Surveillance of Culicoides biting midges in northern Honshu, Japan, during the period of Akabane virus spread

Tohru YANASE1)*, Yoko HAYAMA2), Hiroaki SHIRAFUJI1), Toshiyuki TSUTSUI2) and Yutaka TERADA3)

1)Kyushu Research Station, National Institute of Animal Health, NARO, 2702, Chuzan, Kagoshima 891-0105, Japan
2)Viral Disease and Epidemiology Research Division, National Institute of Animal Health, NARO, 3-1-5, Kannondai, Tsukuba, Ibaraki 305-0856, Japan
3)Bacterial and Parasitic Disease Research Division, National Institute of Animal Health, NARO, 3-1-5, Kannondai, Tsukuba, Ibaraki 305-0856, Japan

ABSTRACT. A surveillance of Culicoides biting midges with light suction traps was conducted in the northern region of Honshu, main island of Japan, during the summers and autumns of 2009 and 2010. A total of 106 trap collections across 37 cattle farms were investigated for the structure and distribution of Culicoides species. Forty-thousand and one hundred forty-nine specimens of Culicoides biting midges were identified at the species level, and ≥19 species were included in the specimens. Culicoides oxystoma, which is a known major vector of Akabane virus (AKAV), appeared not to have expanded in northern Honshu during the surveillance. Of the potential AKAV vectors suggested by a previous laboratory experiment, C. tainanus and C. punctatus widely infested cowsheds across northern Honshu. The AKAV circulation was confirmed by serological surveillance of sentinel cattle in northern Honshu during the summer and autumn of 2010 and, consequently, >200 calves affected by the virus were identified as of spring 2011. Our surveillance demonstrated that C. tainanus and C. punctatus were widely spread and often dominated at cattle farms in/around the seroconverted regions, and our results thus suggest that these species played a critical role in the AKAV transmission in 2010. Because the distribution ranges of C. tainanus and C. punctatus cover almost all of mainland Japan, a potential risk of AKAV transmission might be expected even in areas outside the range of C. oxystoma.

KEY WORDS: Akabane virus, arbovirus, congenital malformation, entomological surveillance, vector competence
detected from limited Culicoides species including C. brevitarsis in Australia [9, 10] and C. imicola in the Middle East [3, 43]. Because AKAV has been most frequently isolated from C. oxystoma, this species is considered the most incriminated vector in Japan [14, 19, 54].

A laboratory experimental infection also indicated that C. oxystoma has capacity as a vector of AKAV [53]. In the past, the typical epidemic regions of Akabane disease have been limited to the southern half of Japan, including Kyushu, Shikoku, and the western part of the main island of Honshu, and these regions overlapped with the distribution range of C. oxystoma. However, several epidemics of Akabane disease were irregularly expanded over the known range of this species [13, 52]. More than 7,000 affected calves and lambs were reported between autumn 1985 and spring 1986 in six prefectures of northern Honshu [32, 36]. In a 1999 epidemic, Akabane disease spread across the same region and into a further northern area located in the southern part of the island of Hokkaido [26, 51].

These outbreaks reminded us of two possibilities regarding the AKAV transmission in northern Honshu. The first possibility is that C. oxystoma transiently or stably expanded its distribution range to the affected regions. The second is that other Culicoides species which are indigenous to northern Honshu had a primary role in the AKAV transmission. The northward expansion of Aedes albopictus, a mosquito vector of dengue virus, has been observed in northern Honshu [17, 41]. Those investigations revealed that the average temperature has gradually risen in northern Honshu, and the rise in the temperature probably enhanced the establishment of A. albopictus. This phenomenon seems to support the validity of the first possibility.

In 2006, bluetongue virus (BTV), a Culicoides-borne pathogen of ruminants, had newly emerged in northern Europe in areas where the original vector species, C. imicola, was absent. Virus detection from Culicoides biting midges collected in the affected area showed that several northern Palaearctic Culicoides species (rather than C. imicola) served as vectors [8]. More recently, Schmallenberg virus (SBV), which is also Culicoides-borne and belongs to the genus Orthobunyavirus, emerged and caused a large outbreak of congenital malformations in ruminants throughout Europe [2]. Entomological surveillance clearly showed that indigenous Culicoides species in northern Europe also contributed to the SBV transmission [4].

These outbreaks suggest the necessity of searching for other potential AKAV vector species rather than C. oxystoma in northern Honshu to test the second possibility described above. Unfortunately, the fauna of Culicoides species in northern Honshu remains uncertain, except for a surveillance of Culicoides associated with cowsheds in Aomori Prefecture, which is located at the northernmost end of Honshu [45].

