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Research article

The influence of landscape's dynamics on the Oriental Migratory Locust habitat change based on the time-series satellite data

Yue Shi [a, b], Wenjiang Huang [a, *], Yingying Dong [a], Dailiang Peng [a], Qiong Zheng [a, c], Puyun Yang [d]

[a] Key Laboratory of Digital Earth Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Science, Beijing 100094, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] College of Geoscience and Surveying Engineering, China University of Mining and Technology (Beijing), Beijing 100083, China
[d] National Agro-technical Extension and Service Centre, Ministry of Agriculture, Beijing 100026, China

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ABSTRACT

Landscape structure and vegetation coverage are important habitat conditions for Oriental Migratory Locust infestation in East Asia. Characterizing the landscape's dynamics of locust habitat is meaningful for reducing the occupation of locusts and limiting potential risks. To better understand causes and consequences of landscape pattern and locust habitat, it is not enough to simply detect locust habitat of each year. Rather, landcover transitions causing the change of locust habitat area must also be explored. This paper proposes an integrated implement to quantify the influence of landscape's dynamics on locust habitat changes based on three tenets: 1) temporal context can provide insight into the land cover transitions, 2) the detection of locust habitat area is operated on patches rather than pixels with full consideration of landscape's ecology, 3) the modeling must be flexible and unsupervised. These ideas have not been previously explored in demonstrating the possible role of changes in landscape characteristics to drive locust habitat transitions. The case study focuses on the Dagang district, a hot spot of locust infestation of China, from 2000 to 2015. Firstly, the seasonal characteristics of typical landcovers in NDVI, TVI, and LST were extracted from fused Landsat-MODIS surface reflectance imagery. Subsequently, a landscape membership-based random forest (LMRF) algorithm was proposed to quantify the landscape structure and hydrological regimen of locust habitat at the patch level. Finally, we investigated the correlations between the specific landcover transitions and habitat changes. Within the 16 years observations, our findings suggest that the sparse reeds and weeds in the vicinity of beach land, riverbanks, and wetlands are the dominant landscape structure associated with locust habitat change ($R^2 > 0.68$), and the fluctuation in the water level is a key ecological factor to facilitate the locust habitat change ($R^2 > 0.61$). These results are instrumental for developing precision pesticide use to reduce environmental degradation, and providing positive perspectives for ecological management and transformation of locust habitats.

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1. Introduction

The Oriental migratory locust (*Locusta migratoria manilensis*) is one of the most critical pests plaguing in East Asia, severely threatening the ecology and agriculture (Ji et al., 2006). Unlike the traditional insects with host specificity, locust development requires suitable landscape pattern and vegetation conditions within favorable breeding area, which lead to a “hot spot” effect on locust habitats, thus, an increase in local population density promote inter-individual contacts, gregarization, and migration, and further results in a severe impact on a larger area (Despland et al., 2004). China is one country suffering from serious locust calamities (Zhang and Li, 1999), especially in the region of North Dagang Reservoir of Tianjin, a hot spot of locust infestation on North of China, where the conditions are ideal for locust breeding due to reduced river and reservoir levels and an increase in abandoned farmland since the mid-1990's (Tong et al., 2006). Owing to the

* Corresponding author.
E-mail addresses: shiyue@radi.ac.cn (Y. Shi), huangwj@radi.ac.cn (W. Huang), dongyy@radi.ac.cn (Y. Dong), pengdl@radi.ac.cn (D. Peng), yangpy@agri.gov.cn (P. Yang).

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strong capacity of migration, the outbreaks of locusts in Dagang district frequently result in serious crop yield losses and ecological degradation in the entire North China Plain (Bian and Zhang, 2001; Zhang and Li, 1999). According to the statistics from the Plant Protective Station of Tianjin (TPPS), annual plague area of summer and autumn locust in Dagang was greater than 20,000 ha from 2000 to 2015, and locust density in severe plague years were recorded as high as 4000–5000 per square meter in localities that suffered from the attacks (http://www.tjpps.cn/), suggesting that the trend of heightened locust plague has been mostly attributed to the increasingly dry climate and landscape dynamics (Scanlan et al., 2001). Oviposition and development of locust are generally preceded by specific landscape structure and habitat conditions, such as favorable host components, suitable vegetation coverage, and hot soil temperature. Locust control services in China seek to prevent the development of dense swarms that area capable of emigration flights from the Dagang district near the Bohai bay toward the North China Plain (Ma et al., 2004), which requiring comprehensive understanding of the influence of landscape ecological dynamics on locust habitat change.

The Dagang district has an area of more than 900 km^2, the traditional locust infestation area exceeds 500 km^2 (Ma et al., 2004). As a result of ecological transition, the novel emerged locust habitat in the past decade approximately 120 km^2 (Liu et al., 2006). Due to the large extent of the potentially infested area, conventional approaches for locust habitats monitoring based on regular manual investigations of potential breeding areas are usually inadequate to capture the landscape pattern of locust habitat over the large areas (Ji et al., 2004). On the other hand, the interannual habitat change is affected by landcover transition, climate variation, and anthropogenic activities (Crooks and Cheke, 2014; Despland et al., 2004; Müller, 1976), making it more difficult to quantificationally uncover the influence of landscape's dynamic on habitat change based on the manual investigations.

