

## Impact of climate variation on mosquito abundance in California

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Received 25 September 2007; Accepted 13 December 2007

**ABSTRACT:** Temporal variation in the abundance of the encephalitis virus vector mosquito, *Culex tarsalis* Coquillett, was linked significantly with coincident and antecedent measures of regional climate, including temperature, precipitation, snow pack, and the El Niño/Southern Oscillation anomaly. Although variable among traps, historical records that spanned two to five decades revealed climate influences on spring and summer mosquito abundance as early as the previous fall through early summer. Correlations between winter and spring precipitation and snow pack and spring *Cx. tarsalis* abundance were stronger than correlations with summer abundance. Spring abundance was also correlated positively with winter and spring temperature, whereas summer abundance correlated negatively with spring temperature and not significantly with summer temperature. Correlations with antecedent climate provide the opportunity to forecast vector abundance and therefore encephalitis virus risk, a capability useful in intervention decision support systems at local and state levels. *Journal of Vector Ecology* 33 (1): 89-98. 2008.

**Keyword Index:** Climate variation, California, virus vector, *Culex tarsalis*, disease risk, forecasting.

### INTRODUCTION

In the western United States, the mosquito-borne encephalitides of public and veterinary health concern include western equine encephalomyelitis (WEEV), St. Louis encephalitis (SLEV), and now West Nile (WNV) viruses. These viruses are maintained and amplified in nature in similar enzootic transmission cycles involving several mosquito species within the genus *Culex* and multiple bird species (Reisen and Monath 1989, Komar 2003, Reisen 2003). Outbreaks occur sporadically, due partly to climate-driven population fluctuations of the primary rural vector mosquito, *Culex tarsalis* Coquillett. California has had a comprehensive mosquito surveillance program for more than 50 years making it possible to investigate the impact of climate variation on mosquito dynamics measured at different spatial and temporal scales (Cayan et al. 2002).

Climate variation affects the population dynamics of mosquitoes such as *Cx. tarsalis* because body temperatures approximate ambient conditions and larvae develop in aquatic habitats created directly or indirectly by precipitation (Reisen and Reeves 1990). Temperature governs most *Cx. tarsalis* biological rates including blood feeding, reproduction, and larval development (Reisen 1995), whereas precipitation determines the quantity and quality of larval habitats and therefore adult population size. Epidemiologically, mosquito population size and reproductive rate are important components of vectorial capacity that determine the frequency of host contact, the rate of pathogen transmission, and therefore the risk of human infection (Smith

1987). Climate variation affects all of these processes at multiple scales. Seasonal cycles create periods of the year with favorable conditions for population reproduction and growth, whereas variation among years determines inter-annual changes in population size. Interannual patterns of climate have been linked to changes in sea surface temperatures and storm tracks, which, in turn, have been linked to various aspects of human health (Epstein 2002), including patterns in the occurrence of vector-borne disease outbreaks (Gubler et al. 2001).

Climate models provide forecasts that predict climate variation, ecosystem dynamics (Cayan et al. 1999), and therefore changes in the risk of some vector-borne diseases (Bouma et al. 1994, Pascual et al. 2000). Perhaps the best-studied system relates the El Niño-Southern Oscillation (ENSO) to flooding, vegetative change, and the subsequent risk of Rift Valley fever virus epizootics and epidemics in east Africa (Davies et al. 1985, Linthicum et al. 1987, Anyamba et al. 2001). Ground measures of surface wetness have also been used to forecast the activity levels of SLEV and WNV in Florida (Shaman et al. 2004, Shaman et al. 2005). Although climate variation acts on mosquito-borne pathogens mostly through the mosquito vector(s), studies linking climate to vector-borne disease rarely include sufficient measures of mosquito population size to explore these relationships (Hacker et al. 1973a, Hacker et al. 1973b, Shone et al. 2001, Shone et al. 2006).

In most of California, summers are hot and usually dry, whereas winters are cool and wet (<http://www.wrcc.dri.edu/narratives/CALIFORNIA.htm>). The amount of