The present study describes the results of our 2009 and 2010 entomological surveillances conducted to improve the knowledge of Culicoides species in northern Honshu. Coincidentally, seroconversion to AKAV was observed in sentinel cattle in northern Honshu during the summer and autumn of 2010, and subsequently, AKAV-infected calves showing arthrogryposis and hydranencephaly were reported until the following spring [31, 44]. A total of 218 affected calves were reported during the epidemic [27]. Therefore, to identify potential vector species in northern Honshu, we clarified the distribution and diversity of Culicoides species and examined the collected data along with the sero-surveillance data of AKAV occurrence in 2010.

MATERIALS AND METHODS

Insect collection

During the summers and autumns of 2009 and 2010, we selected a total of 37 cattle farms across nine prefectures (Aomori, Iwate, Akita, Miyagi, Yamagata, Fukushima, Ibaraki, Niigata and Tochigi) for the investigation (Table 1, Fig. 1). These sites were selected for thorough coverage across the northern Honshu region. For the surveillance in 2010, Ibaraki and Niigata Prefectures were added in place of Fukushima Prefecture. Collections were carried out at 28 sites in 2009 and 22 sites in 2010. Of them, 13 sites were surveyed in both years. Most of the midge trappings took place from July to September, when arbovirus transmissions have frequently occurred in Japan [14, 52, 54].

Because C. oxystoma prefers to use damp ground for immature breeding [55], we set most of the trapping sites (the exceptions were sites 4 and 35) in the vicinity of a paddy field (Table 1). The midge collections were conducted using light-suction traps equipped with a 6W black-light tube. The traps were deployed approximately 1.5 m aboveground inside cowsheds and operated overnight (for approximately 18 hr from 4:00 p.m.). The collected midges were killed by freezing at −20°C and preserved in 70% ethanol. The species identification was performed under a stereoscopic microscope according to the morphological keys provided by Wada [49]. If it was difficult to distinguish the species based on wing patterns, the head and wings were separated with needles from the other parts of the body, and the dissected parts were slide-mounted in NEO-SIGARAL (Shiga Konchu Fukyusha, Tokyo) for detailed observation. When abundant midges were caught, subsampled specimens (approximately 500–1,000) were sorted to estimate the ratio of each Culicoides species. The presence/absence of C. oxystoma was checked in all catches.

Serological surveillance data

In Japan, nationwide sero-surveillance for AKAV using sentinel cattle has been conducted every year since 1985 [33, 48]. Approximately 50 sentinel calves were selected in each of Japan’s 47 prefectures every year. Sera of naïve calves with no previous exposure to AKAV were collected four or five times between June and November, and virus neutralization tests for AKAV were performed using the established method as described previously [46]. Antibody titers that were increased more than fourfold were defined as positive for neutralization antibodies to AKAV in the sentinel calves. We obtained the sero-surveillance data of AKAV in 2010 from Japan’s Ministry of Agriculture, Forestry and Fisheries, and examined the locations and timing of seroconversion. ArcGIS software (ver. 10.6; Esri, Redlands, CA, U.S.A.) was used to generate a map.
RESULTS

A total of 106 separate light trap collections (60 and 46 collections in 2009 and 2010, respectively) were conducted in northern Honshu during the study period (Table 1). Of them, 104 collections included one or more Culicoides biting midges (Fig. 2). Of the collected midges, 40,149 specimens (17,555 and 22,594 collected in 2009 and 2010, respectively) were identified to the species level. A total of 19 Culicoides species were found during the surveillance. In the samples collected in 2010, C. sanguisuga was not found, but C. arnaudi, C. jacobsoni and C. nipponensis were newly identified. Spatial and temporal heterogeneity of the abundance and structure of Culicoides species was observed in both the 2009 and 2010 collections. The most widespread species during the surveillance was C. tainanus, which was recorded from 28 sites in 2009 and 20 sites in 2010. C. tainanus was also dominant in 25 collections at 16 sites in 2009 and in 8 collections at 5 sites in 2010. The highest proportion of C. punctatus was recorded in 13 collections at 8 sites in 2009 and in 11 collections at 10 sites in 2010. The collected midges from 9 collections at 6 sites in 2009 and 12 collections at 6 sites were dominated by C. arakawae. The species C. erairai, C. lungchiensis, C. matsuazawai and C. ohmorii were occasionally dominant in 1–5 collections in each year. No C. oxystoma was included in any of the samples. Male midges of 11 species (with the exceptions of C. arnaudi, C. dubius, C. humeralis, C. jacobsoni, C. kibunensis, C. matsuazawai, C. sanguisuga and C. saninensis) were collected through the surveillance.

