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USING GIS APPROACHES TO STUDY WESTERN TARNISHED PLANT BUG IN THE SAN JOAQUIN VALLEY OF CA

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Abstract

The western tarnished plant bug (*Lygus hesperus*) is a key pest in many crops in the San Joaquin Valley (SJV) including cotton, dry beans, seed alfalfa, and various fruits and vegetables. Populations of this indigenous insect begin at very low densities in spring but build through the summer on a variety of host plants. As one plant or crop becomes unsuitable the insect moves into neighboring crops. Geographic Information Systems (GIS) provides an ideal tool to study the concentration and movement of lygus through the season. GIS techniques were used to characterize various landscapes in the study area that provide lygus habitat. Several townships were analyzed throughout the valley in general to identify differences in cropping patterns, and specifically to investigate the pattern of cotton and alfalfa adjacency. In addition, Landsat imagery was processed to identify areas of senescing natural vegetation that are in close proximity to cultivated areas. Finally, actual lygus population dynamics in bordering farm areas were mapped using real-time field data. These approaches provide a powerful tool to understand the landscape in lygus population development and movement. The concept of crops and plants acting as sources out of which lygus move or sinks into which lygus move can be studied on a regional scale. The role of individual crops such as alfalfa hay on the intensity of lygus in an area might be used in a predictive manner to prescribe regional management of this pest. GIS also provides useful tools to help cotton growers and consultants visualize complex crop interactions and lygus movement.

Background

The western tarnished plant bugs (*Lygus hesperus*) or lygus bugs are important insect pests on many crops including cotton, beans, lettuce, seed alfalfa, strawberries, and tree fruit. Their population density begins low in the spring and increases during the summer. Many crops and weeds can act as hosts during this population buildup. In certain years insects can develop high population densities in the foothills surrounding the San Joaquin Valley (SJV) and threaten cotton as the vegetation becomes unsuitable as a host. Within the SJV, populations increase and as one crop is prepared for harvest, lygus are forced to move into neighboring crops. As crops are harvested through the season, lygus are forced to concentrate into smaller areas of remaining crops.

During the 1990's, lygus is estimated to have caused an average yield loss of $18,789,254 or 1.88% of the total production value in cotton. Since lygus builds as an external pest and moves into fields as surrounding hosts become unsuitable, the SJV cotton producer must sample the field frequently to avoid early and mid-season fruit loss. Thus, a cotton field may be in biological balance one day but out of balance the next due to an event external and not of the farmer's making. In cases in which the movement of lygus is concentrated, control options are limited to broad-spectrum insecticides that can result in secondary pest disruptions, lead to an insecticide treadmill and threaten profitability (Goodell et al, 1997).

The concept of cotton being embedded in a landscape mosaic of lygus sources and sinks was suggested over 30 years ago (Stern, 1969). The ecological understanding of lygus buildup and movement provided improved management tools. For example, every year since 1978, the foothills surrounding the SJV have been surveyed for the presence of lygus. In 1978, population densities of lygus built to high levels and resulted in an extended movement into the SJV that caused severely depressed yields and a higher cost of production as a result of increased insecticide expenses. The combination of winter and spring rainfall and the resulting collection of plant hosts determines the severity of the lygus threat in May and June (Goodell, 1998). Surveys have consisted of locating hosts and sampling for lygus populations with a sweep net along loosely established route of roads that cross through these areas. The abundance of hosts and the population density of lygus are related to a potential threat and a statement of the potential threat is issued to the cotton industry in late May. Resource constraints and access to private land have been limitations to our survey large areas.

During the 1960's, a series of cultural management practices were developed to mitigate the movement of lygus into cotton and offered alternatives to corrective insecticide treatments. These practices included the treatment of sources before lygus move (Sevacherian et al, 1977), interplanting preferred hosts with cotton (Stern et al, 1969; Goodell and Eckert, 1998), and preserving habitat by managing alfalfa hay (Stern et al, 1967). While some of these practices were widely accepted (e.g. treating safflower), most were found to be impractical. The value of alfalfa hay in managing lygus in a regional context has recently been emphasized (Goodell et al, 2000, Goodell, 2000), but specific guidelines are lacking.

Thus, 30 years later, the cotton industry is still reliant on chemically based management strategies partially due to our incomplete understanding of lygus movement across a large area. Understanding the spatial relationships of lygus sources and sinks could lead to improved decision-making and offer guidance to the utilization of cultural and chemical control strategies.