precipitation varies markedly across the state, resulting in a complex hydrological and vegetative landscape, with deserts in the southeast and temperate rain forests in the northwest. There is considerable variation in the amount of water delivered between decades, between years, and within the early, middle, and later parts of the wet season during a given year. Although there is moderate winter rainfall at lower elevations, most precipitation falls as snow at higher elevations in the Cascade Range and the Sierra Nevada. The amount of winter precipitation determines the availability of surface water for early season mosquito reproduction, whereas accumulated mountain snowpack, and when and how fast it melts, has a strong influence on early and late season flooding, water storage, and availability and cost for irrigating summer agriculture (California Department of Water Resources 2007). Collectively, these patterns alter the abundance and phenology of *Cx. tarsalis* from a bimodal pattern with early spring and fall peaks in the SE deserts to a unimodal pattern with a single summer peak in the Sacramento Valley (Bohart and Washino 1978). Short term climate variations can greatly alter the timing and amplitude of these *Cx. tarsalis* profiles and allow near-term forecasts of abundance, an early indication of encephalitis virus risk, because models indicate that postdiapause reproductive success may be linked strongly to summer population size (Moon<sup>3</sup>). Prior to the construction of modern water management systems in the early to mid-20<sup>th</sup> Century, flooding of the San Joaquin Valley was common and a useful predictor of *Cx. tarsalis* population size and WEEV transmission (Reeves et al. 1990b). Even in the era of modern dams and water management systems, snowpack and flow rates in the Kern River watershed remained correlated with flooding of the valley floor and *Cx. tarsalis* abundance (Wegbreit and Reisen 2000). In the rice-growing areas of the Sacramento Valley, *Cx. tarsalis* abundance from 1960 to 1978 was correlated positively with degree-day accrual between March and April and negatively with rice acreage, and these relationships provided some skill for predicting annual abundance (Washino and Thomas 1985). These patterns have been altered somewhat by extensive mosquito control programs that gradually have expanded to protect 90% of the California population living in an area of 156,000 mi<sup>2</sup> (Barker et al. 2004).

Our current research addresses the hypothesis that interannual variation in mosquito abundance, an important component of the risk of arbovirus transmission, can be predicted months in advance by examining antecedent climate variation. To test this hypothesis, we compared relationships between *Cx. tarsalis* abundance measured by light trap counts and ground-based measures of temperature, precipitation, and snowpack in five regions of California over a 50-year period.

## MATERIALS AND METHODS

Our analyses focused on *Cx. tarsalis*, because this species is widespread and an important vector of arboviruses in California (Reeves et al. 1990a), exploits rural habitats and depends entirely on surface water sources for larval development (Reisen and Reeves 1990), and is attracted to New Jersey (NJ) light traps (Reisen et al. 2002). This species enters reproductive diapause by the autumnal equinox and terminates diapause physiologically just after the winter solstice (Reisen et al. 1995). Emergence from diapause and the initiation of blood feeding varies as a function of latitude and is temperature-dependent (Bennington et al. 1958), occurring earlier in southern and later in northern California. Mosquito abundance is monitored by special Mosquito and Vector Control Districts (MVCD) using NJ light traps (Mulhern 1953). We used data from 282 geocoded trap sites that were operated weekly for at least 15 years between 1950 and 2000. Trap locations were restricted geographically to areas within MVCD boundaries (Figure 1). Traps were operated from three to seven days per week depending upon the agency, with the captured mosquitoes enumerated by species.

Climate within California regions was characterized by historical records from ground recording stations and division averages over selected time periods (Figure 1). Because mosquito surveillance was constrained by MVCD boundaries, collections in the Southeast Desert region were limited to Coachella Valley MVCD and the South Coast region to the Greater Los Angeles County VCD; these clusters have been referenced accordingly. Climate measures included monthly and seasonal mean temperatures and total precipitation and accumulated snow, in the form of the snow water equivalent, at Donner Summit in the Sierra Nevada on 1 April. These measures were compared to mosquito counts at each trap within the climate regions. Anomalies, or deviations of average sea surface temperatures (SSTA) within the Niño 3.4 region (5°N-5°S, 120°-170°W), from 1971 to 2000 averages were used to investigate possible tropical Pacific linkages to seasonal mosquito abundance.

Mosquito counts were standardized to females per trap night per week to account for differences in sampling effort among agencies. These standardized counts, or  $y$ , were transformed by  $\ln(y+1)$  to normalize the data and control the variance. Counts then were detrended by regressing transformed counts as a linear function of time to account for long-term changes that presumably were unrelated to climate variation. Detrended and georeferenced mosquito abundance data for each trap within each region (Figure 1) were related to climate measures within the associated Climate Division by computing correlations of the transformed counts over time. To examine relationships between antecedent climate conditions and mosquito abundance during fall (Oct, Nov, Dec; OND), winter (Jan, Feb, Mar; JFM), spring (Apr, May, Jun; AMJ) and summer (Jul, Aug, Sep; JAS), counts from each trap were compared to mean temperature, total precipitation, snowpack, and SSTA recorded during quarters of the same year or previous

<sup>3</sup>Moon, T.E. 1973. A statistical model of the basic infection cycle of western equine encephalitis virus. Ph.D. Dissertation. University of California, Berkeley, CA.