### Table 1. Location of cattle farms where Culicoides trapping was performed in northern Honshu in 2009 and 2010

| Site ID | Location | Prefecture | No. of collection | Collection period 2009 | Collection period 2010 | No. of counted midges (a) | Ecological factors in the immediate vicinity (b) |
|---------|----------|------------|-------------------|------------------------|------------------------|--------------------------|--------------------------------------------------|
|         |          |            |                   | Jul., Aug.             | Jul., Aug.             | 1,122                    | + + +                                             |
| 1 Imabetsu | Aomori  | 4          | 4                 | Jul., Aug.             | 1,038                  | + + +                    | + + +                                             |
| 2 Higashidoori | 4         | 4          | 4                 | Jul., Aug.             | 1,075                  | + + +                    | + + +                                             |
| 3 Hiroki  | 2 Aug.   | 2          | 2                 | Jul., Aug.             | 1,075                  | + + +                    | + + +                                             |
| 4 Tsugaru | 2 Jun., Aug. | 2           | 2                 | Jul., Aug.             | 1,075                  | + + +                    | + + +                                             |
| 5 Towada | 2 Jun., Aug. | 2           | 2                 | Jul., Aug.             | 1,075                  | + + +                    | + + +                                             |
| 6 Gonohe | 4 Jun., Aug. | 4           | 4                 | Jul., Aug.             | 1,075                  | + + +                    | + + +                                             |
| 7 Hashikami | 2 Jun., Aug. | 2           | 2                 | Jul., Aug.             | 1,075                  | + + +                    | + + +                                             |
| 8 Kitaakita | Akita    | 4          | 4                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 9 Akita  | 2 Aug.   | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 10 Yuzawa | 2 Aug.   | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 11 Yokote | 4 Aug.   | 4          | 4                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 12 Sakata A | Yamagata | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 13 Sakata B | 4 Aug.   | 4          | 4                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 14 Funagata | 4 Aug.   | 4          | 4                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 15 Nakayama | 4 Aug.   | 4          | 4                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 16 Yamagata | 2 Aug.   | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 17 Esashi | 4 Aug.   | 4          | 4                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 18 Tanzawa A | 2 Aug.   | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 19 Shizukushi A | 2 Aug.   | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 20 Shiwa  | 2 Aug.   | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 21 Shizukushi B | 1 Oct.  | 1          | 1                 | Oct., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 22 Tanzawa B | 1 Oct.  | 1          | 1                 | Oct., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 23 Tome  | 2 Aug.   | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 24 Iwanuma | 4 Aug.   | 4          | 4                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 25 Koriyama A | Fukushina | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 26 Koriyama B | 2 Aug.   | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 27 Azuhange | 2 Aug.  | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 28 Yagawa | 2 Aug.   | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 29 Nishigo A | 5 Oct.  | 5          | 5                 | Oct., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 30 Nishigo B | 3 Oct.  | 3          | 3                 | Oct., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 31 Niigata | 4 Aug.   | 4          | 4                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 32 Tainai | 4 Aug.   | 4          | 4                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 33 Tochigi | 2 Aug.   | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 34 Utsunomiya | 2 Aug.  | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 35 Nasushiobara | 2 Aug. | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 36 Daigo | 2 Aug.   | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| 37 Hitachiomiya | 2 Aug. | 2          | 2                 | Aug., Jul., Aug.       | 1,000                  | 2,092                    | + + +                                             |
| Total   | 106      | 106        | 106               | 17,555                 | 22,594                 | 17,555                   | 22,594                                            |

(a) Numbers for which a portion of collected midges was counted are written in Italic. (b) + and − means presence and absence of each habitat, respectively.

doi: 10.1292/jvms.19-0303
and accounted for 1.1 and 4.5% of the counted midges in 2009 and 2010, respectively. Males of *C. lungchiensis* became subdominant in the total collections of midges at 2 farms in 2010, i.e., 29.0% at site 6 and 41.1% at site 13. Overall, female midges generally predominated in the counted midges at most of the collection sites. The proportions of blood-fed *Culicoides* females were highly variable depending on the species and collection sites (0–100%).

Among the 104 collections, the average feeding proportion of the counted female midges was 34.9%. Of the 19 species, 14 species were found to be engorged. No engorged female of *C. arnaudi, C. japonicus, C. kibunensis, C. pictimargo* or *C. sanguisuga* was included in the counted midges. Although *C. arakawa* were collected in 68 of the 104 collections, the blood-feeding ratio ranged from zero to very low (average blood feeding ratio: 3.0%). Five species (*C. dubius, C. erairai, C. ohomorii, C. punctatus* and *C. tainanus*) which were included in over 20 collections showed high average feeding proportions (46.9–66.8%).