Geographic Information Systems (GIS) offer powerful tools to increase our knowledge of cropping systems interactions. Our goals in these studies are to:

1. apply GIS to spatially analyze the diversity of landscape mosaics within the SJV as it relates to lygus hosts
2. use satellite imagery to investigate the spatial *and temporal* pattern of senescing natural vegetation along the western rim of the SJV and apply this regional pattern as a data layer (map) in the GIS.
3. use GIS to follow lygus populations within a complex landscape community
4. (spatial and temporal dynamics)
5. investigate using the above mentioned data layers to predict lygus movement.

Methods and Materials

Improving Lygus Infestation Projections

Landsat 7 imagery consists of radiance data for seven reflectance bands (a panchromatic band at a spatial resolution of 15 meters and six others at 30 meters) and two thermal emission bands (at a spatial resolution of 60 meters). Landsat 7 passes over a given scene every 16 days and provides an image that is 170 km by 185 km in size (31,450 km^2). The scene that covered the western edge of the SJV along the Interstate 5 (I5) corridor was path 42, row 35 and the time period of interest was March through early May. Thumbnail images and descriptions of the scenes were available on the Internet for inspection shortly after the satellite passed overhead. These images were inspected for clarity and an absence of cloud cover. Only two dates provided clear, unobstructed views, April 25 and May 11 2001 and were purchased. The images were incorporated into GIS systems to overlay roads, towns, and political boundaries to allow specific locations to be identified and visited.

The image data that were used in the analysis were rectified to one another to facilitate change detection analyses. Atmospheric haze correction was performed upon the raw image data using water bodies as dark targets. Regressions were performed and the results were used to adjust the raw values for atmospheric haze prior to conversion to reflectance values. The image data were then converted to planetary reflectance in the manner described in Chapter 11 of the Landsat 7 Science Data Users Handbook (Anonymous, 2002). This was done to reduce between-scene variability through a normalization for solar irradiance. This is important because solar irradiance will change between image dates due to changing solar illumination angles and Earth-Sun distances. Failure to compensate for these changing parameters could lead to "change" being detected at a given location when none may have occurred.

To enhance the presence of vegetation, color infrared images were developed using the green, red, and near infrared reflective bands. The resulting color infrared images indicated healthy vegetation in reddish tones that contrasted well with the bluish-green tones of soil surfaces. These images were used to locate areas of vegetative growth. A normalized difference vegetation index (NDVI) was used to characterize vegetation health. NDVI was calculated for each Landsat image using their respective red and near infrared (NIR) bands in the following equation:

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED}) \quad (1)$$

Although the theoretical values for NDVI range from –1 for water surfaces and +1 for dense, healthy vegetated surfaces, actual values will fall well within these limits. Since it was desired to locate areas where vegetation was senescing, an image of the percent change of NDVI (PCNDVI) was calculated using the following equation:

$$\text{PCNDVI} = \{(\text{NDVI}_{\text{May 11}} - \text{NDVI}_{\text{April 25}}) / \text{NDVI}_{\text{April 25}}\} * 100\% \quad (2)$$

The PCNDVI image was examined along with the color infrared images. It was found that areas with very high negative values of PCNDVI corresponded well with fields of harvested crops. Conversely, areas with very low negative values of PCNDVI corresponded well with areas of little vegetation change. For example, such areas might have little healthy vegetation growing at all in both Landsat scenes. Thus, to improve the interpretability of the PCNDVI image, only those areas with PCNDVI values between -31% and -80% were used in the analysis and the resultant image was color-coded to facilitate interpretation. Ground observations were utilized to corroborate the results.

Contrasting Cropping Patterns in the SJV

The cropping patterns in SJV townships (ca. 36 $miles^2$) were compared, including Five Points (Fresno County), Buttonwillow (Kern County), Chowchilla (Madera County) and Woodville (Tulare County). Crops were inventoried using a in a variety of methods. At Buttonwillow, a query of the Kern County Ag Commissioner Pesticide Use Permit database was conducted. At Five Points, the area was physically surveyed. For Chowchilla and Woodville, historic Department of Water Resources crop maps were utilized for 1995 and 1993, respective. The data were converted to Arc View shape files. When alfalfa and cotton were present, the ratio of the crops was analyzed. Tables of crop frequency were developed. Nearest neighbor analysis for alfalfa was conducted to determine the median distance between alfalfa fields.

