Advances in Entomology, 2015, 3, 6-15
Published Online January 2015 in SciRes. http://www.scirp.org/journal/ae
http://dx.doi.org/10.4236/ae.2015.31002

Location and Characterization of Breeding Sites of Solitary Desert Locust Using Satellite Images Landsat 7 ETM+ and Terra MODIS

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Received 13 December 2014; accepted 6 January 2015; published 16 January 2015

Abstract

In the southern Algerian Sahara, populations of the desert locust have been monitored during the past 43 years. On a limited study area, the use of remote sensing data from Landsat 7 ETM+ and Terra MODIS, coupled with the locust population database, allowed the identification and mapping of solitary desert locust breeding areas during remission periods. These sites are mainly located in wadis and in areas of accumulation/spreading of rainwater. The use of this methodology to all the Algerian Sahara is surely possible in order to improve the preventive management of this pest.

Keywords

Desert Locust, *Schistocerca gregaria*, Remote Sensing, Modis, Landsat, Early Warning

1. Introduction

The desert locust, *Schistocerca gregaria* (Forskål, 1775), is a dreaded insect because of the extent of damage it can inflict on agricultural production and of the socio-economic disruptions that may result [1] [2]. The consequences of its invasions can be disastrous for food security of many states in affected areas in Africa and Asia [3]. In addition, large amounts of chemical insecticides commonly used for control operations can result in se-

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How to cite this paper: Lazar, M., Diongue, A., Yang, J., Doumandji-Mitiche, B. and Lecoq, M. (2015) Location and Characterization of Breeding Sites of Solitary Desert Locust Using Satellite Images Landsat 7 ETM+ and Terra MODIS. *Advances in Entomology*, **3**, 6-15. http://dx.doi.org/10.4236/ae.2015.31002

rious damage to the environment [4]. Respectively 26 and 13 million hectares have been treated to stop the last two major invasions of 1987-1988 and 2003-2004 [5].

The natural risk posed by these locust invasions can be effectively managed by the application of a preventive control strategy based, in particular, on the monitoring of potential risk areas, the outbreak areas [6] [7]. It is within these gregarious areas that conditions favorable for the departure of an outbreak and an invasion are most frequently encountered. The preventive control strategy involves early warning and rapid response capacities of all the countries with outbreak areas of this locust. This involves the regular monitoring of environmental conditions in outbreak areas, the estimation of the level of locust populations, as well as the implementation of preventive control measures against the very first gregarious populations. This strategy was recommended by the Food and Agriculture Organization of the United Nations (FAO) as early as the 1960s [8]-[13]. The required capacities have been developed gradually and implemented—to varying degrees—in most countries with outbreak areas [1] [2]. In parallel and gradually, the areas to be monitored have been reduced from 31 million km^2 of the invasion area to 15 million km^2 of the recession area and 250,000 km^2 of the outbreak areas. It has moved from a large area where all efforts may seem vain, to a much smaller area where the implementation of a preventive strategy becomes possible [7].

However, access to these areas located in the Saharan zone is difficult, and the areas to be monitored are still very large. The main concern of desert locust control units is to do this monitoring in the shortest time by optimizing routes prospecting of ground crews [14]. Early identification of breeding (maturation of groups of solitary adults as a result of favorable ecological conditions, egg laying and hopper development) is particularly crucial to have a chance to conduct effective preventive treatments before the first gregarious swarms disperse [6].

The use of satellite remote sensing technology has raised many hopes for forty years to support locust monitoring [15]-[20]. The research has focused mainly on locust species worldwide, *Locusta migratoria* [21], *Chortoicetes terminifera* [22], *Rhammatocerus schistocercoides* [23] and *Nomadacris septemfasciata* [24], but also on various grasshoppers species [3] [25]. For the desert locust, these techniques can in theory allow researchers, firstly, to better locate and map potential areas for reproduction and gregarization, and secondly, to identify in real time the appearance in these areas of suitable ecological conditions for breeding (rain, runoff and development of green vegetation), well before the first signs of gregarization [7] [26]. To date, however, there is no direct operational application based on remote sensing to guide ground surveillance teams of the desert locust [27].