In 2010, seroconversion of AKAV in sentinel cattle was observed in 37 municipalities in northern Honshu (Fig. 1). Among them, seroconversion occurred in August in 6 municipalities, in September in 25 municipalities, and in November in 6 municipalities. During that period, 12 trapping sites (sites 8, 9, 11, 13–15, 17, and 20–24) were located at or nearby municipalities where seroconversion to AKAV in sentinel cattle was observed (Fig. 1). At 5 trapping sites, *C. punctatus* was most dominant. *Culicoides arakawa* and *C. tainanus* were predominant at 2 sites. *Culicoides lungchiensis* and *C. ohmorii* dominated at 1 site. *Culicoides*
Fig. 2. The structures of collected Culicoides species at cowsheds in northern Honshu in 2009 and 2010.
DISCUSSION

Historically, *C. oxystoma*, which is a major vector of AKAV in Japan, has been unevenly distributed in lower latitude regions in Japan [49], probably due to the mild winter in those regions, which appears to be favorable for the overwintering and continuous population of *C. oxystoma*. Recent climate changes have potentially enhanced the northward expansion of its range. However, our present investigation did not reveal any evidence of the existence of *C. oxystoma* in northern Honshu in 2009 and 2010. Our results suggest that, at the very least, *C. oxystoma* was not established in northern Honshu and did not contribute much to the AKAV transmission in the summer and autumn of 2010. Although it cannot be denied that *C. oxystoma* initially brought AKAV from its epizootic region to northern Honshu, our results strongly support the concept that indigenous Culicoides species transmitted AKAV through the 2010 epizootic.

Of the species collected during the surveillance, *C. tainanus*, *C. punctatus* and *C. jacobsoni* were confirmed to be infected with AKAV by laboratory experimental infection [53]. *Culicoides tainanus* and *C. punctatus* were widely distributed in northern Honshu, and their range overlapped with the seroconverted regions during the 2010 AKAV spread. In addition, these species were predominant at many trapping sites and their blood-feeding ratio was generally high. Although the blood meal origins of the collected midges were not determined in this study, engorged midges trapped inside cattle sheds have likely fed on cattle, as shown in previous studies [24, 34]. It was also reported that both the species prefer to feed on cattle [37]. *Culicoides tainanus* and *C. punctatus* may thus have played crucial roles in the AKAV transmission in 2010. It should be noted that *C. punctatus* in East Asia is uncertain to be conspecific with that in Europe, because of the high genetic diversity between them [28, 39]. Further research into these suspected cryptic species will be essential for accurate revision of the distribution of Culicoides.

*Culicoides jacobsoni* were only identified at sites located in Niigata and Ibaraki Prefectures, where no seroconversion to AKAV was observed in sentinel cattle in 2010. This species has often been recorded in tropical and subtropical zones of Asia and Oceania, and its previous northernmost record in Japan was from Tokyo [49, 50]. The collected sites were probably close to the northern limit of the expansion of *C. jacobsoni*. During the study, *C. arakawai* was caught at many trapping sites, probably because the sites were close to paddocks, which are a major breeding site of this species [55]. However, this species prefers to feed on birds [16], and its feeding proportion was much lower than those of other engorged species.

*Culicoides lungchiensis* was also predominant/subdominant at several collection sites in/around the seroconverted regions in 2010. However, AKAV has not been detected in field-collected specimens of this species in the epizootic areas in southern Japan, and no laboratory experimental infection has suggested its vector capacity for the virus [14, 53, 54]. Our current knowledge may not be sufficient to elucidate the role of *C. lungchiensis* as a vector.

Unfortunately, the detection of AKAV RNA from 2,060 midges collected in/around the seroconverted regions in the summer and autumn of 2010 failed (data not shown). Thus, at present, there is no conclusive evidence of a potential role of Culicoides species in northern Honshu. Because the circulation of AKAV seems to be ephemeral in the environments around individual infected farms [14, 19, 54], the opportunities for AKAV RNA detection from midges may be very few. In fact, the proportion of infected midges collected from fields has been reported to be quite low during the epizootic of SBV in Europe [4]. Further large-scale and frequent insect collections will be needed to identify infected Culicoides species during the AKAV circulation.

The distribution ranges of *C. tainanus* and *C. punctatus* almost cover mainland Japan [49]. Immature habitats of these species are normally present around cowsheds in Japan: *C. tainanus* and *C. punctatus* emerged from soil mixed with cattle dung around a compost barn and in a paddock, and from mud on the margin of a stream and a spring, respectively [37]. These habitats are normally present around cowsheds in Japan, and these species might easily become abundant in such environments. In addition, *C. tainanus* maintained its flight activity under lower temperature compared to *C. punctatus* in East Asia, and these species might easily become abundant in such environments. In contrast, the resurgence of BTV and SBV was observed over several consecutive years in northern Europe [2, 42]. A previous study indicated that adult midges, probably containing the infected individuals, were often active and survived inside warm stables during the cold winter months [25]. Differences in the vector species and the styles of stables between northern Honshu and northern Europe might affect the capacity of midge survival in winter.