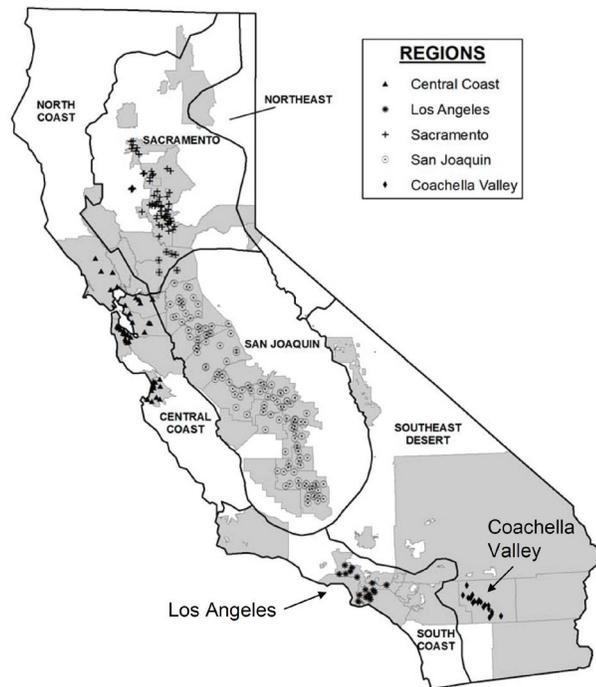


Figure 1. Locations NJ light traps within geographic regions. Also shown are associated boundaries of Mosquito and Vector Control Association of California districts (gray areas) and California Climate Divisions (labeled, with black boundaries). Six trap sites within Sacramento County were used in both San Joaquin and Sacramento Regions.

Table 1. Correlations of female *Cx. tarsalis* abundance during spring [AMJ] and summer [JAS] with climate variation measured during fall, winter, spring, and summer. Sign indicates the direction, if any, in which the observed distribution significantly differs from the permuted distribution when tested by Chi-square.

Female *Cx. tarsalis* - April-May-June

Region	Temperature			Precipitation			Snow pack		Niño3.4		
Central Coast	<b>+W</b>	<b>+S</b>		<b>+F</b>	<b>+W</b>	<b>+S</b>	<b>+F</b>	<b>+W</b>	<b>+f</b>	<b>+W</b>	<b>+S</b>
Sacramento	<b>+F</b>	<b>+W</b>	<b>+S</b>	<b>-F</b>	<b>-W</b>	<b>-S</b>		<b>-W</b>	<b>-F</b>	<b>-W</b>	<b>+S</b>
San Joaquin	<b>-F</b>	<b>+W</b>		<b>+F</b>	<b>+W</b>	<b>+S</b>	<b>+F</b>	<b>+W</b>	<b>+F</b>	<b>+W</b>	<b>+S</b>
Los Angeles	<b>+F</b>		<b>+S</b>	<b>+f</b>	<b>+W</b>		<b>+F</b>	<b>+W</b>		<b>+W</b>	<b>+S</b>
Coachella	<b>-f</b>		<b>+s</b>	<b>+F</b>	<b>+W</b>		<b>+F</b>			<b>+w</b>	<b>+S</b>

Female *Cx. tarsalis* - July-August-September

Region	Temperature				Precipitation				Snow pack		Niño3.4		
Central Coast		<b>-S</b>	<b>+v</b>		<b>+F</b>	<b>+W</b>	<b>+S</b>	<b>+V</b>	<b>+F</b>	<b>+W</b>			
Sacramento	<b>-F</b>	<b>+W</b>	<b>-S</b>	<b>-V</b>		<b>+W</b>	<b>+S</b>	<b>+V</b>	<b>+F</b>	<b>+W</b>	<b>+F</b>	<b>-W</b>	<b>-S</b>
San Joaquin	<b>-F</b>	<b>-W</b>	<b>-S</b>		<b>+F</b>	<b>+W</b>	<b>+S</b>	<b>+V</b>	<b>+F</b>	<b>+W</b>	<b>-F</b>		<b>-S</b>
Los Angeles	<b>-F</b>							<b>+V</b>					
Coachella	<b>-F</b>	<b>+W</b>	<b>-S</b>	<b>-V</b>	<b>+F</b>	<b>+W</b>		<b>+V</b>	<b>+F</b>	<b>+W</b>	<b>+f</b>		

p < 0.01 = **BOLD UPPER CASE**

p < 0.05 = **UPPER CASE**

p < 0.10 = lower case

F = fall      Oct, Nov, Dec      (or Jan 1 snow)  
 W = winter    Jan, Feb, Mar            (or Apr 1 snow)  
 S = spring    Apr, May, Jun  
 V = summer   Jul, Aug, Sep

Temperature = mean for indicated season.

Precipitation = total accumulated for the indicated season.

Snow pack = snow water equivalents at Donner summit on January 1 and April 1.

Niño3.4 = sea surface temperature anomaly for Niño3.4 region.

