Landscape associations of the sand fly, Lutzomyia (Heleocyrtomyia) apache (Diptera: Psychodidae), in the southwestern United States: a geographic information system analysis

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ABSTRACT: Landscape associations of the sand fly, Lutzomyia apache, Young and Perkins, in the southwestern U.S. were investigated by light/suction trap sampling and the development of a GIS-generated distribution map. In the mid-Rio Grande River valley, N.M., female and male L. apache were captured in updraft light/suction traps set in desert shrubland, irrigation levee, and bosque vegetation communities. Small numbers of flies were captured, but the presence of males and females in spatially separate and diverse plant communities at two locations suggest that L. apache are dispersed among available vegetation types. These data, along with 22 previously published collection site records, were used with a suite of physiographic features to characterize the biogeographic conditions suitable for L. apache. Suitable conditions encompass three life zones: the Rocky Mountain steppe province, the Colorado semi-plains province, and the American semi-desert province, all within the dry domain region of the western U.S. The potential range of L. apache was then estimated based on elevation, mean and max - min temperature, precipitation, wet days, and relative humidity. The estimated range includes large contiguous areas in north-central Colorado, east-central New Mexico and west Texas, the lower mid-Rio Grande River valley, and southern Arizona, along with smaller, patchy, areas in northern Arizona, California, Nevada, Utah, and central Idaho. The spatial relationship between the estimated distribution of L. apache and the location of livestock exposed to vesicular stomatitis virus at the onset of recent outbreaks is presented. Journal of Vector Ecology 29 (2): 205-211. 2004.

Keyword Index: Sand fly, geographic information system, habitat suitability, range prediction, vesicular stomatitis virus.

INTRODUCTION

The ecology of sand flies common to the southwestern United States is poorly known, and only a limited number of taxa, five of 14 U.S. species, are adapted to the arid environment of this region; most of the other ca. 404 New World sand fly species are forest inhabitants (CIPA Group 1999). Sand flies are known biological vectors of several arboviruses, including the rhabdoviruses that cause vesicular stomatitis (VS) disease among domestic livestock in Central and South America and the southeastern U.S. (Comer and Tesh 1991). Sporadic epizootics of New Jersey and Indiana serotypes of VS virus have occurred in Arizona, New Mexico, and Colorado since the mid-1800s (Hanson 1981). The epidemiology of VS outbreaks in the southwestern U.S. is consistent with the involvement of blood-feeding insects (Walton et al. 1987), but entomologic investigations conducted during outbreaks have not detected sand flies on premises with infected livestock (Schmidtmann et al. 1999). This condition, in part, may reflect the focus of study on premises with infected animals and the use of generalized sampling methods.

Recently, the sand fly Lutzomyia apache Young and Perkins was detected on a cattle ranch in the mid-Rio Grande River valley, Socorro County, NM, using updraft light traps set near the ground surface (Schmidtmann et al. 2002). Because this area has a history of VS virus activity (Bridges et al. 1997), we conducted the field study reported herein to identify possible vegetation community (habitat type) associations of L. apache as a basis for further understanding the distribution of adults, along with identifying potential vertebrate host and microhabitat associations. We then used the collection
site data, along with known collection records for *L. apache*, as a basis for developing new information about the range and potential distribution of the species using geographic information system (GIS) methods. It was anticipated that GIS analysis would help to clarify the possible involvement of *L. apache* in the epidemiology of VS viruses in the southwestern U.S. by providing an opportunity to compare the predicted distribution of a potential vector species with spatial characteristics of livestock exposed to VS virus during recent outbreaks. The coincidence of a vector species with distribution of disease in host populations is a key criterion for incriminating an arthropod as a biological vector of a vertebrate pathogen (Barnett 1960).