Crops were classified according to their suitability as a lygus host using a 1 (poor) to 4 (excellent) scale (table 1). Ratings are a subjective based on experience. In some crops such as almonds, the understory vegetation may or may not be a good host. In field crops such as garlic and onions, weeds may be the source rather then the crop.

Mapping Lygus in Cotton

A community project in Buttonwillow, Kern County, was developed. An area of approximately 8,000 acres was selected because of the cooperation between neighbors and the area was serviced by only two pest control advisors (PCAs). Kern County Agricultural Commissioner provides a current crop map for the county. This map is provided in ArcView shapefile format and is used as the base map to monitor lygus movement. The cotton fields in the study area were divided into quadrants and the weekly lygus data (taken by PCAs) were taken to coincide. In this way, the spatial resolution of the collected data was improved significantly. The weekly lygus samples were taken as part of the routine pest management activity of the growers' PCAs.

Results

Improving Lygus Infestation Projections

We were able to locate potential lygus hosts using the color infrared images of the Landsat scene. In the area along the I5 corridor, rainfall provided ideal conditions for the development of tarweed (*Hemizonia* sp.) The color infrared image of this area, acquired on April 25, provided sufficient detail to identify large patches of healthy vegetation identified (figure 1). The location of these vegetation patches corresponded with known sites of tarweed distribution. Thus, the pattern of distribution of healthy stands of this potential lygus host was identifiable from the image. Changing reflectance patterns indicated reduced plant distribution further south. Ground observations supported this interpretation. In 2001, lygus was not present on this host. The change in reflectance patterns was substantial between April 25 and May 11 as rain subsided and temperatures increased and were displayed as color-coded values of PCNDVI (figure 2). Ground surveys confirmed that the vegetation in locations with PCNDVI values between -31% and -80% had almost completely dried out and was unsuitable as lygus hosts.

Contrasting Cropping Patterns in the SJV

The four townships had about the similar crop diversity with about 10 to 11 different crops or crop groupings in each area (table 2). Cotton was a predominate crop in the landscape at all locations but trees, alfalfa or vegetable crops were next in abundance depending on the location. Trees and vines were most abundant in Woodville and Chowchilla, but Five Points had more vegetables. Buttonwillow had the greatest amount of alfalfa for an area followed by Chowchilla and Woodville.

The areas differed in the collection of lygus hosts (figure 3). Five Points had more area with "Good" and "Fair" hosts (83%) than Buttonwillow (69%), Woodville (73%) or Chowchilla (77%). Alfalfa represented the majority of crops ranked as an "Excellent" host. The ratio of cotton to alfalfa was 1.4 to 1 in Chowchilla, 1.5 to 1 in Woodville and 2 to 1 in Buttonwillow. There was no alfalfa in the Five Points survey area.

Mapping Lygus in Cotton

The Buttonwillow area consisted of about 5,000 acres of mixed crops managed by family farmers. Weekly lygus data were collected from June 21 to August 3, 2001. Weekly data were placed on the map and color coded to population density (figure 4). Historically, lygus are not an annual problem in this area (Touma, personal communication). The population densities during 2001 reflected this observation with total numbers for the season ranging from zero to about 18 per 50 sweeps with an average per week of 2 per 50 sweeps.

Discussion

GIS offers tools that could help develop IPM. Generally, IPM has been developed and practiced at the field and farm level. Moving IPM beyond the farm to the next level of system integration offers opportunities for new decision-making and management approaches. Lygus has long been recognized as a prime candidate for regional management but we have been limited by a lack of tools to investigate its ecology over such wide and diversely managed area.

These studies make an initial attempt at using the GIS tools to expand our view of the landscape in which lygus develops, moves and creates pest management concerns. Two key elements were explored in these studies; first our ability to locate non-cultivated host development over a wide area and second, the characterization of large areas relative to crop diversity, abundance of key crops, and the spatial relationship between key sources of lygus and the susceptible sinks.

We demonstrated that our spring survey efforts can be improved by using existing Landsat 7 satellite images to locate potential hosts and track their decline. While the presence of such hosts do not ensure lygus, integrating the satellite imagery into GIS map layers provides opportunities to visit specific sites for sampling, thus optimizing limited resources of labor and time. Alternatively, a bottom-up approach can be employed in which known hosts are sampled and precisely located through the use of geographical positioning systems (GPS). As hosts senesce, the area can be estimated and its contribution to lygus population in the SJV projected.

