for oviposition expand. Locust control services in Uzbekistan seek to prevent the development of dense swarms that are capable of emigration flights from the Amudarya delta near the Aral Sea toward crop areas (Latchininsky and Gapparov, 2010). Survey teams monitor the spatial distribution and temporal development of reed vegetation and water surfaces and, if necessary, spray insecticides.

The Amudarya delta has an area of more than 10,000 km^2 (Latchininsky et al., 2007). During outbreaks the area of reeds treated with insecticides exceeds 5000 km^2 (Sivanpillai and Latchininsky, 2007). Due to the large extent of the potentially infested area, insufficient road infrastructure and resources such as vehicles and personnel, *in-situ* surveys can be conducted on a limited portion of the delta only. Although the desiccation of the Aral Sea (Micklin, 2010) caused a severe reduction in reed areas in the Amudarya delta (Gapparov and Latchininsky, 2000) ground surveys by locust control units remain an extremely difficult, costly, and time-consuming task. Annual and seasonal changes in hydrology create a very dynamic locust habitat (Löw et al., 2013b), complicating the planning of ground surveys.

Thus, to assess locust risks and develop preventive measures, data on land cover habitat conditions are needed over large and partly inaccessible areas (Latchininsky, 2013). Remote sensing, in terms of satellite image data, can be instrumental in addressing the challenge of scale. Several studies have demonstrated the general usefulness of multi-spectral space-borne sensors for mapping vegetation cover and land cover types over large areas (Friedl and McIver, 2002; Hüttich et al., 2011; Klein et al., 2012). Most accurate results were usually created by classifying multi-temporal satellite imagery with non-parametric machine learning algorithms like random forest (RF), support vector machines (SVM), or artificial neural networks (Duro et al., 2012; Huang et al., 2002; Rodriguez-Galiano et al., 2012a; Shao and Lunetta, 2012). As locusts themselves remain undetectable with the current spatial resolution commercial satellites (Kibasa, 2006), remote sensing-studies focused on mapping theirs potential habitats (Latchininsky et al., 2007; Pekel et al., 2011; Piou et al., 2013; Renier et al., 2015; Sivanpillai and Latchininsky, 2007). High spatial resolution data like multispectral Landsat TM/ETM$^+$ (30 m) or SPOT-HRG (between 2.5 and 20 m) have successfully been used to create annual maps of reeds (Navratil and Wilps, 2013; Sivanpillai et al., 2006). However, data sets from the aforementioned sensors cover only a small area (185 × 180 km for Landsat TM/ETM+, 60 × 60 km for SPOT HRG). Even more limiting for monitoring of seasonal developments is their low and often irregular revisit frequency of just a few cloud-free scenes per year. Multi-spectral satellite data with high-frequency revisit are more useful for timely seasonal monitoring of locust habitats at the regional scale (Sivanpillai and Latchininsky, 2007). The Moderate Resolution Imaging Spectroradiometer (MODIS), for instance, combines the above-described aspects, acquiring spectral information in 36 bands from the visible blue to the thermal infrared, at least one image per day at the latitude of the study area. Two of the instruments bands, red and near infrared, have a moderate spatial resolution of 250 m which is still sufficient for identification of reeds, other vegetation compositions and water surfaces (Löw et al., 2013b; Sivanpillai and Latchininsky, 2007). Previous studies have in common that they created only one map of locust habitats and with classification accuracies remaining moderate, for example 76% (Propastin, 2012), 74% (Sivanpillai and Latchininsky, 2007), 80% (Löw et al., 2013b), and 79% (Sivanpillai et al., 2006).

However, a higher accuracy and spatial representation of classification uncertainty in the map (Foody, 2002) would more useful for management practices (Loosvelt et al., 2012b; Löw et al., 2015b). Further, key to locust management is the availability of maps within the growing season and over many years. In the case of Desert Locust, Pekel et al., 2011 developed a methodology for mapping the potential locust habitat over its entire distribution area every ten days. These maps are operationally produced and used in the daily operations by the National Locust Control Centres and by the Food and Agriculture Organization (FAO) which coordinates the activities. To further reduce the survey costs, Renier et al. (2015) proposed a method for identifying areas becoming less-favored for the locust populations, i.e., not worthy of surveying as locust are likely to leave. Likewise, seasonal re-flooding of dry reed stands, which lowers the potential of reed stands to become a source for locust outbreak, should be assessed in the Amudarya delta.

Because traditional ground monitoring methods can hardly achieve the task for monitoring LMI habitats in such an enormous area like the Amudarya delta, developing a cost effective system for a near-real-time risk assessment of locust emergence is of utmost importance. Satellite earth observation may play a major role in providing timely and reliable maps of the reed spatial and temporal distribution (Latchininsky, 2013). This in turn could contribute to reducing the agriculturists' exposure to locust outbreaks (Latchininsky, 2013). The aim of this study is thus to provide maps of vegetation types, based on satellite remote sensing, with a particular emphasis on reed growth and water distribution because both affect the presence and abundance of locust. This information will be provided on an 8-day basis and eventually enable locust control units to target high-risk areas for locust outbreaks, to guide their specialists in the field and plan adequate insecticide treatments based on the current state of the growing season, instead of the current cost-ineffective practise of blanket surveys.

2. Methods and materials

2.1. Study area

The Amudarya River delta extends South of the former Aral Sea shoreline and consists of numerous channels, ponds, lakes, large and small rivulets and islands. For the scope of this study, an area of 26,837 km^2 was selected. This area belongs to the autonomous republic of Karakalpakstan, which is part of Uzbekistan. It includes the northern portion of the delta and adjoining sandy areas, as well as the southern portion of the desiccated Aral Sea (Fig. 1A). Climate is strongly continental with low annual precipitation of 106 mm. With the recession of the Aral Sea extended areas with saline soils, nowadays called Aralkum desert (Breckle et al., 2012), are present.

The common reed is a perennial grass that overwinters at a rhizome state. Above-ground growth resumes in late April or early May, reaching its maximum height of up to 6 m within 6–8 weeks (Sivanpillai and Latchininsky, 2007). Flowering begins in July, and senescence starts in late August or early September. By the end of October, the aboveground reed vegetation withers, but dead dry stems often remain standing through the winter.

Locusts are grasshopper species capable of expressing phase polyphenism, a form of phenotypic plasticity (Latchininsky, 2010). An increase in local population density, triggered by precipitation and vegetation development within favourable breeding areas (Latchininsky, 2010), favours inter-individual contacts and therefore gregarization (Latchininsky, 2013; Piou et al., 2013). The life cycle of the Asian Migratory locust, is closely synchronized with the development of the common reed as its primary host plant (Novityky, 1963). Locusts use sandy river banks as oviposition sites, and exploit the reeds for food and helter. Hatching occurs in late