Possible Introduction of Epizootic Hemorrhagic Disease of Deer Virus (Serotype 2) and Bluetongue Virus (Serotype 11) into British Columbia in 1987 and 1988 by Infected *Culicoides* Carried on the Wind

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ABSTRACT

Outbreaks of epizootic hemorrhagic disease of deer and of bluetongue began in British Columbia in August and October 1987 respectively and recrudescence of infection by both viruses was detected the following year in August. Weather records for up to 18 days before the initial outbreaks of disease, isolation of virus or seroconversion were examined to determine if the viruses could have been introduced by infected *Culicoides* carried on the wind. Data on temperature, rainfall, wind speed and direction and pressure together with backward trajectory analysis showed that there were suitable winds which could have introduced *Culicoides* infected with epizootic hemorrhagic disease of deer virus on 13 August 1987 (14 days before disease was observed), *Culicoides* infected with bluetongue virus on 1 October 1987 (7 days before virus was isolated and 13 days before disease in sheep) and *Culicoides* infected with bluetongue or epizootic hemorrhagic disease of deer viruses on 20 July 1988 (15 days before seroconversion was detected). The arrival on 13 August 1987 coincided with the passage of a cold front and rain and that on 1 October 1987 with a fall in temperature and calm winds. The source of the *Culicoides* before arrival could have been the Okanogan Valley as far south as the junction of the Okanogan and Columbia rivers in Washington, USA. Flight would have been at temperatures of 12.6°C or higher and at heights up to 1.5 km.

RÉSUMÉ

Des éruptions de maladie hémorragique du cerf (MHC) et de fièvre catarrhale du mouton (FCM) apparurent en Colombie-Britannique respectivement en août et en octobre 1987. Une recrudescence de l'infection par ces deux virus fut décelée au mois d'août de l'année suivante. On examina les relevés météorologiques rétrospectivement jusqu'à 18 jours préalablement à l'éruption initiale de la maladie, ainsi que les résultats de l'isolement viral ou la présence de séroconversion, afin de déterminer si les virus en cause avaient pu être introduits par des moustiques du genre *Culicoïdes*, transportés par le vent. L'analyse des données concernant la température, la pression barométrique, les précipitations, la vélocité et la direction des vents ainsi que l'étude de leurs mouvements rétrogrades, a permis de mettre en évidence la présence de vents favorables qui auraient pu introduire des *Culicoïdes* infectés par le virus de la MHC le 13 août 1987 (14 jours avant que la maladie soit observée), des *Culicoïdes* infectés par le virus de la FCM le 1er octobre 1987 (7 jours avant que l'isolement viral soit effectué et 13 jours avant l'observation de la maladie chez les moutons), et des *Culicoïdes* infectés par l'un ou l'autre des virus le 20 juillet 1988 (15 jours avant la détection d'une séroconversion). L'arrivée du 13 août 1987 coïncida avec le passage d'un front froid et de pluie, tandis que celle du 1er octobre 1987, avec une baisse de température et des vents faibles. Les *Culicoïdes* infectés auraient vraisemblablement pu provenir de la Vallée d'Okanagan ainsi que des régions situées aussi au sud que la jonction des rivières Okanagan et Columbia dans l'état américain du Washington. Les insectes se seraient déplacés à une hauteur pouvant atteindre 1,5 km à une température de 12,6 °C ou plus. (*Traduit par Dr Richard Drolet*)

INTRODUCTION

In 1987 there were outbreaks of epizootic hemorrhagic disease of deer (EHD) and bluetongue (BT) in the Okanagan Valley, British Columbia and EHD serotype 2 and BT serotype 11 viruses were isolated (1). In the following year, 1988, seroconversion to BT11 and EHD2 virus serotypes was detected in sentinel cattle and BT virus serotype 11 was later isolated (2). The present analysis was undertaken to determine if the first outbreaks of each disease in 1987 or the seroconversion in 1988 could have resulted from the introduction of EHD2 or BT11 virus serotypes by infected *Culicoides* carried on the wind from further south in western USA. Carriage on the wind of infected *Culicoides* was shown to be a possible method of introduction of bluetongue into Portugal, Cyprus and Florida (3–5).

MATERIALS AND METHODS

Clinical disease due to EHD virus was first seen near Osoyoos (Fig. 1) in deer on 27 August 1987 (6, L. Karstad,

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Submitted December 6, 1990.

