Factors affecting the spread of *Culicoides brevitarsis* at the southern limit of distribution in eastern Australia

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Summary

Culicoides brevitarsis Kieffer is the main vector of bluetongue and Akabane viruses in Australia. Its threat to animal health and livestock exports requires that areas free of the vector and viruses be defined clearly. In New South Wales, survival of the vector over winter is limited to the northern coastal plains. *C. brevitarsis* therefore has to reinfest areas outside the endemic area each year. Models have been developed to predict the extent and nature of its movements. It can move at different rates and this is partly due to significant delays of movement due to the barrier formed by the altitude of the Great Dividing Range. *C. brevitarsis* subsequently retains a coastal distribution in most years. At the end of the season, the times when activity would effectively cease can be estimated from temperature data. These data allow evidenced-based conclusions on zonal and seasonal freedom to be made in combination with light trap monitoring.

Keywords

Altitude – Australia – Bluetongue – *Culicoides brevitarsis* – Dispersal – Models – Vector freedom.

Introduction

There are several species of biting midge from the genus *Culicoides* (Diptera: Ceratopogonidae) that transmit viruses to animals in Australia (14). *Culicoides brevitarsis* Kieffer is the main species responsible for the transmission of bluetongue and Akabane viruses to livestock (10). In New South Wales (NSW), *C. brevitarsis* and the viruses move from the endemic mid-northern/northern coastal plain in spring-summer (2, 3). Establishment and survival outside the endemic area then depends primarily on temperature (4), moisture and habitat/host availability. *C. brevitarsis* normally retains a coastal distribution and virus transmission occurs within its dispersive limits.

The patterns of occurrence of *C. brevitarsis* and virus transmissions in NSW have been consistent with their failure to survive winter away from the endemic area. The vector then makes passive and gradual seasonal movements (that probably occur regularly) down the southern coastal plains and up coastal valleys towards the west (2, 3). This is consistent with epidemiological evidence which suggests that the long-distance spread of many viruses is related to the wind-borne dispersal of midge vectors (6, 13).

Threats to animal health and livestock exports in Australia require that vector- and virus-free areas be clearly defined. In NSW, these can be determined from knowledge of vector survival and dispersal, supported by seasonal monitoring with light traps. The key elements of this determination require predictions of times when vector activity ceases before winter and estimates of the potential for the vector to survive over winter (1) as well as predictions of probable reinfestation in areas where it cannot survive winter.

Our aims were as follows:

1) to model the observed dispersal of *C. brevitarsis* to the south and west of its endemic area in NSW by considering that the Hunter Valley was the most likely route of dispersal to the west
2) to model the dispersal of *C. brevitarsis* up three major coastal valleys leading from the endemic mid-north coast to the western slopes and plains of NSW, taking into account the effect of a barrier formed by the altitude and escarpment of the Great Dividing Range.

Materials and methods

The two aims were investigated in separate studies. The first has been described previously (5). This study provided predictive models for *C. brevitarsis* movement down the coastal plain and up the Hunter Valley towards the western slopes and plains where there are high densities of susceptible cattle and sheep. *C. brevitarsis* was sampled at selected sites throughout NSW from 1990 to 1999. Data were compiled based on the time that *C. brevitarsis* first occurred at a site. The objective of the analysis was to model the dispersal data as a linear function of site distance from the endemic area and of weather variables (temperature, rainfall, wind frequency from different directions and wind speed). The area of dispersal was divided into the three regions based on observed biological and geographical constraints. Four key conclusions were made, as follows:

- the dispersal of *C. brevitarsis* can be explained by distance from the endemic area in NSW.
- the movement of *C. brevitarsis* is dependent on temperature and wind speed from northerly and easterly directions.
- the models predict times of first occurrence within regions down the southern coastal plain or up the Hunter Valley towards (but rarely reaching) the western slopes and tablelands
- *C. brevitarsis* moves at different rates in different areas. These were mainly expressed as significantly slower movement up the Hunter Valley than down the coastal plain and suggested that the speed of dispersal could be influenced by geographical features, such as urban areas, increasing altitude and the escarpment of the Great Dividing Range acting as physical barriers.