As described above, our entomological survey indicated that *C. tainanus* and *C. punctatus* could be potential vectors of AKAV in northern Honshu, Japan. However, to understand the AKAV epizootics and assess the risk of arbovirus transmission, further research is required to improve our knowledge of the ecology of Culicoides biting midges. For this, ecological analyses using environmental data such as climate, vegetation, and land use data would be useful to understand factors associated with the distribution and abundance of Culicoides biting midges. Although the sudden appearance of AKAV in northern Honshu indicated that the infected midges were directly transported on winds from overseas, the mechanism of introduction remains unclear. Previous studies in other regions indicated that long-distance dispersals of Culicoides biting midges from overseas contribute the range expansion of arboviruses [6, 11]. Further investigations of the long-distance incursion of Culicoides biting midges using...
ACKNOWLEDGMENTS. We thank all the staff of the Aomori, Mutsu, Tsubaru, Towada and Hachinohe livestock hygiene centers of Aomori Prefecture, the Chuo and Kennan livestock hygiene centers of Iwate Prefecture, the Hokkubu, Chuo and Nanbu livestock hygiene centers of Akita Prefecture, the Tobu and Sendai livestock hygiene centers of Miyagi Prefecture, Shonai, Mogami and Chuo, the livestock hygiene centers of Yamagata Prefecture, the Kench and Aizu livestock hygiene centers of Fukushima Prefecture, the Kenhoku livestock hygiene center of Ibaraki Prefecture, the Kenman, Kenou and Kenhoku livestock hygiene centers of Tochigi Prefecture, the Chuo and Kenhoku livestock hygiene centers of Niigata Prefecture, and the National Livestock Breeding Center for their considerable support of the collection of biting midges. Our gratitude goes to the farmers who permitted the midge collection in their cowsheds. The technical assistance from Mr. Hirotaka Horiwaki is also acknowledged. This work was financially supported by a grant from National Agricultural Research Organization (NARO), Japan.

REFERENCES

1. Adams, M. J., Lefkovitz, E. J., King, A. M. Q., Harrach, B., Harrison, R. L., Knowles, N. J., Kropinski, A. M., Krupovic, M., Kuhn, J. H., Mushegian, A. R., Nibert, M., Sabanadzovic, S., Sanfaçon, H., Siddell, S. G., Simmonds, P.,Varsani, A., Zerbini, F. M., Gorbalenya, A. E. and Davison, A. J. 2017. Changes to taxonomy and the International Code of Virus Classification and Nomenclature ratified by the International Committee on Taxonomy of Viruses. Arch. Virol. 162: 2505–2538. [Medline] [CrossRef]

2. Afonso, A., Abrahamantes, J. C., Conraths, F., Veldhuis, A., Elbers, A., Roberts, H., Van der Steede, Y., Méróc, E., Gache, K. and Richardson, J. 2014. The Schmallenberg virus epidemic in Europe-2011-2013. Prev. Vet. Med. 116: 391–403. [Medline] [CrossRef]

3. al-Busaidy, S. M. and Muller, P. S. 1991. Isolation and identification of arboviruses from the Sultanate of Oman. Epidemiol. Infect. 106: 403–413. [Medline] [CrossRef]

4. Balenghien, T., Pagès, N., Goffredo, M., Carpenter, S., Augot, D., Jacquier, E., Talavera, S., Monaco, F., Depaquit, J., Grillet, C., Pujols, J., Satta, G., Kaabari, M., Setier-Rio, M. L., Izzo, F., Alkan, C., Delécolle, J. C., Quaglia, M., Charrel, R., Polci, A., Bréard, E., Federici, V., Cêtre-Sossah, C. and Garros, C. 2014. The emergence of Schmallenberg virus across Culicoides communities and ecosystems in Europe. Prev. Vet. Med. 360–369. [Medline] [CrossRef]

5. Borkent, A. 2005. The biting midges. pp.113—126. In: Biology of disease vectors, 2nd ed. (Marquardt, W.C ed.), Elsevier, Amsterdam.

6. Burgin, L. E., Glover, J., Sanders, C., Mellor, P. S., Gubbins, S. and Carpenter, S. 2013. Investigating invasions of bluetongue virus using a model of long-distance Culicoides biting midge dispersal. Transbound. Emerg. Dis. 60: 263–272. [Medline] [CrossRef]

7. Carpenter, S., Veronesi, E., Mullens, B. and Venter, G. 2015. Vector competence of Culicoides for arboviruses: three major periods of research, their influence on current studies and future directions. Rev. Sci. Tech. 34: 97–112. [Medline] [CrossRef]

8. Carpenter, S., Wilson, A. and Muller, P. S. 2009. Culicoides and the emergence of bluetongue virus in northern Europe. Trends Microbiol. 17: 172–178. [Medline] [CrossRef]