**MATERIALS AND METHODS**

**Field study**

Sampling for adult *L. apache* was conducted at two areas in the mid-Rio Grande River valley, NM during June, July, and August, 2001. Location 1 was a cattle ranch near Abeytas, Socorro County, NM, where sand flies were collected previously (Schmidtmann et al. 2002). Location 2 was the Sevilleta National Wildlife Refuge, La Joya, Socorro County, NM, a distance of ca. 30 km southwest. Updraft light/suction CDC-type traps (ABC Standard trap with updraft adapter kit, Clarke Mosquito Co., Roselle, IL), were set in three vegetation communities (habitat types) at each area: 1) bosque (riparian zone) bordering the Rio Grande River; 2) an irrigation canal levee; and 3) desert shrub-land vegetation (Figure 1). Traps were suspended from a tripod (Cabelas, Sydney, NE) that facilitated positioning the efferent aperture of the trap at ca. 0.01 m above ground. Traps were baited with ca. 2 kg dry ice, activated by phototimer at sunset, and harvested shortly after sun-up the following morning. The numbers of traps set in each habitat and female and male *L. apache* captured are listed in Table 1.

**Sand fly identification**

Male and female sand flies were cleared in phenol, the heads and abdomens removed and mounted with the body on a microslide in Hoyer’s solution. Specimens were identified based on anatomical characters of the cibarium and genitalia (Young and Perkins 1984).

**GIS analysis**

Twenty-two collection sites for *L. apache* defined by latitude and longitude were available for analysis. Coordinate values for collection sites were obtained for Colorado from (Alsuhaibani 1990), Arizona (McHugh 1999) and New Mexico (Schmidtmann et al. 2002). As necessary, coordinate values were converted from degree, minute, seconds to decimal degrees (dd). The GIS procedures used to describe suitable habitat and estimate the potential range of *L. apache* are summarized as follows:

1. A data base was created for each collection site defined by latitude and longitude. The Add Event Theme of ArcView (Environmental Systems Research Institute, Redlands, CA) was used to position each point in its corresponding grid, which was then converted into a shapefile.
2. Digital elevation models (DEMS) were downloaded for each collection site, imported into ArcView, and converted to grids. The ArcView Spatial Analyst extension was used to derive elevation, slope, and aspect for each collection site.
3. Environmental data were downloaded from websites in either vector or raster formats. Data used were geology, soil, ecoregions, plant hardiness, land

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Table 1. Light/suction trap capture data for *Lutzomyia apache*, mid-Rio Grande River valley, New Mexico, June, July, and August, 2001.

<table>
<thead>
<tr>
<th>Location</th>
<th>Vegetation community</th>
<th>No. light-suction traps samples/week</th>
<th>No. <em>L. apache</em> captured/week (♀, ♂)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>June</td>
<td>July</td>
</tr>
<tr>
<td>Cattle ranch, Desert shrub-land</td>
<td>8/0</td>
<td>8/0</td>
<td>7/4</td>
</tr>
<tr>
<td>Socorro Co., NM Irrigation levee</td>
<td>7/0</td>
<td>8/2♀</td>
<td>7/0</td>
</tr>
<tr>
<td>Bosque</td>
<td>8/0</td>
<td>8/0</td>
<td>6/0</td>
</tr>
<tr>
<td>Sevilleta National Desert shrub-land 1</td>
<td>3/0</td>
<td>2/1♀</td>
<td>2/1♂</td>
</tr>
<tr>
<td>Wildlife Refuge, Desert shrub-land 2</td>
<td>2/0</td>
<td>2/0</td>
<td>0/0</td>
</tr>
<tr>
<td>Socorro Co., NM Bosque</td>
<td>6/0</td>
<td>4/0</td>
<td>3/1♀</td>
</tr>
</tbody>
</table>
Figure 1. Light trap sample sites at cattle ranch in Socorro Co., NM. Vegetation communities (habitat types) are bosque (left), irrigation ditch levee (center), and desert shrub-land (right). Star symbol denotes sites where *L. apache* captured; circle denote sites where *L. apache* was not captured.

Figure 2. Spatial relationship between GIS-estimated distribution of *L. apache* (shaded areas) and index (first diagnosed) cases of vesicular stomatitis disease in livestock (symbols) during recent outbreaks. Square = 1995; circle = 1997; and triangle = 1998.
Table 2. Physiographic features of life zones where *L. apache* reported (light trap sampling).

