

Bluetongue virus, spread by *Culicoides* gnat, causes mouth ulcers in sheep and lameness due to edema, inflammation of the hoof wall, and muscle damage. Abortion and congenitally deformed lambs may also occur.

Clues to control of bluetongue virus

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Control strategy aimed at early life stages of vector gnats is one possibility

Bluetongue disease of California livestock and wildlife is most severe in sheep and in certain species of wild ruminants, notably white-tailed deer and antelope. Caused by a virus, the disease is generally subclinical in cattle, but subtle losses associated with reproductive failure may be more significant than producers realize. Cattle are considered a primary reservoir host for the virus, which then may be spread to other more susceptible species.

The disease apparently originated in southern Africa, where many serotypes have been isolated and identified in wild and domestic ruminants. Bluetongue was first diagnosed in the United States in the late 1940s and was present in California by 1952. Twenty-four serotypes are recognized worldwide, of which five are known to exist in the United States and four are in California (types 10, 11, 13, and 17).

Statewide serological surveys in 1978-80 by B.I. Osburn, J.L. Stott, and coworkers

at the School of Veterinary Medicine, University of California, Davis, demonstrated that at least 41 percent of cattle, 42 percent of sheep, and 21 percent of goats had been exposed to bluetongue. The virus was more prevalent in central and southern California; animals in the north had less exposure to bluetongue. Bluetongue virus serotype 11 was most commonly isolated from infected animals.

Bluetongue affects animal agriculture in several ways. Infected animals often feed poorly because of ulcers in the mouth and lameness due to edema, inflammation of the hoof wall, and muscle damage. Abortion and congenitally deformed calves and lambs also occur, and infected sheep often succumb to secondary pneumonia. Additionally, there are international trade restrictions on animals and semen from bluetongue-endemic areas to countries free of the disease.

Although the virus can be transmitted from an infected dam to her offspring through the placenta or from an infected bull to a heifer or cow venereally (shed in the semen), bluetongue is transmitted primarily by blood-sucking *Culicoides* gnats (fig. 1). Knowledge of the gnat's biology and details of its role in virus transmission are of considerable importance in controlling this disease.

Vector life cycle

The primary transmitting agent of bluetongue virus in the United States is *Culicoides variipennis*, a blood-sucking gnat about 2.5 mm (0.1 inch) long. A few workers feel that *C. variipennis* consists of multiple subspecies or perhaps two species. Since behavioral and morphological characteristics vary considerably with habitat and temperature, most workers currently consider *C. variipennis* to be a single species.

The basic biology is similar regardless of geographic region or habitat. Eggs are laid at dusk or at night just above the waterline, primarily on shallow, silty mud banks at the edges of ponded or slowly moving water, particularly when it is polluted with manure. Eggs hatch in about three days, and the four larval stages develop in the surface mud at the pond edge, presumably feeding on bacteria, algae, and organic detritus. Larval development time varies with temperature and perhaps larval dietary factors, but takes two to four weeks during warm weather. Pupation takes place above the waterline, and adults emerge about three days later.

After a delay of one to two days, females are ready to seek a blood meal (needed for egg development), often from the most abundant mammals in the area. Cattle, sheep, rabbits, and even pigs have been reported as hosts. Humans are seldom attacked, though this trait apparently varies in different gnat populations. After a blood meal, egg development requires about three days.

Gnat distribution

From 1978 to 1980, larval and adult gnat sampling surveys were done in 10 counties, from Butte and Mendocino in the north to Imperial in the south, to determine the distribution of *C. variipennis* in California and begin to characterize larval development sites. The gnat was widely distributed and is probably present essentially throughout the state, except at high altitudes or in areas without water sources.

Some larvae occurred along natural waterways, but most larval sites were man-made. Urban/industrial sources, such as oxidation ponds, supported light to moderate densities. Dense populations (more than 100 larvae per 25 cc of mud) generally were found in agricultural areas. Of these, dairy wastewater lagoons were prime sources; 55 percent of 113 dairy lagoons were positive for this species. In southern California, as many as 7,600 larvae have been recovered from only 30 cc (1 ounce) of mud in these habitats. Some large dairy lagoons produce literally millions of gnats per week during late summer and fall emergence periods.