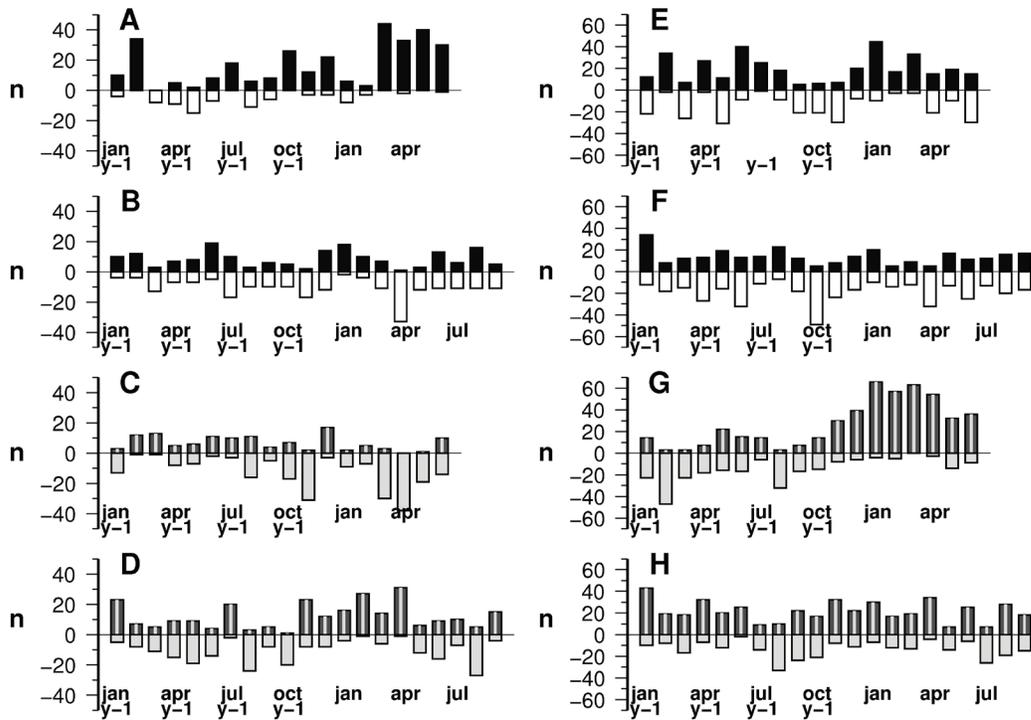


Figure 2. Frequency of positive or negative correlations  $>0.25$  of *Cx. tarsalis* abundance in the Sacramento (A – D) and San Joaquin (E – H) Regions during spring (AMJ: A, E, C, G) or summer (JAS: B, F, D, H) with monthly antecedent temperature (A, B, E, F) or precipitation (C, D, G, H).

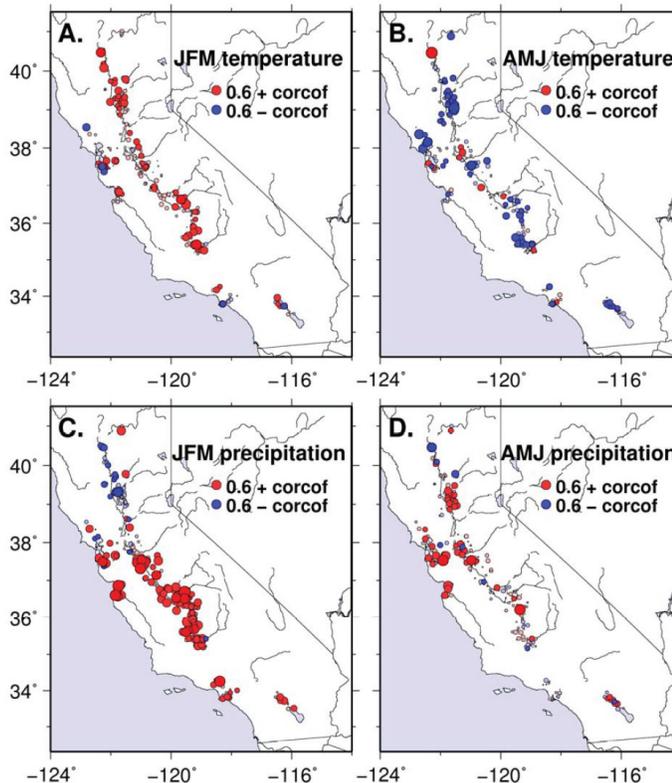


Figure 3. Correlations among *Cx. tarsalis* abundance measured at 282 sites from 1950 to 2000 during spring (AMJ) with temperature (A) and precipitation (C) measured during winter (JFM) and during summer (JAS) with temperature (B) and precipitation (D) measured during spring (AMJ).

fall. Correlation values for each trap were then consolidated into frequency distributions per region to determine the consistency of the response and the strength and direction of the association. A nonparametric random permutation test was used to determine whether the resulting distributions of correlations deviated significantly from neutral reference distributions of correlations statistically centered on zero. To generate the reference distributions, mosquito abundance measures were randomly permuted 100 times using Monte Carlo sampling and paired with the meteorological data. The observed correlation distribution was compared to the permuted series (the expected distribution) using a  $\chi^2$  test. This statistical approach was exemplified for spring *Cx. tarsalis* abundance and winter temperature; all analyses are summarized in Table 1.