To monitoring the annual locust habitat in Dagang district and assess the influence of landscape dynamics on locust habitat change, data on landcover habitat conditions area needed over large and inaccessible areas. Satellite-based remote sensing technology, that has been proven to be instrumental in addressing the challenge of scale (Ji et al., 2004), is capable of monitoring and tracking changes on landscape pattern, and detecting the cause and consequence of these changes which affected the habitat conditions for locust breeding. The spatio-temporal information provided by the single use of Landsat or MODIS imagery, however, was rarely implemented in remote monitoring of locust hot spots because of the limitations on spatial resolution and revisit frequency (Zhan et al., 2002; Hansen and Loveland, 2012). Before more advanced sensors with higher spatial resolution and revisit cycles become available, image fusion techniques must be used to provide a timely and spatially continuous overview of the habitat factors over large area for bridging merits of MODIS and Landsat data (Sun et al., 2013; Moosavi et al., 2015; Park and Na, 2007; Swathika and Sharmila, 2017). In some cases, the applications of fused satellite data for monitoring changes of land cover and temperature at the regional scale had been reported (Butt et al., 2015; Sobrino et al., 2004; Sun and Schulz, 2015; Zewdie and Csaplovies, 2015).

For the satellite-derived detection and analysis of locust habitat change, full characterization of change requires not just detection of a change, but also an understanding of the proximal cause of change. Therefore, linking the landscape dynamics caused by landcover transitions, climate changes, or human activities to locust habitat change at the patch scale is also a challenge for quantifying the influence of landscape dynamics on locust habitat change over large area (Liu et al., 2008; Tian et al., 2008). By extracting locust habitat area and detecting those landscape changes in a consistent manner, remote sensing may provide insight into the proximal landscape's ecological characteristics associated with locust habitat change over large and partly inaccessible areas (Li et al., 2008).

In this study, attribution at the pixel scale may not work, because many landscape structure changes exert influence over a geographic patch within which a suite of pixel-scale factors transitions might jointly affect the formation of locust habitat. Therefore, method should be patch based, flexible enough to define diverse ecological factors, and able to incorporate temporal information to capture the distribution and annual dynamics of locust habitat. In this paper, we extend the application of data fusion down to sub-field scales for locust habitat extraction over Dagang district. The contributions of this research are to detect the spatial distribution of locust habitats, and to understand the cause and consequence of locust habitat change affected by the landscape dynamics, such as landcovers transition, vegetation composition variation, and land temperature change, at an annual time step from 2000 to 2015. Specifically, this paper aims: 1) to generate and evaluate seasonal characteristics of the indices derived from the fusion of Landsat-MODIS reflectance data, including triangular vegetation index (TVI), normalized difference vegetative index (NDVI), and land surface temperature (LST); 2) to propose a LMRF algorithm to extract annual locust habitat area at the patch scale; 3) to quantify the influence of landscape dynamics on locust habitat change, and provide suggestions for ecological management of locust habitats.

2. Materials and methods

2.1. Study area

Bordering Bohai Bay to the east, the study area is located in Dagang district (38°32′–38°57′N, 117°13′–117°37′ E), in Tianjin Municipality, China (Fig. 1), where is a typical hot spot of Oriental Migratory Locust in North China Plain. For the scope of this study, an area of 909.2 km^2 was selected. This district lies in a warm temperate continental monsoon climate zone. Fluvo-aquic soils are the most widely distributed soil type. Numerous water resources, including Dagang reservoir, Duliujian river, and Lier bay, provide ideal conditions for the local wetland vegetations: reeds (*Phragmites communis trin*), Suaeda salse (L.) Pall, *Carex* sp., and *Miscanthus sacchariflorus* (Maxim.) Benth. These locations frequently suffered from droughts in spring and water-logging in summer, Common reed growth in late April, reaching its maximum vegetation coverage in the period of June to August, and senescence starts in early September. By the mid October, the common reed withers, but the dry stems remain standing through the winter. These ecological conditions provide an adequate habitat conditions for locust growth and propagation, leading to severe plagues taking place in Dagang district. Moreover, an increase in local population density facilitates inter-individual contacts and gregarization (Latchininsky, 2013), and the strong capacity of the swarm migration further impacts the ecological environment and agricultural production in North China.

2.2. Data acquisition

2.2.1. Statistics on plagues of oriental migration locusts

Tianjin Plant Protection Station (TPPS) investigated the cumulative progress of major locust outbreak areas at their key growth stages from 2000 to 2015. Considering that these data are proprietary, the specific investigation sites and the ID numbers are not provided by TPPS. For this reason, the study mainly relies on the published district-level statistic data. According to these

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