Various studies are underway to try to improve the real-time detection of favorable ecological conditions, mainly green vegetation. These studies are based on Terra-MODIS and SPOT-VEGETATION images [28], and they try to solve problems related to low vegetation cover in Saharan environments [29]. In addition, all areas, even covered with vegetation, are not all equally favorable. The most potentially suitable habitats are grouped within the outbreak areas and represent a small fraction of those areas. Regarding mapping of the potentially favorable areas, some studies using high-resolution satellite imagery (1 pixel = 20 m side) have resulted in a spatial delineation of habitats of the desert locust. The works of Dreiser [30], Voss and Dreiser [31] and Dreiser *et al*. [32]-[35] based on analysis of Landsat images provide a first attempt to map locust habitats. However, these maps are not related to the probability of reproduction and gregarization of solitary populations. It is more maps of vegetation development at a given time and not real maps of locust habitats. Any operational use is illusory. Habitat maps of the desert locust by Popov [36] were designed thanks to the large field experience of this scientist, but without use of satellite imagery. Recently, Piou *et al*. [37] analyzed, in Mauritania, the relationship between historical prospection data of desert locust observations from 2005 to 2009 and spatio-temporal statistics of a vegetation index (NDVI) gathered by remote-sensing (MOD13Q1 from MODIS satellite) with the help of multiple models of logistic regression. The multi-model framework showed that vegetation development in a month and a half before the survey was amongst the best predictors of locust presence.

The main objective of this work, carried out on a pilot area in southern Algerian Sahara, is to integrate data from locust monitoring during the past 43 years, with remote sensing multispectral data of high resolution to locate, characterize and map the main breeding areas of solitary populations during remission periods, and thus to highlight the main sites to be preferentially monitored—if ecological conditions become favorable—through prevention operations during remission periods.

2. Methodology

2.1. Study Area

A pilot area was chosen for this study in the southwest of the Hoggar, in the region of Tamanrasset, which contain the largest number of square degrees with a high frequency of reproduction of the desert locust in its solitary phase (**Figure 1**). The pilot study is a permanent habitat for the desert locust.

2.2. Locust Data

The National Institute of Plant Protection performs regular monitoring of desert locust populations across the Algerian territory and especially throughout the recession area located in the Saharan zone. Data collected are density and age of locust populations, their phasis status (solitarious, transient, gregarious) and some environmental parameters particularly vegetation. These data are stored in the RAMSES database (Reconnaissance and Monitoring System of the Environment of Schistocerca) implemented by desert locust Information Service of FAO [38] in all the countries concerned by desert locust survey and preventive control. RAMSES is a computerized GIS-based application through which any user can store, view and retrieve desert locust related information at a national scale. This RAMSES basis for Algeria has more than 35,000 records resulting from surveys carried out in the field from 1965 to 2008. Data refer to geographical location of the surveyed areas (geographic coordinates), locust populations (density, biological state, phasis status) and various environmental parameters. From this basis it was possible to identify and map all the sites where reproduction of solitary populations were observed (only the egg laying females, hoppers as well as control operations against concentrations of solitary locust populations were used as an index of breeding).

2.3. Satellite Data

Satellites data of March 2005 issued from Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) and from Terra Modis (Moderate-resolution Imaging Spectroradiometer) have been downloaded from the following sites: http://glcf.umd.edu/data/landsat/ and http://iridl.ldeo.columbia.edu/maproom/Food_Security/Locusts/index.html. Mapping and satellite image processing were performed by the software ENVI 4.6 and ArcView 3.4. The base map used is from the National Geographic Institute (IGN) in Paris at the scales of 1:1,000,000 and 1:500,000.

2.4. Data Analysis

The difficulties related to the spectral characteristics of desert environments have necessitated the development of a specific methodology to bring out the breeding sites of the desert locust in its solitary phase. Vegetation was not useful as, in arid areas, it has often a reduced photosynthetic activity. Some dry years, there is virtually no

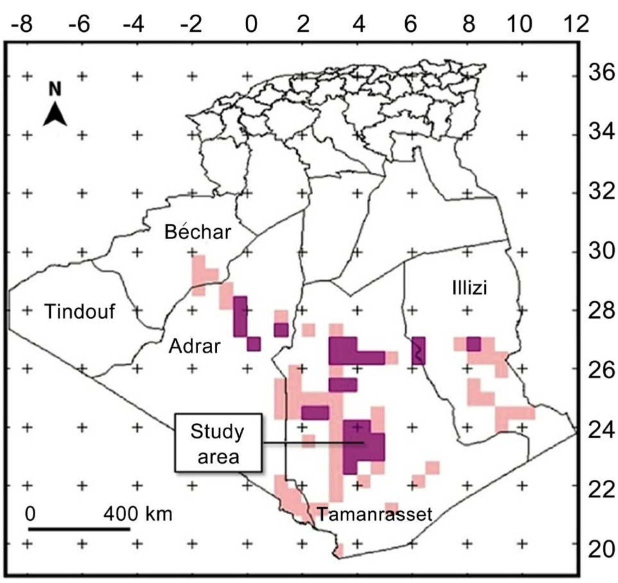

Figure 1. Distribution of quarter degree squares with a high frequency of reproduction of solitary locust populations (dark pink: high frequency; light pink: average frequency).