## RESULTS

Initially, we examined the consistency of *Cx. tarsalis* responses to monthly antecedent measures of temperature and precipitation in the Sacramento and San Joaquin Regions to ensure that there were systematic patterns in correlations across monthly time scales (Figure 2). These data and those presented below show that 1) climate explained only a fraction of the variability in *Cx. tarsalis* abundance, 2) correlations with coincident and antecedent climate measures exhibited systematic patterns, indicating meaningful climate influences that spanned several months preceding and during the mosquito seasons considered, 3) the climate influence on spring mosquito populations was detected, in some cases, as early as the previous fall and persisted through the end month of the targeted mosquito season, 4) *Cx. tarsalis* populations differed markedly in their responses to the same climate parameters during different seasons and in different regions, and 5) the intensity of response varied markedly among traps within regions. In the following analyses, correlations were used to explain changes in these relationships in time and space using data pooled across seasons. Meaningful associations between a given climate measure and regional mosquito abundance were gaged by the level of significance in Chi-squared tests applied to the frequency distributions of correlation coefficients from the expected distributions from the permuted series (Table 1).

Spring abundance of *Cx. tarsalis* females at most sites was correlated significantly with antecedent winter (Figure 3A) and contemporaneous spring temperatures (Table 1). Correlations were greatest and their frequency distributions were significantly more positive than permuted reference distributions in the Sacramento, San Joaquin, and Central Coastal Regions, but not in the Los Angeles and the Coachella Valley Regions (Figure 4). In contrast, summer mosquito abundance was correlated negatively with spring temperatures in all regions, except Los Angeles (Figure 3B). Collectively, these data indicated that warm winters tended to be followed by increased spring *Cx. tarsalis* abundance. In all regions except the San Joaquin, warm spring months accompanied increased spring *Cx. tarsalis*

abundance, especially in the Sacramento Region. Likewise, these correlations indicated the converse tendency that cool temperatures in winter and spring were associated with decreased spring *Cx. tarsalis* abundance. Interestingly, in residential Los Angeles, neither spring nor summer *Cx. tarsalis* abundances were correlated strongly with winter or spring temperatures (Figures 3A, 3B, 4). In Los Angeles, *Cx. tarsalis* abundance typically was low, sampling sensitivity limited by competing illumination, and larval habitats limited to embedded parks and residual wildlife habitats along riparian corridors. In most instances, the positive correlations between anomalous winter and spring temperature and springtime mosquito abundance did not continue into summer. In fact, warm springs, perhaps a harbinger for above-normal summer temperatures, were correlated negatively with summer *Cx. tarsalis* abundance.

Spring *Cx. tarsalis* abundance was correlated positively with winter precipitation in all regions, except the Sacramento region where the signal was either weak or negative (Figure 3C, Table 1). As with temperature, there was only a weak statistical association between summer abundance and winter precipitation. In all regions except Los Angeles, positive correlations with precipitation were evident beginning in fall of the previous year continuing through the spring period. Positive correlations between spring rainfall and summer abundance were somewhat stronger in the wetter Central Coast and Sacramento Regions (Figure 3D) than in the drier San Joaquin and Coachella Regions. Frequency distributions of correlations were not significantly different from those in the permuted randomized series in Coachella Valley, Los Angeles and San Joaquin Regions where spring rainfall events were infrequent and light. In agreement, significant positive correlations occurred in the San Joaquin Delta area of the San Joaquin Region where spring rainfall intrusions from the coast are more common, whereas the drier southern portion of the San Joaquin Region yielded weak or negative correlations (Figure 3D).

The water content of snowpack on 1 April at Donner Summit in the Sierra Nevada was a surprisingly good predictor of *Cx. tarsalis* abundance over most of California in spring and, to some extent, summer. The strength and breadth of these associations were likely a result of spring snowpack accruing regional climate influences from late fall through spring. Significant correlations with snowpack and subsequent *Cx. tarsalis* abundance began to emerge in early winter (1 January) and continued and strengthened in early spring (1 April). Except for the Sacramento region, this linkage indicated that heavy snowpack was generally associated with increased spring *Cx. tarsalis* abundance (Table 1, Figure 5A), except for Coachella Valley which was affected minimally by snow pack. In the Sacramento region, spring abundance correlated inversely with snowpack, consistent with its negative association with early season precipitation. The linkage of abundance to winter and spring Sierra snowpack continued into summer in all regions, except Los Angeles. All regions exhibited positive correlations between summer abundance and prior winter