There are several valleys that originate in the eastern escarpment of the Great Dividing Range and are adjacent to the endemic coastal area (Fig. 1). The valleys are approximately oriented east to west and all movements of *C. brevitarsis* were assumed to be in a westerly direction with the prevailing winds. A single light trap was placed at each of fifteen sites in and beyond three of these valleys for eight seasons from 1995 to 2003 (Fig. 1). Seven additional sites were sampled in the Hunter Valley from 1993 to 2003 to test if the slower movement previously recorded was related to altitude (5). The altitudes and distances from the coast were recorded for each site. *C. brevitarsis* activity and numbers were recorded from catches in standardised light traps (7). Each trap had a 3.2-V globe and a small downwardly-directed fan driven by three D-cell batteries. A photoelectric cell automatically triggered operation at sunset. The traps were suspended about 2 m above the ground in areas with cattle. Collections were made into plastic bottles containing 70% alcohol. *Culicoides* spp. were separated from other insects under a binocular microscope, *C. brevitarsis* was identified by its wing pattern and numbers were recorded.

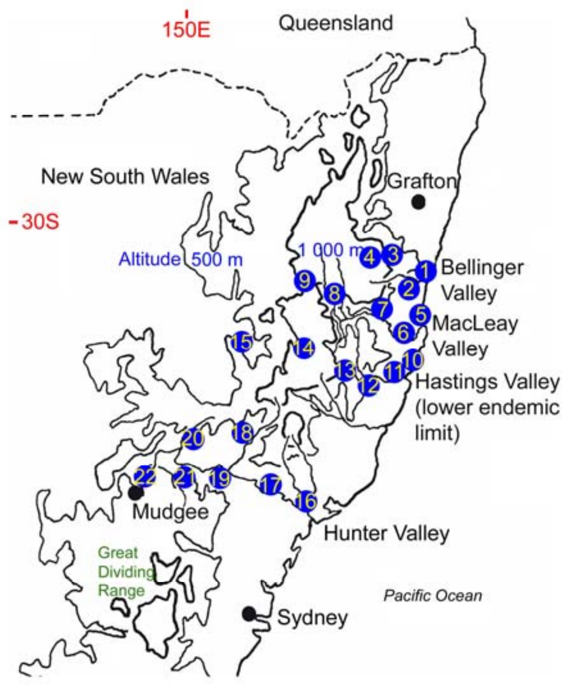

Figure 1
Locations of light traps for *Culicoides brevitarsis* in four coastal valleys of New South Wales, Australia from 1995 to 2003

The sites were sampled over a 29-week period when *C. brevitarsis* was active (October to May in each year). Catches were made over two nights, three times per month with the week of the full moon excluded. Two data sets were compiled.

The first was based on the time that *C. brevitarsis* first occurred at a site, regardless of any future event.

The second aim of this study was based on the times when *C. brevitarsis* first occurred and when it also occurred for a second time at a site in the same season. A second occurrence was defined as happening when *C. brevitarsis* was found at a site at least three zero sampling weeks after the first record, a period long enough to assume that *C. brevitarsis* had not previously been established. A second occurrence was treated as a new event and the result of repeated movements.

First and second occurrence models were developed from their respective data sets. The three valleys and the Hunter Valley data sets were analysed separately. The methodology used the same principles as those employed by Bishop *et al.* (5) except that it was based on weeks instead of days. S-Plus (9) was used to fit a generalised failure time model to the data (15, 16). The relationship between time, distance and altitude was written in the z variable, as follows:

$$\mathbf{z} = \{\mathbf{t} - [b0 + b1\,\mathbf{D} + b2\,\mathbf{A}]\} / \sigma$$

where the observed value **t** = time and follows the normal distribution, **A** = altitude (m) and **D** = distance (km) from the coast for the three coastal valleys or **D** = $\log_e$ distance (km) from the first site in the Hunter Valley.