A. Peatt, G.C. Dulac, D. Ward, unpublished observations, 1988). Bluetongue virus serotype 11 was isolated first from the blood of a heifer collected on 8 October 1987 near Okanagan Falls and antibodies to BT virus were detected in the heifer's blood collected on 26 October 1987 (G.C. Dulac, C. Dubuc, unpublished observations, 1988). Clinical disease due to BT virus occurred in sheep on 14 October 1987 at Oliver and antibodies to BT virus were found in sheep blood collected on 19 October 1987 (L. Karstad, A. Peatt, G.C. Dulac, C. Dubuc, D. Ward, unpublished observations, 1988). In 1988 seroconversion to BT serotype 11 and EHD serotype 2 viruses was first detected in cattle bloods collected on 4 August at Oliver and BT serotype 11 virus was isolated from blood collected in early October (2, G.C. Dulac, unpublished observations, 1989). Periods during August, September and October 1987 and July 1988 were examined for days on which flight of *Culicoides* could have occurred. The possible interval before disease, isolation of virus or seroconversion had to take account of the incubation period of EHD and BT in the deer and sheep (5–11 days), the minimum time required for development of EHD and BT viruses in *Culicoides* before transmission (7–10 days), the first appearance of BT viremia in cattle (2 days onwards) and the period after infection for antibodies to either virus to develop (10 days onward) (3–5, 7–9).

The six-hourly surface and 12-hourly 850 mb daily weather maps of the Canadian Climate Centre, the surface daily weather maps of the National Weather Center, USA and the Meteorological Summaries for Penticton Airport, British Columbia were examined for temperature, precipitation (rain), wind speed and direction, pressure and the position of fronts. In addition backward trajectories of winds were computed for every 6 h for 120 h starting at three levels in the boundary layer (1000, 900 and 850 mb) at approximate heights of 0.1, 1.0 and 1.5 km above sea level as previously described (5, 10). Osoyoos, British Columbia was chosen as the starting point for the trajectories as the area where EHD was first reported. It is the closest town to the US-Canadian border at the southern end of the Okanagan Valley (Fig. 1).

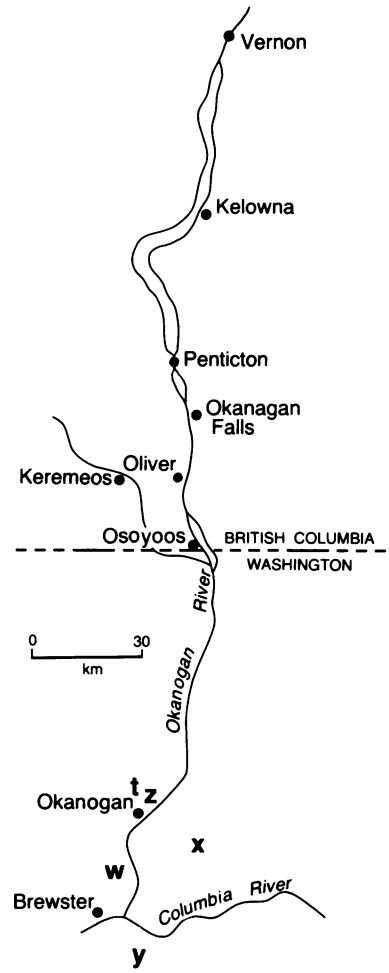

Fig. 1. Location map of the Okanagan Valley, British Columbia, Canada and of the Okanogan Valley, Washington, USA.
t — z: location of backward trajectories of winds 6 h before arrival at Osooyos —
t — 1000/900 mb, 13 August 1987 1800 GMT
w — 850 mb, 13 August 1987 1800 GMT and 850 mb, 20 July 1988 1800 GMT
x — 1000/900 mb, 2 October 1987 0000 GMT
y — 850 mb, 2 October 1987 0000 GMT
z — 1000/900 mb, 20 July 1988 1800 GMT.
- - - - - - : US/Canada border.