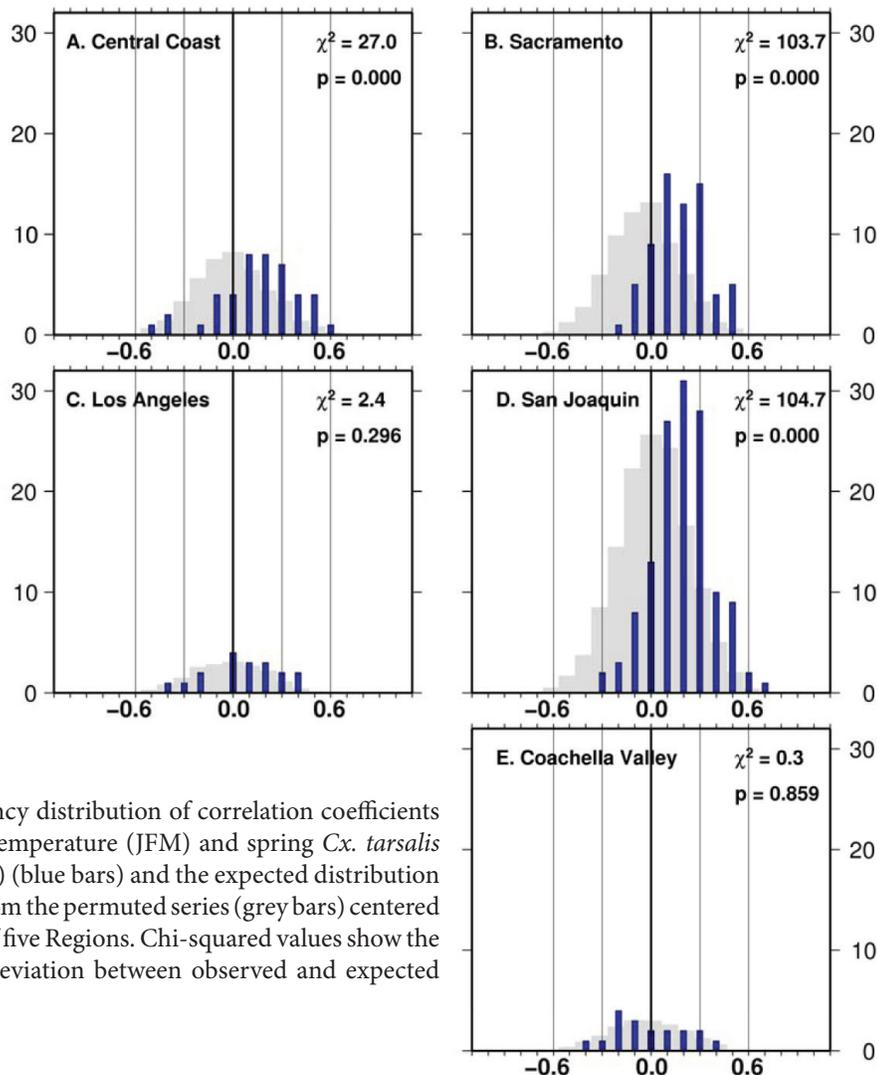


Figure 4. Frequency distribution of correlation coefficients between winter temperature (JFM) and spring *Cx. tarsalis* abundance (AMJ) (blue bars) and the expected distribution of correlations from the permuted series (grey bars) centered at zero for each of five Regions. Chi-squared values show the strength of the deviation between observed and expected distributions.

or spring snowpack (Table 1, Figure 5B).

Niño 3.4 Sea surface temperature anomalies (SSTA) during the antecedent fall and winter had variable but significant associations with *Cx. tarsalis* abundances during the following spring and, to some extent, summer (Figure 6, Table 1). SST anomalies during fall and winter resulted in significant responses in spring *Cx. tarsalis* abundance that were positive for many trap sites south of a line between San Francisco and Sacramento, and negative in many of the sites north of that line. This linkage was consistent with the tendency for El Niño events (positive Niño 3.4 SSTA) to produce heavier than normal winter precipitation in California, especially in the southern half of the state (Cayan and Peterson 1993), and with the previous results showing that greater precipitation in the Sacramento Valley was associated with negative *tarsalis* abundance. For spring abundance, correlations improved if winter rather than fall Niño 3.4 SSTA was used. Correlations linking fall and winter Niño 3.4 SSTA with summer abundance were weaker and more scattered than the correlations with spring

abundance. Interestingly, in the Sacramento and San Joaquin Regions, spring Niño 3.4 SSTA proved to be positively correlated with spring abundance but negatively correlated with summer abundance, perhaps reflecting a tendency for peak abundance to shift from spring to summer during prominent Niño 3.4 episodes.