Results

The hazard function expressing the first time that *C. brevitarsis* was found at sites is given as follows:

$$\mathbf{z} = \{\mathbf{t} - [-3.3\ (\pm 1.0) + 0.18\ (\pm 0.02)\ \mathbf{D} + 0.0048\ (\pm 0.0022)\ \mathbf{A}]\}/2.2.$$

The hazard function expressing the time taken for *C. brevitarsis* to be found a second time is given as follows:

$$\mathbf{z} = \{\mathbf{t} - [-3.3\ (\pm 1.1) + 0.16\ (\pm 0.026)\ \mathbf{D} + 0.011\ (\pm 0.0025)\ \mathbf{A}]\}/2.2.$$

First and second occurrences were significantly related to the distance from the coast and the altitude of sites ($P < 0.05$). These functions can be used to estimate the time when *C. brevitarsis* would reach any site in the respective valleys for a first or second time.

The time taken for *C. brevitarsis* to travel a set distance for the first time was extended by 0.48 (±0.22) weeks (approximately 3.4 days) for every 100 m increase in altitude.

The time taken for *C. brevitarsis* to travel a set distance for the second time was extended by 1.14 (±0.24) weeks (approximately 8.0 days) for every 100m increase in altitude.

The hazard function representing the time that *C. brevitarsis* was observed at sites in the Hunter Valley is given as follows:

$$\mathbf{z} = \{\mathbf{t} - [-0.7\ (\pm 1.6) + 2.1\ (\pm 0.53)\ \mathbf{D} + 0.037\ (\pm 0.07)\ \mathbf{A}]\}/2.0.$$

Occurrence was also related to distance travelled and the altitude of the sites ($P < 0.05$).

Discussion

Knowing areas of Australia where *C. brevitarsis* is permanently or seasonally absent is necessary to define the epidemiology of bluetongue and Akabane viruses and is critical for the establishment of protocols for the livestock export industry. Any incursions into western regions of NSW are a serious threat to the maintenance of a certifiable virus-free area. This paper reports on defining conditions under which *C. brevitarsis* moves to areas that are normally free of both vector and virus.

The usual dispersal of *C. brevitarsis* down the coastal plain of NSW is a function of distance, temperature and wind conditions but can also be explained solely by the distance to be travelled by the vector (5). Several coastal valleys (Fig. 1) provide direct routes to the west but movements up these valleys are delayed by both distance and altitude of the Great Dividing Range. Delay and declining temperatures restrict movements to the top of the Range. Slower movement up the Hunter Valley (5) was also due to its distance from the endemic area and the effects of increasing altitude. Therefore, distribution normally remains primarily along the coast. Exceptions are infrequent and possibly only occur under chance weather conditions (11, 12).

Conclusions

There is strong experimental evidence to support the argument for determining areas of NSW that are free of vector and virus. It has been shown that temperatures normally limit the over-wintering survival of *C. brevitarsis* to the northern coastal plain. Areas where it cannot survive have been calculated from historical temperature data and can also be calculated for any given year (1). *C. brevitarsis* must therefore reinfest areas outside the endemic area in most years. The dispersal models used enable the prediction of the times of possible occurrences to the south and west of the endemic area. The barrier formed by the Great Dividing Range makes a significant contribution to *C. brevitarsis* retaining a coastal distribution. There are possibly some exceptions, but any abnormal incursions can be detected from a network of light traps controlled by the National Arbovirus Monitoring Program (8). Should *C. brevitarsis* reinfest an area, temperature data can be used to estimate the time when its activity would effectively cease at the end of the season (1). In combination, the predictions of first, second and last occurrence of *C. brevitarsis*, and survival probability away from the endemic area, lead to confident evidence-based conclusions on zonal and seasonal freedom.

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