Drawbacks to using Landsat imagery include the requirement for cloud free days and the lengthy period (16 days) between over-flights. A missed opportunity due to cloud cover results in a month between images. Satellites with more frequent over-flights are available, but spatial resolution is reduced from 30 m on Landsat with a 16 day re-visit to 250 m available on the MODIS sensor on NASA's EOS AM-1 satellite with a 1-2 day re-visit, for example. Further research is required to develop a balance between spatial resolution and frequency of images. Finally, estimating total coverage of an area by a specific host cannot be done without close ground observations. Identification based solely on reflectance may be unreliable due to similarity of signatures between plants. Coupling space based imagery with *a priori* knowledge from ground observations improves the reliability of both technologies.

Tools useful in characterizing landscapes continue to be developed (Forman, 1999). Scale is an important component in understanding and interpreting the complexity of landscape mosaics that contain basic spatial elements of patches, corridors, and matrix. Our analysis is still incomplete but we believe alfalfa forage should be a focus in understanding lygus movement between sources and sinks. We chose townships (6 miles by 6 miles) as our level of scale because it is large enough to incorporate farms and fields but small to manage for ground survey. The DWR land use data was on a slightly larger scale (ca. 10,000 more acres) but is still useful for comparative purposes.

The presence of alfalfa in the landscape may play a pivotal role. It is a preferred host of lygus and the only widely crop grown that is not harvested for its reproductive parts. Alfalfa is not allowed to senesce but is cut every 28 to 30 days during its peak vegetative state. Strip cutting alfalfa has been demonstrated to be a valuable tool in limiting movement into cotton (Stern et al, 1967; Goodell et al, 2000). In situations where alfalfa fields are abundant in an area and are located in close proximity to each other, lygus severity in cotton is reported to be reduced.

GIS provides a convenient tool to visualize the relationship of alfalfa to cotton. Further analysis with GIS tools provides an indication of alfalfa abundance (percent area cover) and proximity (nearness to other alfalfa fields). For example, in three of the four landscapes, Woodville, Chowchilla and Buttonwillow, alfalfa represented 15%, 19%, and 22% of the total area with 30%, 45% and 70% of the fields located with 25ft of another field, respective (table 3). By placing these factors on two axes, we believe an important tool for characterizing landscapes for lygus movement can be created (figure 5). In the extreme situations, areas might have no alfalfa or have large areas of contiguous alfalfa. The placement of landscape areas between these extremes may provide an important tool in determining the annual severity of lygus to cotton.

The Buttonwillow community may provide a location to test the value of alfalfa for managing lygus on a regional scale. Further analysis incorporating nearest neighbors is required to identify sources that moved into cotton and relate the lygus movement to crop production activities such as harvest preparation. One obvious crop of interest is alfalfa and its cutting cycles. Providing these data in near real time is an important goal. The grower community expressed interest in seeing the lygus distribution maps and learning more about lygus movement within their area. We are currently developing Internet-based applications to provide lygus of data input and enable the community of growers and PCAs to visualize the population distribution of lygus.

The value of GIS in community management of lygus is just beginning. These powerful tools will aid in improving our understanding of lygus movement in an area. Perhaps as important, they can provide a means to visualize the complex crop interactions and help PCAs and growers better manage this key pest.

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Table 1. Subjective ranking of crops as lygus hosts found within study areas in 2001.

Crop	Host classification	Numerical ranking
Alfalfa	excellent	4
Almond	fair	2
Apples	fair	2
Broccoli	fair	2
Cherry	poor	1
Corn	fair	2
Cotton	good	3
Garbanzo	poor	1
Garlic	fair	2
Grain	poor	1
Grape	fair	2
Lettuce	fair	2
Melons	poor	1
Onions	fair	2
Peach	good	3
Pistachio	fair	2
Safflower	excellent	4
Sugar beets	excellent	4
Tomato	fair	2
Tomato, processing	good	3
Veg. Seed Crop	good	3
Wheat	poor	1

Table 2. Composition of crops in four locations of the SJV in 2001.