## DISCUSSION

A statewide array of California mosquito abundance data collected by MVCDs during the last two to five decades demonstrated that climate fluctuations, here represented by antecedent and contemporaneous temperature, precipitation, snow pack, and sea surface temperature, exerted significant influences on *Cx. tarsalis* abundance during spring and summer (Table 1). The strength and character of the responses to each climate measure varied, depending on season and region. Climate linkages to spring and summer abundance were not limited to individual months or seasons, but rather appeared to relate to a

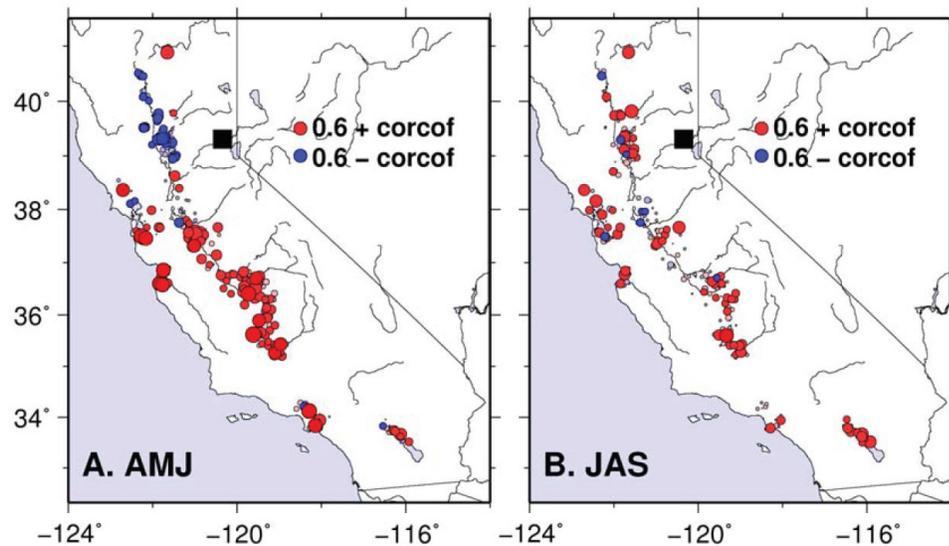


Figure 5. Correlations of *Cx. tarsalis* abundance measured at 282 sites from 1950 to 2000 during A) spring (AMJ) and B) summer (JAS) with April 1 snow water equivalent measured at Donner summit in the Sierra Nevada (shown as black square on map).

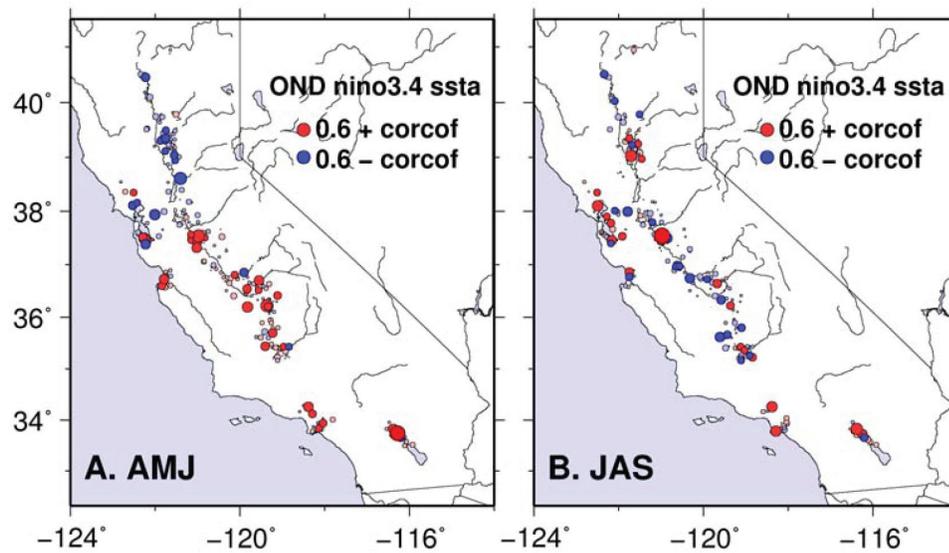


Figure 6. Correlations of *Cx. tarsalis* abundance measured at 282 sites from 1950 to 2000 during A) spring (AMJ) and B) summer (JAS) with the previous fall (OND) Niño 3.4 SST anomaly.

chain of climate events that began to develop as early as the preceding fall and often continued to be discernable through early summer. Considerable variability among climate linkages and mosquito abundance was apparent at traps within regions, even when the overall tendency was significant. These independent trends may be associated with very local climate conditions that occur at spatial scales finer than the regional measures used in this study and/or other factors not captured by climate.