9. Cybinski, D. H. and Muller, M. J. 1990. Isolation of arboviruses from cattle and insects at two sentinel sites in Queensland, Australia, 1979–85. Aust. J. Zool. 38: 25–32. [CrossRef]

10. Doherty, R. L., Carley, J. G., Standfast, H. A., Dyce, A. L. and Snowdon, W. A. 1972. Virus strains isolated from arthropods during an epizootic of bovine ephemeral fever in Queensland. Aust. J. Vet. 48: 81–86. [Medline] [CrossRef]

11. Eagles, D., Melville, L., Weir, R., Davis, S., Bellis, G., Zalucki, M. P., Walker, P. J. and Durr, P. A. 2014. Long-distance aerial dispersal modelling of Culicoides biting midges: case studies of invasions into Australia. BMC Vet. Res. 10: 135. [Medline] [CrossRef]

12. Elbers, A. R., Koentraad, C. J. and Meiswinkel, R. 2015. Mosquitoes and Culicoides biting midges: vector range and the influence of climate change. Rev. Sci. Tech. 34: 123–137. [Medline] [CrossRef]

13. Forman, S., Hungerford, N., Yamakawa, M., Yanase, T., Tsai, H. J., Joo, Y. S., Yang, D. K. and Nha, J. J. 2008. Climate change impacts and risks for animal health in Asia. Rev. Sci. Tech. 27: 581–597. [Medline] [CrossRef]

14. Kato, T., Shirafuji, H., Tanaka, S., Sato, M., Yamakawa, M., Tsuda, T. and Yanase, T. 2016. Bovine arboviruses in Culicoides biting midges and sentinel cattle in southern Japan from 2003 to 2013. Transbound. Emerg. Dis. 63: e160–e172. [Medline] [CrossRef]

15. Kirkland, P. D. 2015. Akabane virus infection. Arch. Virol. 162: 71–83. [Medline] [CrossRef]

16. Kurogi, H., Inaba, Y., Takahashi, E., Sato, K. and Goto, Y. 1977. Experimental infection of pregnant goats with Akabane virus. Arch. Virol. 47: 71–83. [Medline] [CrossRef]

17. Kurogi, H., Inaba, Y., Takahashi, E., Sato, K., Otori, M., Miura, Y. and Takahasi, H. 1975. Serologic evidence for etiologic role of Akabane virus in epizootic abortion-arthrogryposis-hydranencephaly in cattle in Japan, 1972–1974. Arch. Virol. 47: 71–83. [Medline] [CrossRef]

18. Kurogi, H., Inaba, Y., Takahashi, E., Sato, K. and Satoda, K. 1977. Congenital abnormalities in newborn calves after inoculation of pregnant cows with Akabane virus. Rev. Sci. Tech. 60: 263–272. [Medline] [CrossRef]

19. Kurogi, H., Inaba, Y., Takahashi, E., Sato, K. and Satoda, K. 1977. Experimental infection of pregnant goats with Akabane virus. Arch. Virol. 47: 71–83. [Medline] [CrossRef]

20. Kurogi, H., Inaba, Y., Takahashi, E., Sato, K. and Satoda, K. 1977. Experimental infection of pregnant goats with Akabane virus. Arch. Virol. 47: 71–83. [Medline] [CrossRef]

21. Kurogi, H., Inaba, Y., Takahashi, E., Sato, K. and Satoda, K. 1977. Experimental infection of pregnant goats with Akabane virus. Arch. Virol. 47: 71–83. [Medline] [CrossRef]

22. Kurogi, H., Inaba, Y., Takahashi, E., Sato, K. and Satoda, K. 1977. Experimental infection of pregnant goats with Akabane virus. Arch. Virol. 47: 71–83. [Medline] [CrossRef]

23. Kurogi, H., Inaba, Y., Takahashi, E., Sato, K. and Satoda, K. 1977. Experimental infection of pregnant goats with Akabane virus. Arch. Virol. 47: 71–83. [Medline] [CrossRef]

24. Kurogi, H., Inaba, Y., Takahashi, E., Sato, K. and Satoda, K. 1977. Experimental infection of pregnant goats with Akabane virus. Arch. Virol. 47: 71–83. [Medline] [CrossRef]

25. Kurogi, H., Inaba, Y., Takahashi, E., Sato, K. and Satoda, K. 1977. Experimental infection of pregnant goats with Akabane virus. Arch. Virol. 47: 71–83. [Medline] [CrossRef]

26. Kurogi, H., Inaba, Y., Takahashi, E., Sato, K. and Satoda, K. 1977. Experimental infection of pregnant goats with Akabane virus. Arch. Virol. 47: 71–83. [Medline] [CrossRef]