RESULTS

In the period 10–25 August 1987 backward trajectories indicated that apart from 13 August the sources of winds were to the west (8 days), northwest (1 day), north (1 day), northeast (3 days) and east (2 days). From 13 August 1200 Greenwich Mean Time (GMT) (0500 local time) to 14 August 0600 GMT (13 August 2300 local time) the sources of winds were to the south. In Fig. 1 can be seen the locations of backward trajectories of winds at 1000/900 mb and 850 mb (corresponding to surface, 1000 m and 1500 m above sea level respectively) 6 h before arrival at Osoyoos at 1800 GMT (1100 local time). On 12 August a cold front lay off the coast of British Columbia; it moved eastwards on 13 August and dissipated as it crossed British Columbia. Showers were reported in the morning and heavy rain in the evening of 13 August at Penticton. Southerly winds were blowing at a mean speed of 13 kmh^{-1} and the distance of 110 km from the junction of the Okanogan and Columbia rivers in Washington State to Osoyoos would have taken a flight time of 8.5 h. If the *Culicoides* had commenced the flight on the late evening of 12 August they would have arrived on the morning of 13 August before the morning showers. Temperatures in the Okanagan Valley were from 15.6°C to 18.1°C during the flight.

During the period 20 September to 6 October 1987 backward trajectories showed sources of winds 12 h previously to the west (3 days), northwest (5 days), east (1 day), south (5 days) and southwest (2 days). On one day it was calm. Southwesterly and southerly winds blew from 20–23 September; on 22 and 23 September the winds were light. There were southerly winds from 1800 GMT on 1 October (1100 local time) until 0000 GMT on 3 October (1700 local time 2 October). Winds at 850 mb arriving at Osoyoos at 0000 GMT on 2 October (1700 local time on 1 October) had their origin 6 h previously not far from the junction of the Okanogan and Columbia rivers (Fig. 1). With windspeeds of 19 kmh^{-1} the distance of 35 km from Osoyoos to Okanagan Falls would have been covered in 1 h 50 min. Thus *Culicoides* infected with BT virus could have started their flight near the junction of the two rivers at 1100 local time on 1 October 1987 and landed near Okanagan Falls (site of first virus isolation) about 1900 local time. Flight would have taken place during the day, when temperatures in the Okanagan

Valley were between 13° and 21°C. Night temperatures for the beginning of October were between 4° and 10°C. The minimum temperature for flight of *Culicoides* was found to be 10°C (11) and the fall of temperature on the evening of 1 October 1987 together with calm conditions from 1900 local time onwards would have contributed to the landing of the *Culicoides*.

In 1988 backward trajectories were examined for the period 13–31 July. On six days winds were from the west, nine days from the northwest, one day from the north, one day from the east, one day from the south and one day from the southwest. The day on which winds blew from the south was 20 July and temperatures during the night of 19–20 July were between 12.6° and 19°C. The locations of backward trajectories of winds at 1000/900 mb and 850 mb 6 h before arrival at Osooyos on 20 July at 1800 GMT (1100 local time) are shown in Fig. 1. At windspeeds of 12–15 kmh^{-1} the flight of infected *Culicoides* from the junction of the Okanogan and Columbia rivers to Oliver (130 km) would have taken 8.7 to 10.8 h.

The interval between the suggested day of arrival of *Culicoides* infected with EHD virus (13 August 1987) and disease in deer (27 August 1987) — 14 days — lies within the incubation period for EHD and the time for development of EHD virus in the midge. If BT virus had been introduced by infected *Colicoides* between 20 and 23 September 1987, the interval before virus isolation from the heifer and before disease in sheep would have been 15–18 and 21–24 days respectively. Although flight on these days might have occurred, a more likely day for introduction would have been 1 October 1987. The interval for arrival on that day was seven days before isolation of BT virus and 13 days before disease in sheep. In 1988, if *Culicoides* infected with BT or EHD viruses had been introduced on 20 July, the interval before seroconversion was detected would have been 15 days. On 25 July 1988, five days before the suggested date of introduction, antibody to BT and EHD viruses was not detected in the cattle (G.C. Dulac, unpublished observations, 1989).

DISCUSSION

Bluetongue virus serotype 11 has been detected in previous years in northern California, Oregon and Washington and EHD virus has been reported in Oregon and Washington (12–15). Antibodies to BT and EHD2 viruses were found in Washington in cattle bloods collected in 1985 (J.E. Pearson, A.L. Shafer, G.A. Gustafson, E.A. Carbrey, unpublished observations, 1987). Epizootic hemorrhagic disease of deer virus serotype 2 was reported in Washington in August 1987 and EHD virus serotype 1 was isolated in Washington from a deer, that had died of an hemorrhagic disease on 10 September 1987 (16, G.C. Dulac, unpublished observations, 1988). The junction of the Okanogan and Columbia rivers was taken as a possible source because of its position east of the Cascade Range at the beginning of the Okanogan Valley leading into Canada. The flight of *Culicoides* would have been up the valley on the southerly winds. Epizootic hemorrhagic disease of deer virus serotype 2 and BT virus serotype 11 were detected in the Okanagan Valley but not EHD virus serotype 1. This may be because from 2 September to 12 September 1987 — the period when the deer in Washington was sick — winds from the south were not recorded.