In general, spring *Cx. tarsalis* abundance appeared to be more predictable from antecedent climate variation than summer abundance. Correlations between winter climate measures and spring abundance were stronger than correlations between winter climate and summer abundance or between spring climate and summer abundance. Summers in most parts of California and in most years are hot, so that summer temperature tends not to be a limiting factor for *Cx. tarsalis* activity or immature development. Summer precipitation is minimal, and so most larval habitats in summer are created by irrigated agriculture and/or effluent from municipal, animal husbandry or wetland water management and indirectly by the volume of winter precipitation stored by various mechanisms.

Although there were marked differences among regions, antecedent and contemporaneous wetter, and to some extent warmer, conditions generally were associated with increased *Cx. tarsalis* abundance. The association between winter precipitation and snowpack was especially predictive of increased spring *Cx. tarsalis* abundance in the San Joaquin Region, agreeing with earlier reports (Reeves and Hammon 1962, Wegbreit and Reisen 2000). In contrast, correlations with precipitation and snow pack during the same periods were weak or negative in the Sacramento Region, where surface water was rarely limiting and *Cx. tarsalis* abundance during spring typically low and temperature limited. Spring flooding associated with heavy winter rain or rapid snow melt may reduce larval mosquito habitat (by inundation or flushing), and/or cool spring temperatures associated with wet years would delay *Cx. tarsalis* emergence from diapause, slow development of the immature stages during the initial generation, and result in delayed and lower adult abundance peaks in summer. Because spring temperature and precipitation are negatively correlated in California (Cayan and Peterson 1993), the negative correlation of *Cx. tarsalis* abundance with precipitation in the Sacramento Valley may be a reflection of a more dominant temperature relationship during the spring.

Although warm winter temperatures were correlated consistently with elevated spring *Cx. tarsalis* abundance, these positive correlations were weaker than those for winter precipitation. Warm winter temperatures may expedite the emergence and reproductive activity of the overwintering cohort leading to higher trap counts during spring, provided that surface water sources are available for oviposition and immature development. Interestingly, these positive relationships changed to negative between spring temperature and summer abundance, perhaps because survival of adult *Cx. tarsalis* decreases as a function of

increasing ambient temperature (Reeves et al. 1994). Hot dry summers following dry spring conditions would also limit the number and size of larval habitats, perhaps increasing the effectiveness of mosquito control. For the most part, the temperature associations with *Cx. tarsalis* abundance appeared to be independent from those with precipitation. Positive winter and spring precipitation and temperature anomalies are rarely correlated in California (Cayan and Peterson 1993); however, except for the Sacramento Region, the relationships that emerged in our study indicated that warmer temperatures and heavier precipitation favored increased spring *Cx. tarsalis* abundances (vice versa for diminished abundance), which is counter to the usual precipitation-temperature alignment.

El Niño events, when central and eastern tropical Pacific SSTs become abnormally warm, impact global weather patterns, including the North Pacific jet stream and storm tracks that bring precipitation to California (Glantz 2001). In California, precipitation is affected more dramatically by El Niño events than is temperature, and during strong El Niños, winter precipitation often exceeds normal levels in nearly all of the state's climate divisions (Earth System Research Laboratory 2007). Conversely, La Niña events are associated with a reduction in precipitation in central and especially southern California (Dettinger et al. 2000), often resulting in droughts. Based on the correlations observed in our study, fall and early winter El Niño (La Niña) conditions in the tropics were associated with increases (decreases) in subsequent spring *Cx. tarsalis* abundance throughout California, except for the reverse associations in the Sacramento Region. These relationships were consistent with those linking the spring mosquito abundance to fluctuations in precipitation and snow pack, reinforcing the interpretation that the tropical Pacific climate connection to California mosquito populations operates mostly through its influence on precipitation (Redmond and Koch 1991).

The current research provides an important step towards the use of antecedent climate variations to forecast mosquito abundance in California. Ongoing analyses are trying to merge the many relationships shown here into multivariate models capable of predicting seasonal changes in *Cx. tarsalis* and other mosquito species abundance, with due recognition of underlying long-term trends associated with changes in human population density, land use, cropping strategies, mosquito control, and perhaps global warming.

#### Acknowledgments

This research was funded by the Climate Variability and Human Health and the California Applications Programs, Office of Global Programs, NOAA; Decision Support through Earth Science Results, NASA; Research Grant AI55607 from the National Institute of Allergy and Infectious Diseases, NIH; the Coachella Valley, Greater Los Angeles, Kern and Sacramento-Yolo Mosquito and Vector Control Districts, and special funds for the Mosquito Research Program allocated annually through the Division

of Agriculture and Natural Resources, University of California. We are especially indebted to the corporate members of the Mosquito and Vector Control Association of California who granted us permission to utilize their surveillance data.

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