Buttonwillow		Five Points	
Crop	**Acres**	**Crop**	**Acres**
Cotton	7,713	Cotton	6,187
Alfalfa	4,016	Tomato, processing	5,537
Almonds/Pistachio	2,898	Fallow	3,528
Corn fodder	1,175	Onion/garlic	2,879
Wheat	1,233	Grain	2,223
Cherry	333	Tree/Vine	733
Tomato, pro.	367	Melons	551
Uncultivated ag land	87	Almond	456
Vineyard	337	Field Crop	326
Safflower	46	Vegetable	232
Miscellaneous vegetables	188		
Total Acres	18,392	Total Acres	22,652

Table 2 (continued). Composition of crops in four locations of the SJV in 2001.

Woodville		Chowchilla	
Crop	**Acres**	**Crop**	**Acres**
Cotton	8,591	Cotton	9,394
Other Deciduous	5,975	Almond & Pistachio	7,319
Corn	5,670	Alfalfa	6,778
Alfalfa	5,542	Corn	4,548
Grapes	3,560	Pasture	1,858
Grain	2,344	Grain	1,586
Vegetable	1,657	Fallow	2,622
Other Field	1,285	Grape	1,321
Almond & Pistachio	714	Other deciduous	661
Fallow	2,050	Tomatoes	26
Subtropical	172	Sub tropical	12
Pasture	72		
Total Acres	37,631	Total Acres	36,126

Table 3. Alfalfa forage abundance and proximity in four areas of the San Joaquin Valley. Abundance is the percent of area planted to alfalfa. Proximity is the percent of fields located within 25ft or less or another field.

Location	Abundance	Proximity
Five Points	0%	0%
Woodville	15%	30%
Chowchilla	19%	45%
Buttonwillow	22%	70%

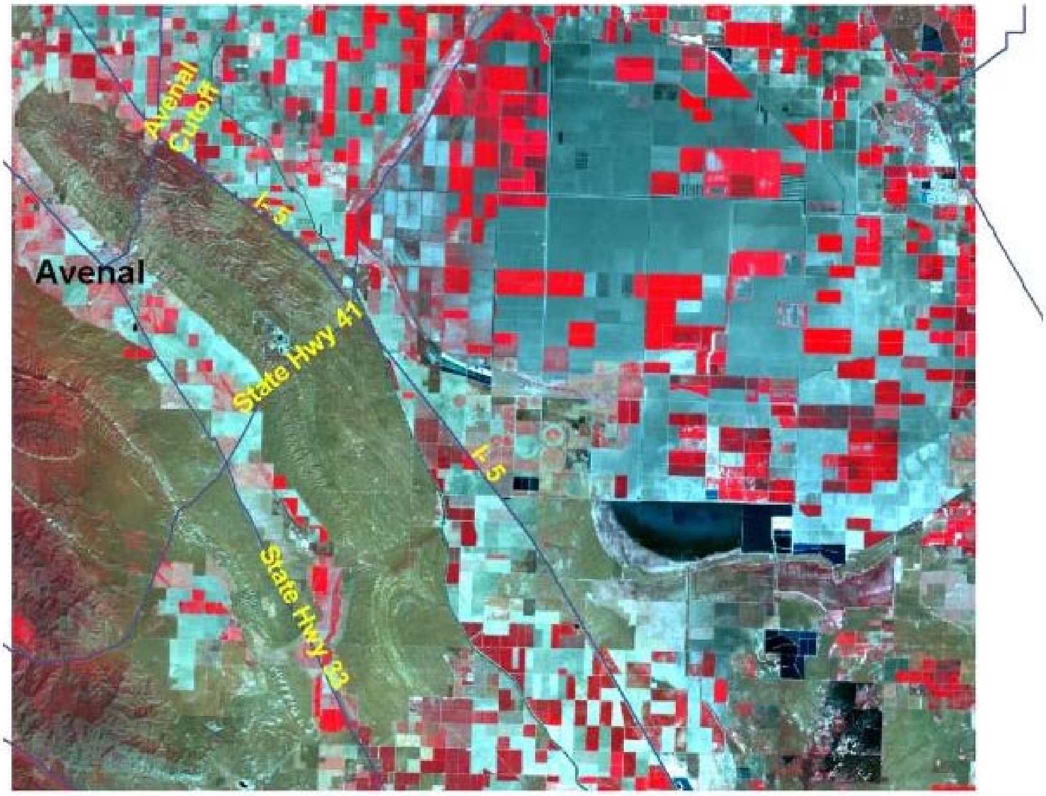

Figure 1. Color infrared Landsat image on April 25, 2001 of western Fresno County using green, red and near infrared bands. Brighter red colors indicate strong vegetative reflectance. Note reddish tinge at Avenal Cutoff, indicating patches of tarweed.