27. Kurogi, H., Inaba, Y., Takahashi, E., Sato, K. and Satoda, K. 1977. Experimental infection of pregnant goats with Akabane virus. Arch. Virol. 47: 71–83. [Medline] [CrossRef]
with Akabane virus. Infect. Immun. 17: 338–343. [Medline]
24. Lassen, S. B., Nielsen, S. A. and Kristensen, M. 2012. Identity and diversity of blood meal hosts of biting midges (Diptera: Ceratopogonidae: Culicoides Latreille) in Denmark. Parasit. Vectors 5: 143. [Medline] [CrossRef]
25. losson, B., Mignon, B., Paternostre, J., Madder, M., De Deken, R., De Deken, G., Deblauwe, I., Fassotte, C., Cors, R., Defrance, T., Delecroix, J. C., Balcells, T., Haubrege, E., Frédéric, F., Bortels, J. and Simonon, G. 2007. Biting midges overwintering in Belgium. Vet. Rec. 160: 451–452. [Medline] [CrossRef]
26. MAFF 2000. Statics on animal hygiene 1999, Ministry of Agriculture, Forestry and Fisheries, Tokyo.
27. MAFF 2014. Data on animal hygiene from 2008 to 2012, Ministry of Agriculture, Forestry and Fisheries, Tokyo.
28. Matsumoto, Y., Yanase, T., Tsuda, T. and Noda, H. 2009. Species-specific mitochondrial gene rearrangements in biting midges and vector species identification. Emerg. Infect. Dis. 23: 47–55. [Medline] [CrossRef]
29. Mellor, P. S., Boorman, J. and Baylis, M. 2000. Culicoides biting midges: their role as arbovirus vectors. Annu. Rev. Entomol. 45: 307–340. [Medline] [CrossRef]
30. Miyazato, S., Miura, Y., Hase, M., Kubo, M., Goto, Y. and Kono, Y. 1989. Encephalitis of cattle caused by Iriki isolate, a new strain belonging to Akabane virus. Nippon Juigaku Zasshi 51: 128–136. [Medline] [CrossRef]
31. Nakahara, H., Yagashgi, G., Oyama, T., Goto, M. and Motokawa, M. 2012. Epidemiological analysis of Akabane disease across cattle in Iwate Prefecture in 2010. Ivate Veterinary 38: 54–58 (in Japanese).
32. Nakamura, K., Morita, J., Hanamatsu, K., Tomabechi, M., Sasaki, M., Saito, S., Arayashiki, S., Uchimi, K., Souma, H. and Toriyabe, S. 1987. A collective outbreak of Akabane disease on sheep farms. Nippon Juishikai Zasshi 40: 513–518 (in Japanese with English summary).
33. National Institute of Animal Health 2018. Nationwide serological surveillance for arbovirus infections using sentinel cattle (in Japanese) http://www.naro-affrc.go.jp/shin/arbo/akabane/index.html [accessed on July 30, 2018].
34. Ninio, C., Augot, D., Delecroix, J. C., Dufour, B. and Deapuaq, J. 2011. Contribution to the knowledge of Culicoides (Diptera: Ceratopogonidae) host preferences in France. Parasitol. Res. 108: 657–663. [Medline] [CrossRef]
35. Oem, J. K., Yoon, H. J., Kim, H. R., Roh, I. S., Lee, K. H., Lee, O. S. and Bae, Y. C. 2012. Genetic and pathogenic characterization of Akabane viruses isolated from cattle with encephalomyelitis in Korea. Vet. Microbiol. 158: 259–266. [Medline] [CrossRef]
36. Oike, Y., Yoshida, K. and Minamino, K. 1988. An epizootic of Akabane disease in cattle in Iwate prefecture from 1985 to 1986. Nippon Juishikai Zasshi 41: 246–250 (in Japanese with English summary).
37. Ohtaishi, M., Yoshida, N. and Shiraiishi, A. 2000. Blood meal sources and immature habitats of Culicoides spp. at a grazing land and cow shed in Morioka City (in Japanese). http://www.naro-affrc.go.jp/project/results/laboratory/tarc/2000/tohoku00-173.html [accessed on July 11, 2018].
38. Oya, A., Okuno, T., Ogata, T., Kobayashi and Matsuyama, T. 1961. Akabane, a new arbor virus isolated in Japan. Jpn. J. Med. Sci. Biol. 14: 101–108. [Medline] [CrossRef]
39. Pagès, N., Muñoz-Muñoz, F., Talavera, S., Sarto, V., Lorca, C. and Núñez, J. I. 2009. Identification of cryptic species of Culicoides (Diptera: Ceratopogonidae) in the subgenus Culicoides and development of species-specific PCR assays based on barcode regions. Vet. Parasitol. 165: 298–310. [Medline] [CrossRef]