<table>
<thead>
<tr>
<th>Collection sites</th>
<th>Abeytas and La Joya</th>
<th>Fresno Wash</th>
<th>Arivaca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horsetooth Reservoir</td>
<td>(n = 12) Larimer, County, CO</td>
<td>(n = 3) Socorro County, NM</td>
<td>(n = 1) Pima County, AZ</td>
</tr>
<tr>
<td>Longitude</td>
<td>40.585 dd</td>
<td>34.458 dd</td>
<td>31.836 dd</td>
</tr>
<tr>
<td>Latitude</td>
<td>-105.427 dd</td>
<td>-106.778 dd</td>
<td>-111.397 dd</td>
</tr>
<tr>
<td>Province:</td>
<td>Rocky Mountain Steppe</td>
<td>Plateau</td>
<td>American Semi-desert and Desert</td>
</tr>
<tr>
<td>Bedrock:</td>
<td>Paleozoic-sedimentary</td>
<td>Neogene sedimentary</td>
<td>Quaternary deposits</td>
</tr>
<tr>
<td>Soil type:</td>
<td>Baller-Sixmile-Renoh</td>
<td>Glendale-Armijo-Hark (4 sites), Madurez-Wink-Pjarit (4 sites)</td>
<td>Comoreo-Riverroad-Arizona</td>
</tr>
<tr>
<td>Plant hardiness zone:</td>
<td>5b</td>
<td>7a</td>
<td>8b</td>
</tr>
<tr>
<td>Community:</td>
<td>shrub-land</td>
<td>shrub-land</td>
<td>shrub-land</td>
</tr>
<tr>
<td>Elevation:</td>
<td>1,623.6 m</td>
<td>1,443 m</td>
<td>1,082 m</td>
</tr>
<tr>
<td>Slope:</td>
<td>14.9 dd.</td>
<td>flat (5 sites); 3 - 7 dd (3 sites)</td>
<td>2 dd</td>
</tr>
<tr>
<td>Aspect:</td>
<td>7° E, 3° NE, 1° N, and 1° SE</td>
<td>NE, SE and W</td>
<td>214° SW</td>
</tr>
</tbody>
</table>
cover, forest type, annual mean precipitation, annual temperature (mean, maximum, and minimum values), annual wet days, and annual relative humidity.

4. For vector data, the ArcView Geo-processing extension was used to assign data to each set of points.

5. For raster data, images were converted to grids, then the ArcView Grid Analyst extension was used to add grid values to an attribute table.

6. Environmental attributes for each point were extracted using the Extract x, y, and z tool of the ArcView Grid Analyst extension.

7. The Spatial Analyst feature of ArcView was used to estimate the potential distribution (range) of *L. apache* (it was assumed that the *L. apache* is able to survive in a range of conditions defined for each variable between its lowest and its highest values). Variables included in the analysis were elevation, temperature (mean, maximum, and minimum), precipitation, wet days, and relative humidity.

8. The Map Query function of ArcView Spatial Analyst was used to generate an area that included the range of values for all variables.

9. A data base was created for first reported cases of VS disease in livestock for outbreaks in 1995, 1997, and 1998, each defined by latitude and longitude. The Add Event theme of ArcView was used to position each VS case location to its corresponding grid, which was then converted to a shapefile.

### RESULTS

The numbers and locations of *L. apache* captured in light/suction traps are presented in Table 1 and Figure 1, respectively. Both male and female *L. apache* were collected, though numbers of specimens were low at both the cattle ranch and Sevilleta National Wildlife Refuge. Collections of flies were greatest in the desert shrubland community, smaller at irrigation levees, and least in bosque vegetation communities.

The bio-geographic features common to the 22 *L. apache* collection sites (e.g. suitable habitat) encompass three life zones that are listed in Table 2. The estimated range of *L. apache* covers large continuous areas in north-central Colorado, east-central New Mexico, and west Texas, as well as southern Arizona and the lower mid-Rio Grande River valley (Figure 2). Smaller, patchy areas of estimated suitable habitat occur in northern Arizona, California, Nevada, Utah, and central Idaho. The location of initial cases of VS in livestock during outbreaks in 1995, 1997, and 1998 are plotted against the estimated range of *L. apache* in Figure 2.