herbaceous annuals (coverage rate close to zero), and woody perennial species remain dry for months. And thus, for locust breeding areas there is rarely a specific spectral pattern. To overcome the difficulties in vegetation mapping, we looked for correlations between the breeding zones of solitary locusts (identified from the RAMSES database) and some easily identifiable geomorphological features using satellite imagery (**Figure 2**). However, the desert areas are characterized by soils generally highly reflective, mainly composed of silica sand and of limestone or gypsum fragments. In addition, they are often dry in surface. For this reason, it was impossible to separate the egg laying sites from other desert habitats (sand dunes, rocky plateaus, bare soil) from a simple classification (supervised or not) because of the reflectance values almost identical for the various layers (**Figure 3**). For all these reasons, and in order to overcome the difficulties related to the nature of the desert, mapping of breeding and egg laying sites required the use of both Terra MODIS and Landsat 7 ETM+ data, and specific digital treatments to optimize satellite images display. The various treatments carried out and the results obtained are described below.

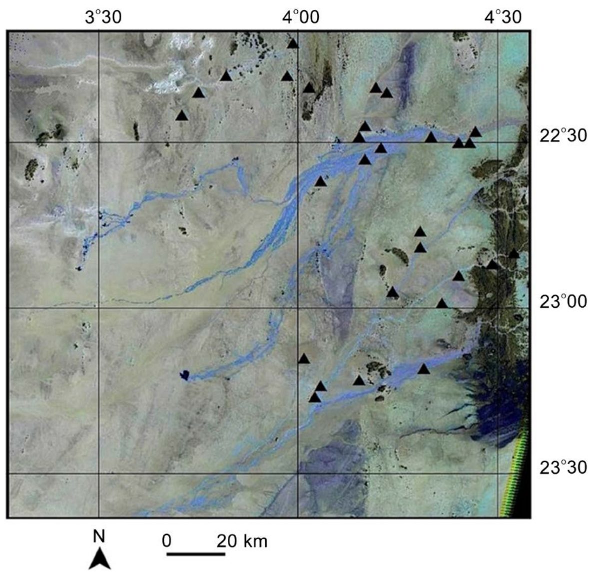

Figure 2. Location of breeding sites on an image of Landsat 7 ETM+ of the study area. The triangles represent sites where solitary laying females were observed during the past 43 years (1965-2008).

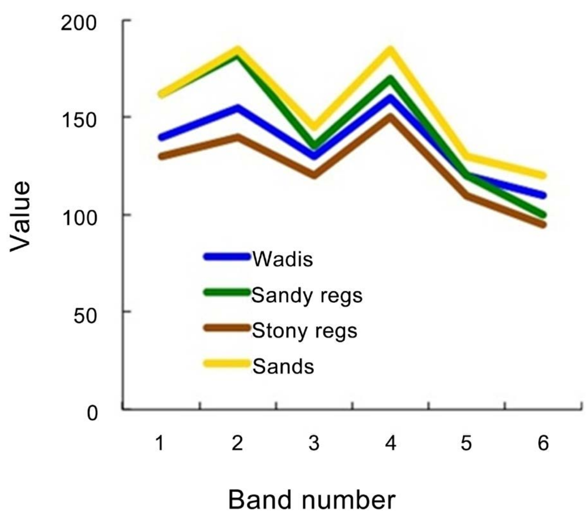

Figure 3. Spectral profiles determined from Landsat 7 ETM+ on wadis, stony regs, sandy regs and sandy soils.

3. Results

In the Saharan zone, it is known that the presence of various mountain ranges proves to be crucial to the locust by the wadis networks associated [39]. These wadis concentrate rainwater and can create conditions for locusts breeding, and this even in case of light rains. Thus, the main mountain ranges that form the main water supply of breeding areas for solitary populations of desert locust in southern Algeria were first mapped by using MODIS images at 250 m resolution. The technique of equal density classes was applied to the MODIS image in order to transform grayscale areas into colour ranges. This treatment transforms the image into RGB (red, green, blue) areas where similar spectral behavior appears in the same color. The highest mountain ranges were displayed with the same color. This color was transformed into a vector, exported and overlaid on a topographic map for identification of mountains (6 in total: 4 in the center of the Algerian Sahara, 1 at the border with Mali and 1 at the border with Niger) (**Figure 4**).