40. Parsonson, I. M., Della-Porta, A. J. and Snowdon, W. A. 1977. Congenital abnormalities in newborn lambs after infection of pregnant sheep with Akabane virus. Infect. Immun. 15: 254–262. [Medline] [CrossRef]
41. Sato, T., Matsumoto, F., Abe, T., Nihei, N. and Kobayashi, M. 2012. Recent distribution of Aedes albopictus in Ivate Prefecture, northern Japan and analysis of climatic conditions for northern limit of geographical distribution by geographical information systems. Med. Entomol. Zool. 63: 195–204 (in Japanese with English summary). [CrossRef]
42. Saegern, C., Berkvens, D. and Mellor, P. S. 2008. Bluetongue epidemiology in the European Union. Emerg. Infect. Dis. 14: 539–544. [Medline] [CrossRef]
43. Stram, Y., Brenner, J., Braverman, Y., Banet-Noach, C., Kuznetzova, L. and Ginni, M. 2004. Akabane virus in Israel: a new virus lineage. Virus Res. 104: 93–97. [Medline] [CrossRef]
44. Takamori, H., Hino, M., Takahashi, K., Toyoshima, T., Takeda, Y., Takano, Y., Tanaka, S. and Yamakawa, M. 2013. Pathological feature of Akabane disease occurring in Miyagi Prefecture, and differences in parts of the viral gene detected in affected calves born in different periods. Nippon Juishikai Zasshi 66: 39–44 (in Japanese with English summary).
45. Takebe, C., Yamaguchi, S., Ohta, K., Sugawara, T., Tsukuda, S., Matsumoto, A., Yoshida, S. and Shoma, H. 1989. Identification of biting midges (Culicoides) and their distribution in Aomori Prefecture. Nippon Juishikai Zasshi 42: 331–337 (in Japanese with English summary).
46. Tsuda, T., Yoshida, K., Yanase, T., Ohashi, S. and Yamakawa, M. 2004. Competitive enzyme-linked immunosorbent assay for the detection of antibodies specific to Akabane virus. J. Vet. Diagn. Invest. 16: 571–576. [Medline] [CrossRef]
47. Tsutsui, T., Hayama, Y., Yamakawa, M., Shirafuji, H. and Yanase, T. 2011. Flight behavior of adult Culicoides oystoma and Culicoides maculatus under different temperatures in the laboratory. Parasitol. Res. 108: 1575–1578. [Medline] [CrossRef]
48. Tsutsui, T., Yamamoto, T., Hayama, Y., Akihira, Y., Nishiguchi, A., Kobayashi, S. and Yamakawa, M. 2009. Duration of maternally derived antibodies against Akabane virus in calves. J. Vet. Med. Sci. 71: 913–918. [Medline] [CrossRef]
49. Wada, Y. 1999. Culicoides biting midges of Japan (Diptera: Ceratopogonidae). Nagasaki-ken Seibutsu Gakkai Zasshi 50: 45–70 (in Japanese).
50. Wirth, W. W. and Hubert, A. 1989. The Culicoides of Southeast Asia (Diptera: Ceratopogonidae). Mem. Am. Entomol. Inst. 44: 1–508.
51. Yamamoto, Y., Shimizu, C. and Oneda, N. 2001. Epidemiological analysis of Akabane disease in Ibari Subprefecture. J. Hokkaido Vet. Med. Assoc. 50: 335–337 (in Japanese).
52. Yanase, T., Kato, T., Hayama, Y., Akiyama, M., Inoh, N., Hiroichi, S., Hiroshima, Y., Shirafuji, H., Yamakawa, M., Tanaka, S. and Tsutsui, T. 2018. Transition of Akabane virus genotypes and its association with changes in the disease of Japan. Transbound. Emerg. Dis. 65: e434–e443. [Medline] [CrossRef]
53. Yanase, T., Kato, T., Hayama, Y., Shirafuji, H., Yamakawa, M. and Tanaka, S. 2019. Oral susceptibility of Japanese Culicoides (Diptera: Ceratopogonidae) species to Akabane virus. J. Med. Entomol. 56: 533–539. [Medline] [CrossRef]
54. Yanase, T., Kato, T., Kubo, T., Yoshida, K., Ohashi, S., Yamakawa, M., Miura, Y. and Tsuda, T. 2005. Isolation of bovine arboviruses from Culicoides biting midges (Diptera: Ceratopogonidae) in southern Japan: 1985–2002. J. Med. Entomol. 42: 63–67. [Medline] [CrossRef]
55. Yanase, T., Matsumoto, Y., Matsunori, Y., Azaiwa, M., Hirata, M., Kato, T., Shirafuji, H., Yamakawa, M., Tsuda, T. and Noda, H. 2013. Molecular identification of field-collected Culicoides larvae in the southern part of Japan. J. Med. Entomol. 50: 1105–1110. [Medline] [CrossRef]