Studies on biology and dispersal

Adult *C. variipennis* are most active at dusk, with a smaller peak of activity at dawn. We have observed that winds decrease flight activity, although some flight may persist close to the ground even during breezy periods. During cool weather, flight may begin well before sunset. Activity at night also is common, especially during moonlit periods, provided temperatures are above 50°F. We usually collect adults with small suction

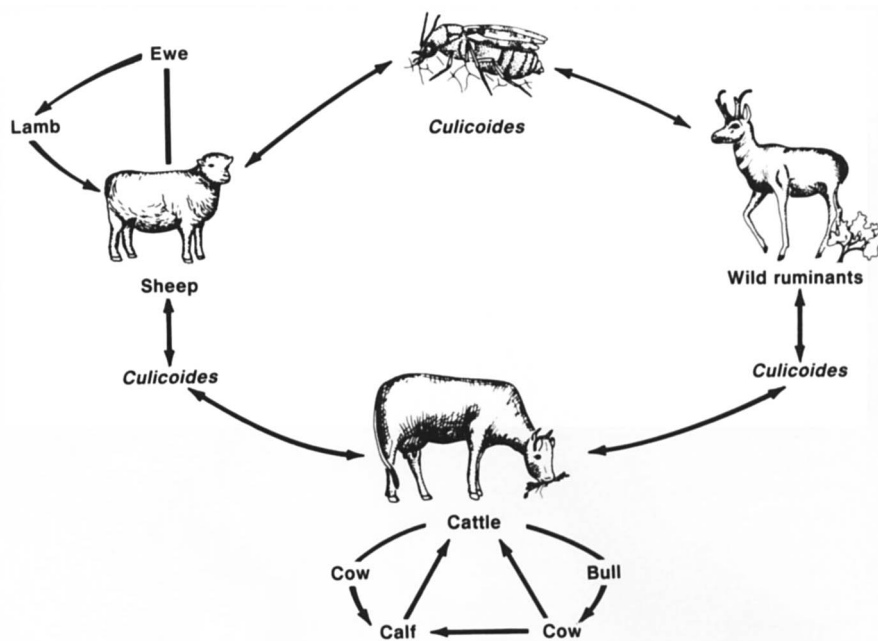


Fig. 1. Transmission cycle of bluetongue virus. Biting gnats (*Culicoides*) take blood meal from virus-infected animal, and virus replicates in the insect's body. The virus can be introduced into a susceptible ruminant when the gnat refeeds 10 to 14 days later. Venereal and transplacental transmission are minor routes, best known in cattle, but transplacental transmission also can occur in sheep.



Culicoides variipennis (adult, above, and pupa, left) is widely distributed, especially in southern areas of the state. It often occurs in sites such as dairy lagoons, where dense populations expose animals to high biting intensity.

traps baited with carbon dioxide, which particularly attracts host-seeking females. Males often form mating swarms 1 to 2 meters above the ground near objects that contrast with the background in color or height.

We have shown that adult males and females often feed on sugar sources, such as flower nectar and plant sap. This behavior probably contributes substantially to survival and dispersal capabilities of the gnats in nature. In southern California, UC research has shown that the gnats are active to some extent year-round, although numbers are very small in late winter and early spring (February to April). The presence of blood-feeding and reproducing adult gnats in the winter raises the possibility of the insect serving as a reservoir of bluetongue, but this has not been proved. In more northerly regions of the state, gnat activity ceases in late fall, and the *Culicoides* overwinter in mud in the late larval stages, emerging as adults the following spring (April to May).

We have collected females that have completed at least five egg batches (at least five blood meals) in southern California. The ability of females to survive and complete several ovarian cycles is a critical component of bluetongue transmission, since they must live at least 10 to 14 days after feeding on a viremic host for the virus to replicate in the insect and be transmitted to another ruminant. Many California populations of *C. variipennis* are susceptible to virus replication, although resistant populations are known.

The basis of susceptibility is still poorly understood, but it appears to be influenced by both genetic and environmental factors.

This species is a good colonizer of new developmental habitats. We have found early larval instars within a week of the flooding of a new dairy lagoon. In California, gnats have been recaptured up to 2 miles from their emergence site. Younger females show a greater tendency to disperse; dispersal to traps baited with carbon dioxide generally is upwind from the developmental sites.

We sample immature *C. variipennis* by removing portions of the mud and rearing the larvae, sieving them, or extracting them by salt flotation. Larval populations peak in the fall and can average over 500 larvae per 30 cc of mud in southern California dairy lagoons (fig 2.) Densities often are much lower during the winter, averaging less than 10 larvae per 30 cc.