### DISCUSSION

GIS methods are increasingly used to process and display spatially-related data that aid surveillance and monitoring of vector-borne pathogens (Beck et al. 1994, Kitron 1998), as well as for interpreting spatially-related factors that influence vector population presence and abundance (Washino and Wood 1994, Hay et al. 1996, Hendrickx et al. 1999). In this study we first used Digital Orthophoto Quarter Quadrangle maps and GIS software to position and accurately visualize the sites where *L. apache* were attracted to light/suction traps and captured. Females and males were collected in the three primary plant communities (habitat types) bosque (riparian), irrigation levee, and desert shrub-land habitats common to this area of the mid-Rio Grande river valley, albeit in low numbers. Alsuaibani (1990) and McHugh (1999) captured numerous *L. apache* in light traps set near nests of the white-throated wood rat, *Neotoma albigula* Hartley, but this species does not commonly occur on the floor of the mid-Rio Grande river valley (Ellis et al. 1997). Our data suggest that adult *L. apache* in the mid-Rio Grande river valley are dispersed among available vegetation types but provide few clues as to their source.

The GIS analysis of 22 collection site records indicate that *L. apache* occupies a range that includes portions of the southern Rocky Mountain steppe - open woodland province in northern Colorado, the Colorado plateau semi-desert province, the mid-Rio Grande river valley in New Mexico, eastern New Mexico and west Texas, and the American semi-desert and desert provinces in southern Arizona. This range lies largely with the dry domain of the western U.S. where evaporation is greater than precipitation. Other sand flies, notably *L. californica* (Fairchild and Hertig), *L. tanyopsis* Young and Perkins, *L. vexator* (Coquillett), *L. aquilonia* (Fairchild and Harwood), and *L. opidanna* (Dampf), are also adapted to arid conditions and the strong winds common to xeric areas of the western U.S. (Fairchild and Hertig 1957, Harwood 1965, Young and Perkins 1984). Many sand fly species cannot tolerate dry conditions and wind because they are susceptible to desiccation during molting and require humid organic substrates for immature development (CIPA Group 1999).

Our GIS estimate of the range of *L. apache* was based on the variables elevation, temperature mean, maximum, and minimum, number of wet days, precipitation, and relative humidity. These variables were used because weather conditions at a given latitude and altitude are defined by temperature and precipitation, which define humidity, and these conditions influence the types of animal and plant associations at a given
location (Holdridge 1967). This estimate of *L. apache* distribution was necessarily conservative because it was based on reported capture locations, which may not represent the full range of the species. In addition to the large contiguous areas of potential habitat in Colorado, New Mexico, Texas, and Arizona, the numerous small, patchy areas of potential habitat in Arizona, California, Nevada, Utah, and Idaho greatly expanded the area and range in which *L. apache* may occur. The type locations for *L. apache* in Portal, Cochise County, Arizona, Springerville, Apache County, Arizona, and Payson, Gila County, Arizona, were not used because latitude and longitude coordinate values were not recorded; these collection sites were each within the predicted distribution of *L. apache*.

The implications of the estimated distribution of *L. apache* relative to the epidemiology of VS viruses in the southwestern U.S. are unclear. Sand flies are known vectors and reservoirs of VS viruses in other areas of the New World (Comer and Tesh 1991), but the presence and possible association of a sand fly with VS viruses in the southwestern U.S. has only recently been recognized (Schmidtmann et al. 2002). In this context, the predicted presence of *L. apache* in large areas of eastern New Mexico and west Texas needs to be validated, in part because this area lies outside of the zone of VSNJ virus activity during recent outbreaks (Bridges et al. 1997). Further, the inclusion within the predicted range of *L. apache* of the five locations where index cases of VS were diagnosed in livestock may be a spurious correlation. Nevertheless, the overlap of vector and susceptible host populations is characteristic of arthropod-borne diseases, and the association of a putative vector with a host in time and space is a criterion used to incriminate an arthropod as a biological vector (Barnett 1960). Accordingly, it is possible that biogeographic and climatic conditions in southern Arizona and southern New Mexico support a transmission cycle of VS viruses.

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