The breeding sites of solitary desert locusts were then superimposed on the map of the mountains. These sites are grouped into 85 quarter degree squares with an annual breeding frequency high or very high. This overlay allowed identifying five breeding areas under the influence of mountains: Hoggar, Ahnet and Assedjrad, Mouydir, Tassili n'Ajjer, and Adrar des Iforas (**Figure 4**). This location of high frequency breeding areas near the mountains is logically explained by the fact that the hydrographic network and the wadis with sandy soil or sandy-clay soils favor locust breeding. These wadis become favorable for breeding when they receive and accumulate rainwaters from the mountains.

The Landsat 7 ETM+ data were then used to map geomorphologic features and to especially identify the wadis where the breeding sites of solitary desert locusts are located. Several treatments have been necessary to separate wadis from other geomorphological structures due to the similarity of their reflectance. The six bands of Landsat 7 ETM+ were first loaded and displayed in composite color using channels 4, 3 and 2, respectively, infrared, red and green (**Figure 5**). A principal component analysis on the six original bands of Landsat 7 ETM+ has reduced the information contained in the six original bands, highly correlated, to only 3 components. This mathematical transformation produces a new image, accentuating the contrast of the original image, and making a much easier geomorphological interpretation (**Figure 6**).

A supervised classification allowed the extraction and mapping of the major wadis in the region (**Figure 7**). It is clear that the quarter degree squares with a high frequency of locust breeding are those containing many wadis and structures of various sizes (**Figure 8**). This layer "wadis" was then transformed into a vector, exported and superimposed on a topographical map for checking (**Figure 9**). We observed a perfect overlay of medium and large wadis mapped with those observed on the topographical map. Only small wadis were not visible on the satellite image, probably as a result of the low 30-meters resolution of Landsat 7 ETM+.

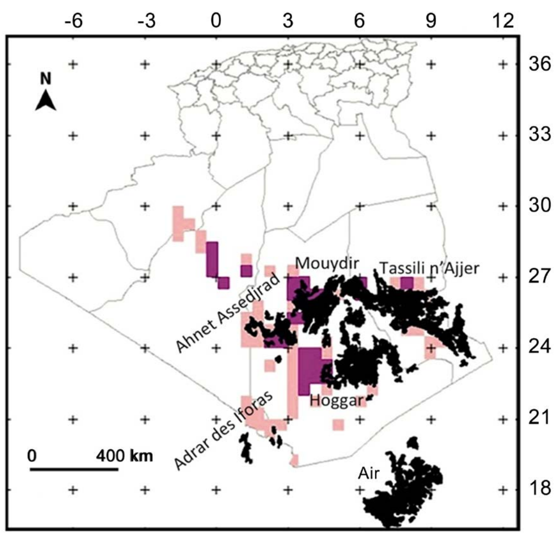

Figure 4. Location of egg laying sites of solitary desert locusts in the Algerian Sahara. Mountains are in black; breeding sites correspond to quarter degree squares coloured in light pink or dark pink.

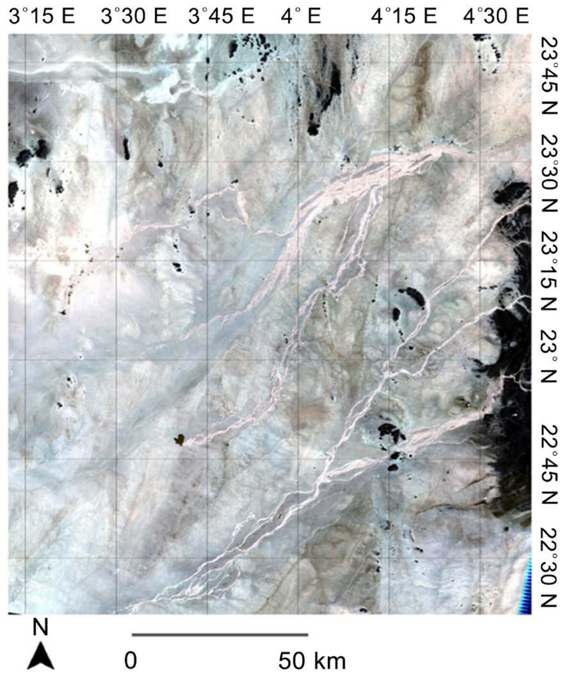

Figure 5. Colourful composition of bands 4, 3 and 2 of a Landsat 7 ETM+ image of 21 March 2005 in south western Hoggar (Tamanrasset region).