Fluctuations in larval numbers and age structure can be extremely valuable in determining when the successive generations emerge. In southern California, the generation interval appears to be close to seven weeks during cooler months, but shortens to 25 to 35 days during the hot summer months. Some overlap occurs in these generations, but it is significant that they remain fairly distinct, even late in the season.

Our studies have shown that eggs and most of the first two larval stages occur at or above the waterline, while the larger third and fourth larval stages usually are

below the waterline. The eggs and early larval stages of these gnats are extremely small (less than 1 mm), but late fourth-stage larvae are 8 to 9 mm in length. Our experiments also have shown that larvae strongly avoid deeply shaded areas, preferring shallow mud exposed to the sun. This behavior is not related to temperature or time of day as much as to light, and may be related to larval feeding habits.

Implications for control

Control of these disease vectors requires a thorough knowledge of their life cycle and ecology and their relationship to disease transmission. California populations of *C. variipennis* are widespread and, particularly in southern areas, have several characteristics that encourage virus transmission. First, the populations are dense, exposing animals to high biting intensities. Second, the gnats are, in general, very susceptible to bluetongue virus replication. Third, survival of adult females appears to be more than sufficient to allow transmission, particularly in light of the generally high biting intensities and susceptibility.

While much remains to be learned about the basic biology, we now have enough information to examine the potential of specific vector control strategies. Since the generations are distinct and are to some extent predictable, efforts can be directed against certain life stages that may be more susceptible. The very early stages, for example, because they are above the waterline and are so small, might be susceptible to scheduled water level fluctuations, insecticide applications, or both. Our observations suggest that deeper, steep-sided ponds are not particularly suitable habitats. Likewise, it appears that ponded water sources with either no manure or a great deal of manure are poor producers of the gnats. These relationships are yet to be quantified.

Sources such as dairy lagoons are unstable, and it is difficult to define the effects that management practices can be expected to have on their gnat populations. Extrapolating these to predict their effect on virus transmission is still more complex, and so we are not yet able to recommend vector control strategies. We are now conducting studies in experimental dairy lagoons, which we hope will lead to the reduction of bluetongue disease in California livestock.

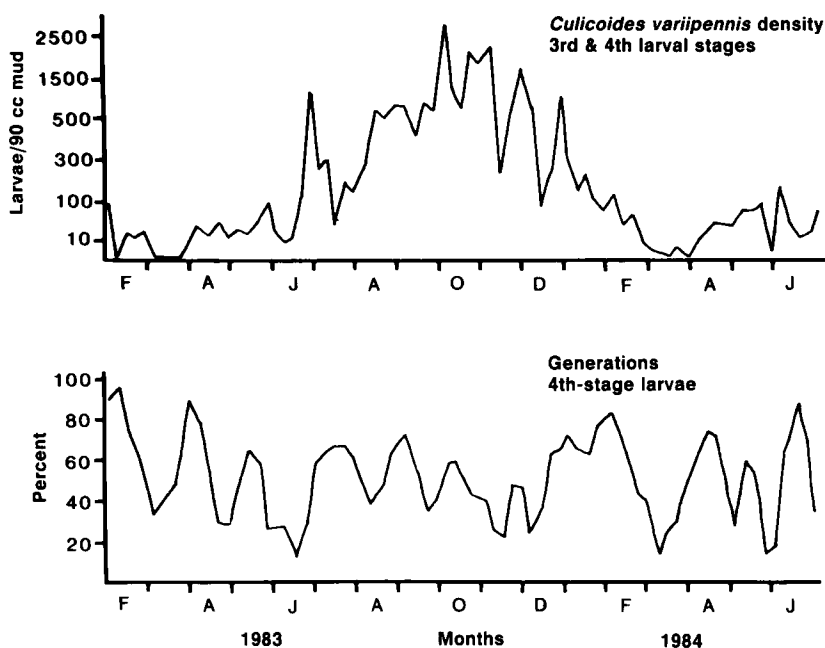


Fig. 2. Highest *Culicoides variipennis* larval densities in southern California dairy lagoon occur in the fall (L3 and L4 are the last two larval stages). Peaks in generations (lower graph) correspond roughly to adult gnat emergence.

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