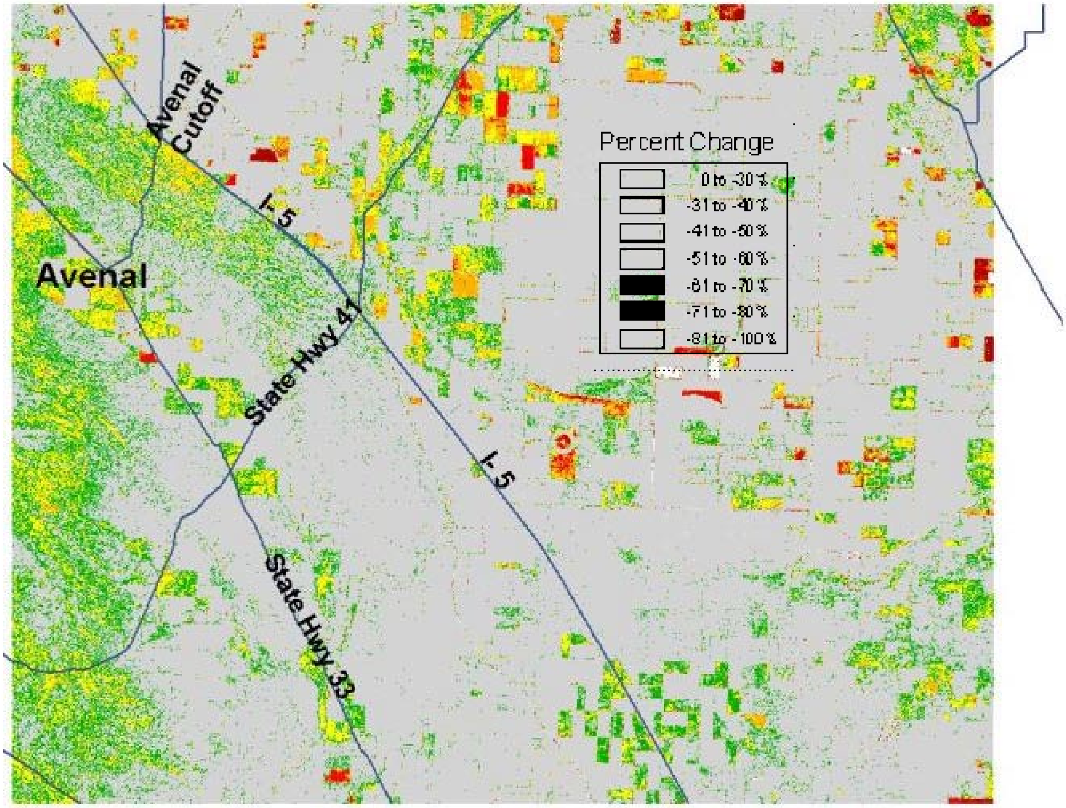

Figure 2. Change in percent normalized difference vegetation index (NDVI) between April 25 and May 11, 2001 in western Fresno Co.

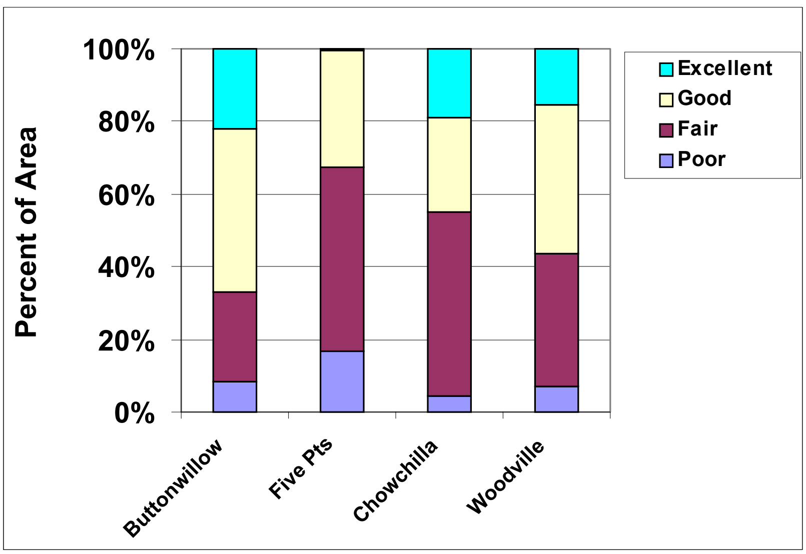

Figure 3. Percent of four areas occupied by plants in the San Joaquin Valley ranked by their suitability as lygus hosts in 2001.