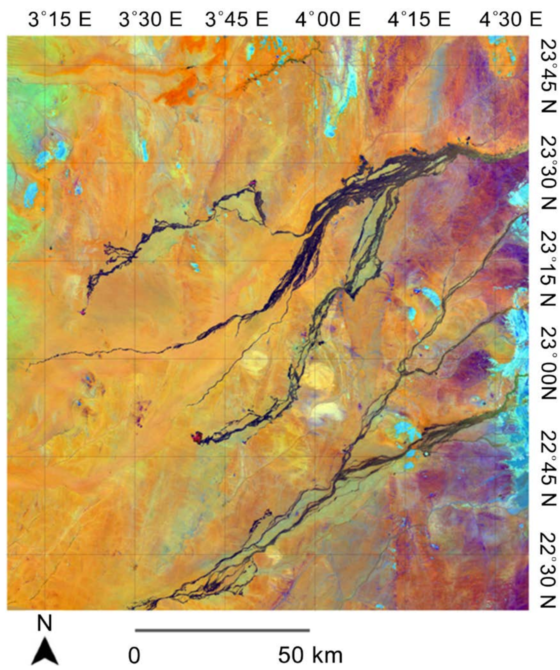

Figure 6. Image of the main component by treating 6 channels of the Landsat 7 ETM+ bands 1, 2, 3, 4, 5 and 7 in south western Hoggar (Tamanrasset region).

4. Discussion

This work shows the potential of Landsat 7 ETM+ images to map the main breeding areas of the desert locust in its solitary phase. Much work has been done in the past on the characterization of habitats of this species by the

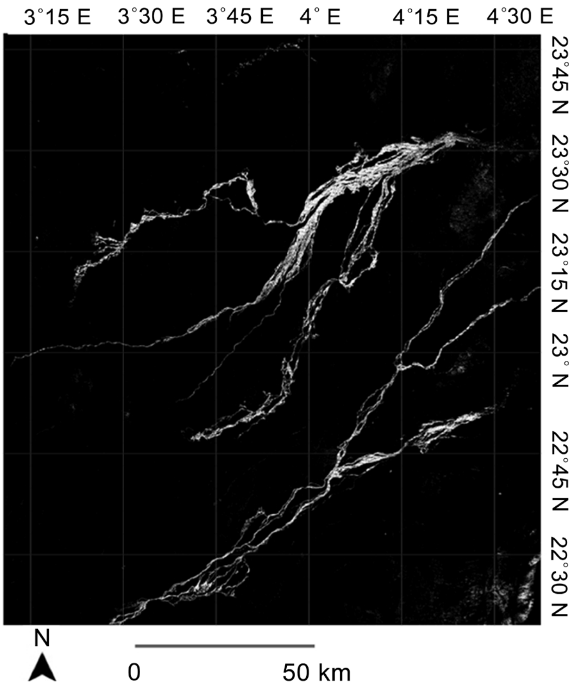

Figure 7. Extraction of the main wadis in the study area.

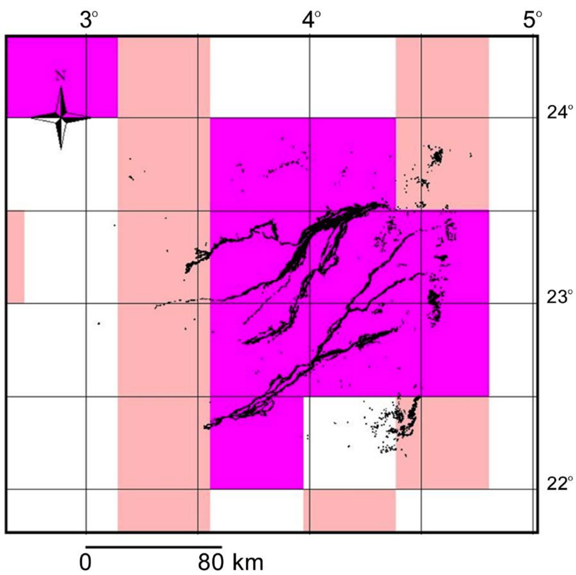

Figure 8. Overlay of the main wadis (obtained by analysis of satellite images) with the quarter degree squares of high (light pink) and very high (dark pink) breeding frequency of solitary locust populations.