It could be that EHD virus serotype 2 was endemic in the Okanagan Valley and that the outbreak in 1987 was a recrudescence. From 1986 to the beginning of the outbreak in 1987 no evidence of EHD virus activity was observed in native Canadian animals (6). Even if it was a recrudescence, the outbreak would more likely have started in June, when numbers of *Culicoides* are at their first peak (17). With BT the number of cattle in the Valley with antibody to the virus was nine in 1982, one in 1983, 1984 and 1986 and none in 1985 (18). Although recrudescence is a possibility, the late date of BT infection in October 1987 suggests introduction of virus from further south. It is possible that EHD and BT viruses could have been introduced by wildlife moving into the Valley from further south, but evidence for this is difficult to obtain.

Seroconversion to BT and EHD viruses in 1988 could have resulted from the survival of the viruses in adult *Culicoides* or in domestic or wild ruminants during the winter. However seroconversion was not detected until the beginning of August, which, although earlier than the initial outbreak of EHD in 1987 (end of August), is later than the first peak of *Culicoides* in June (17). Overwintering of BT was reported to have occurred in Oregon during the winter of 1973–74, as clinical outbreaks were first seen in June 1974 rather than at the usual time in late summer (13). It is possible that the source of infection for the Okanagan Valley in 1988 could have been virus that had survived the winter in Oregon or further south and been introduced by the movement of infected wild ruminants or by wind carriage of infected *Culicoides* or by a combination of both methods.

No *Culicoides* were trapped for identification and virus isolation during the outbreaks. However, the *Culicoides* involved in transmission most likely belonged to the *C. variipennis* complex, which consists of the subspecies *C. v. variipennis*, *C. v. sonorensis*, *C. v. albertensis*, *C. v. australis* and *C. v. occidentalis* (19). Downes (20), on the other hand, considered *C. variipennis* and *C. occidentalis* to be distinct species with *sonorensis*, *albertensis* and *australis* as subspecies of *C. occidentalis*. Individuals of *C. variipennis* and *C. occidentalis* species were caught in the Okanagan Valley in 1976 and 1977 (17, 20), corresponding to the subspecies *C. v. variipennis*, *C. v. occidentalis* and *C. v. sonorensis* of Wirth and Morris (19). *Culicoides v. sonorensis* is considered to be the main vector of BT virus in terms of vector competence (19,21). The distribution of BT and EHD corresponds with the distribution of *C. v. sonorensis*, *C. v. albertensis* and *C. v. australis* as shown in the map of Wirth and Morris (19) and apart from the Fraser Valley in British Columbia with that of *C. occidentalis* as shown in the map of Downes (20,22). McMullen (17) collected *C. occidentalis* in mid-April (earliest in 1977) and at the beginning of October (latest in 1976) with peaks in late June and late August in 1976. *Culicoides*

occidentalis was trapped at heights up to 1820 m. The introducton of EHD virus by *Culicoides* in August 1987 could have preceded an increase in the population of *Culicoides*, whereas at the time of the introduction of BT virus numbers of *Culicoides* were probably decreasing. Thus BT infection would have been less extensive.

In conclusion the analysis suggests that EHD virus serotype 2 was introduced by infected *Culicoides* on the wind on 13 August 1987 and BT virus serotype 11 on 1 October 1987. Reintroduction of both serotypes by infected *Culicoides* carried on the wind could have occurred on 20 July 1988. In 1987 the arrival of the *Culicoides* coincided with the passage of a cold front and rain in August as has been found on other occasions (5,10,23) and with a decrease in air temperature and change to calm conditions in October; in 1988 no association with a cold front or rain was found. The air temperatures associated with flight were within those previously found and flight would have been at heights up to 1.5 km (3,5,23).

ACKNOWLEDGMENTS

The authors are grateful to their colleagues in Agriculture Canada and Environment Canada for their support. A. Afshar, C. Dubuc, G.C. Dulac, L. Karstad and W.G. Sterritt are thanked for information and advice on the field and laboratory aspects of the outbreaks and Joan Graham for typing the manuscript. The Meteorological Office, Bracknell, England was helpful in providing the senior author with access to North American weather data.

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