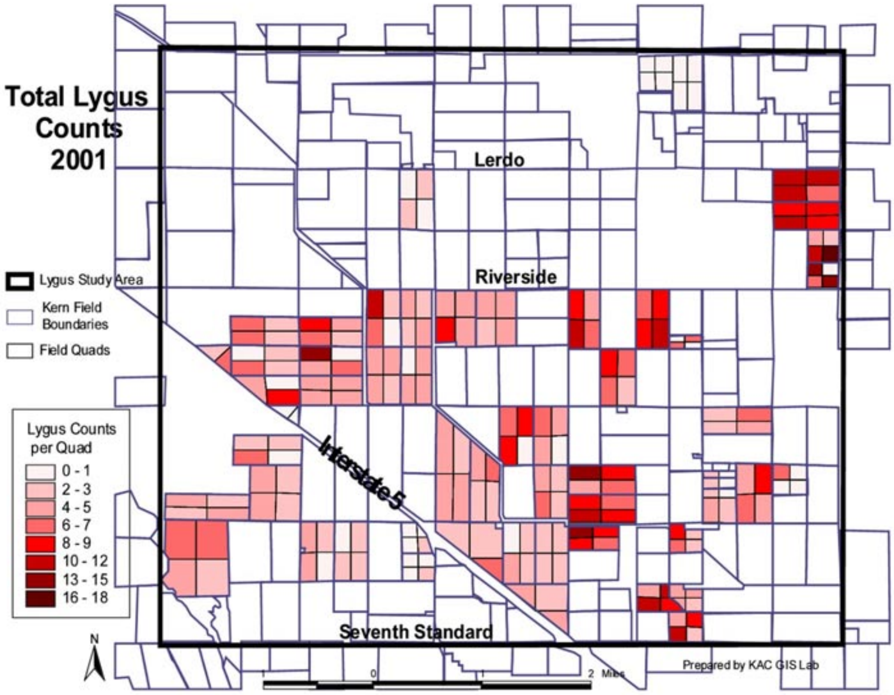

Figure 4. Total lygus captured from cotton in Buttonwillow, Kern County. Counts are for total bugs/50 sweeps.

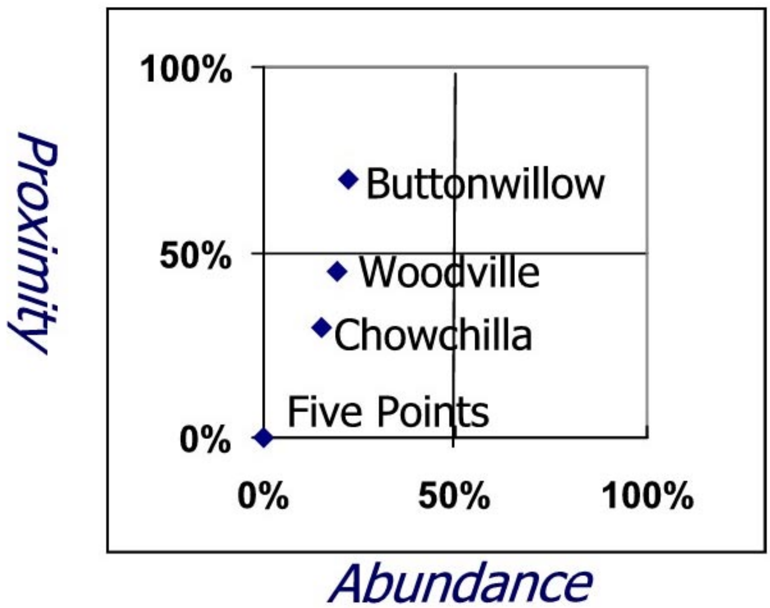

Figure 5. A method of characterizing lygus environments based on alfalfa forage abundance and proximity. Proximity is the percent of alfalfa fields located within 25 ft or less or another alfalfa field. Abundance is the percent of area planted to alfalfa.