use of remote sensing data. These studies have generally been based on attempts to map the vegetation (e.g. Dreiser *et al*. [32]-[35]). However, this mapping has proven to be difficult and costly. Indeed, in the Saharan region, the vegetation is difficult to identify due to a low coverage and often to a spectrum with no specific features [40]. In addition, extensive areas of vegetation vary from season to season and from year to year depending on rainfall, making illusory any attempt to map such an ephemeral parameter. It could never be better that a mere image at a given time. It seemed more useful to get rid of the vegetation and, using satellite imagery, to look for correlations between breeding areas of solitary locusts and some easily identifiable geomorphological features.

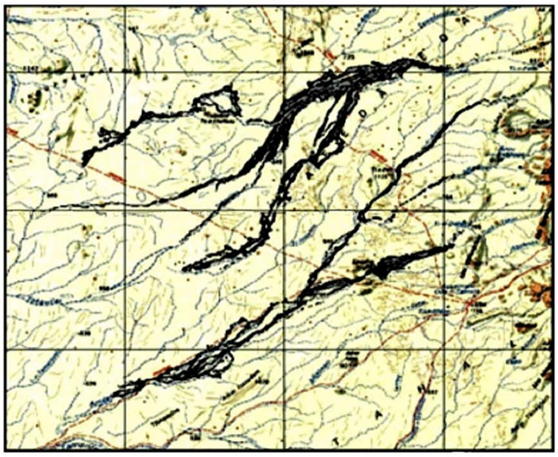

Figure 9. Overlay of a topographic map with the main wadis (in black), forming areas of potential locust breeding and highlighted by analysis of Landsat 7 ETM+ imagery.

In this context, the joint use of remote sensing data and of locust data issued from RAMSES for a period of 43 years (1965-2008) proved to be crucial. These locust data helped to prioritize the different areas according to their interest for the locust ecology. They allowed us to focus only on areas of major interest for the preventive control of this species. For our study area in the Hoggar, it's mainly the wadis on sandy, loam and clay-loam soils that gave the locust very favorable breeding conditions in case of rain or runoff. These wadis related to locust breeding have been fully mapped through various treatments applied mainly to data from Landsat 7 ETM+.

The scale used in this study makes operational results. They can be a cartographic basis of the potential locust breeding areas to be monitored in priority, especially when favorable ecological conditions develop. These results can be used in a geographic information system as a static basis layer of potentially suitable habitats, which may be superimposed on the dynamic information on environmental conditions, in particular vegetation phenology and rainfall [29] [37] [41]. Thus, the areas favorable to locust activity could be better delineated in real time, allowing survey teams to monitor, detect and destroy the first locust outbreaks more efficiently, thus reducing the risk of an invasion.

The method should be extended to all gregarization areas in Algeria and probably to other countries in the region containing outbreak areas, particularly Libya, Mauritania, Mali, Niger and Chad. All these countries have the necessary data bases on desert locust (often several decades of observations) to locate, for solitary populations, breeding areas of high frequency. Landsat images are available for free. This generalization could be done with minimal cost. However, climate change may likely modify the location of these favorable habitats and it will be necessary to remain vigilant on this issue.

The extrapolation of the method to a larger area, however, may pose some difficulties that must be overcome. Indeed, locust archive data showed that while 81% of the females deposited their eggs in the wadis or their surroundings (these wadis have been the subject of this study), there were 19% of egg pods laid in other areas (non characterized in this first approach). The same problem may arise if our method is extrapolated to other regions. It will also be necessary, for these new areas, to check if it is possible to associate the areas of high breeding frequency of solitary populations with geomorphological features (wadis or others) easily identifiable by remote sensing. Nevertheless, despite the limitations, the aim of this study is not so much to map all of these areas than just the most important ones. This will allow quicker reaction with a better focus of the survey teams at the early stages of gregarization when small impacts on locust population size can have dramatic effects and populations are still contained locally [7].

Acknowledgements

The authors wish to thank the FAO Commission for controlling the desert locust in the Western Region (CLCPRO) who financially supported this study, and the National Institute for Plant Protection of Algeria who has provided its data on desert locust and made all the necessary logistical and human support for the field works.

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