AGRICULTURE AND NATURAL RESOURCES

Journal homepage: http://anres.kasetsart.org

Short Communication

Seasonal abundance of *Culicoides imicola* and *Culicoides oxystoma* in Prachuap Khiri Khan province, Thailand

Jumnongjit Phasuk[a,b,*], Suchada Choocherd[a,b], Amonrat Panthawong[c], Pornkamol Phoosangwalthong[a], Wissanuwat Chimnoi[a], Ketsarin Kamyingkird[a], Khampee Pattanatanang[a]

[a] *Department of Parasitology, Faculty of Veterinary Medicine, Kasetsart University, Bangkok 10900, Thailand*

[b] *Center for Advanced Studies for Agriculture and Food, KU Institute for Advanced Studies, Kasetsart University, Bangkok 10900, Thailand (CASAF, NRU-KU, Thailand)*

[c] *Department of Entomology, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand*

Article Info

Article history:
Received 11 April 2023
Revised 23 May 2023
Accepted 25 May 2023
Available online 30 June 2023

Keywords:
Biting midge,
Culicoides imicola,
Culicoides oxystoma,
Seasonal abundance,
Thailand

Abstract

Importance of the work: *Culicoides* spp. (biting midges) are one of the most abundant hematophagous insects in livestock. However, limited information is available about their seasonal abundance in Thailand.

Objectives: To study the seasonal abundance of the most common *Culicoides* species and to assess their association with weather parameters.

Materials & Methods: The seasonality of *Culicoides* (Diptera: Ceratopogonidae) species was assessed monthly from November 2020 to October 2021 using four Center for Disease Control miniature light traps at a horse stable in Hua Hin district, Prachuap Khiri Khan province, Thailand.

Results: In total, 10,849 females of the genus *Culicoides* were identified, representing 23 species, consisting of *C. imicola* (43.4%), *C. oxystoma* (24.4%), *C. peregrinus* (16.7%), *C. tainanus* (3%), *C. actoni* (1.7%), *C. fulvus* (1.5%), *C. flavipunctatus* (1.3%), *C. huffi* (1%), *C. innoxius* (0.9%), *C. orientalis* (0.8%) and another 13 *Culicoides* species that accounted for 2%. Two predominant species—*C. imicola* and *C. oxystoma*—occurred throughout the entire study period. Both species showed no significant differences in seasonal abundance pattern. No significant correlations were identified between numbers of *C. imicola* and *C. oxystoma* with rainfall, temperature or relative humidity.

Main finding: This study was the first investigating the seasonal abundance of *C. imicola* and *C. oxystoma* in Thailand. More detailed studies are needed to better understand abiotic and biotic factors affecting *Culicoides* abundance and distribution.

* Corresponding author.
E-mail address: fvetjjp@ku.ac.th (J. Phasuk)

https://doi.org/10.34044/j.anres.2023.57.3.17

Introduction

Biting midges of the genus *Culicoides* Latreille are small nematocerous Diptera that belong to the family Ceratopogonidae and contain more than 1,300 species described worldwide (Borkent, 2014), except in Antarctica and New Zealand (Mellor et al., 2000). The *Culicoides* females are obligate blood suckers attacking mammals, including humans and birds, although a few species feed on turtles, frogs and insects, while males do not take blood, feeding on flower nectar or honeydew (Borkent, 2005). The biting habit of *Culicoides* spp. causes an allergic reaction in horses known as sweet itch, summer eczema or Queensland itch in many regions worldwide and also in humans, for whom their heavy bite causes painful itching and swelling that can lead to infection and dermatitis from scratching the bites in some regions (Borkent, 2005). In addition, many species of *Culicoides* are known to transmit a wide range of viruses, protozoa and filarial nematodes, especially the transmission of important diseases, such as African horse sickness (AHS) and bluetongue (BT) in horses and ruminants, respectively (Du Toit, 1944; Borkent, 2005). AHS was first reported in Thailand, when an outbreak of this disease in horses began in Pak Chong district, Nakhon Ratchasima province in March 2020 that subsequently spread to 17 provinces, including Prachuap Khiri Khan province (Bunpapong et al., 2021; Castillo-Olivares, 2021). Later, in September 2020, AHS was reported and confirmed in horses in Malaysia (Shere, 2021). These were the first outbreaks reported in Southeast Asia (King et al., 2020; Castillo-Olivares, 2021; Nelson et al., 2022). AHS is endemic in sub-Saharan Africa and has recently invaded Europe and Asia (Carpenter et al., 2017), affecting members of the family Equidae. Horses are the most susceptible to AHS, with a mortality rate of up to 95%, followed by mules, with mortality rates in the range 50–70%, while donkeys and zebras rarely show symptoms after infection (Wilson et al., 2009; Long and Guthrie, 2014). The mortality rate from outbreaks in Thailand has been reported as 93% of infected horses (Bunpapong et al., 2021). The African horse sickness virus (AHSV) is biologically transmitted by the bites of hematophagous biting midges of the genus *Culicoides*. Field and laboratory-based trials have demonstrated that *Culicoides imicola* Kieffer is a major vector of AHSV in South Africa (Paweska et al., 2003; Venter et al., 2000, 2006a, 2009). Notably, *Culicoides oxystoma* Kieffer is considered a potential vector for AHS in Senegal due to its abundance on horses and other widespread species (Fall et al., 2015a, b). These two species have been found in Thailand (Wirth and Hubert, 1989; Thepparat et al., 2015) and Choocherd et al. (2022) observed that both species were the two most-abundant species in horse stables in Prachuap Khiri Khan province.

The seasonal incidence and abundance of adult female *Culicoides* populations are important parameters in determining the timing and intensity of *Culicoides*-borne arbovirus outbreaks (Sanders et al., 2011; Searle et al., 2014). The distribution and transmission of AHS is dependent on the temperature and season and the abundance and prevalence of vectors (Backer and Nodelijk, 2011; Zientara et al., 2015). The relationship between climatic variables and vector abundance can provide useful information about the epidemiological processes of vector-borne diseases.

Materials and Methods

This study was conducted at a horse stable, housing 20 horses (12°34’36.57”N, 99°53’09.00”E; 3 m above sea level, a.s.l) in Hua Hin district of Prachuap Khiri Khan province. This province is located in the lower central part of Thailand on the western coast of the Gulf of Thailand (10°57’–12°39’N and 99°8’–100°04’E; 0–10 m a.s.l) covering approximately 6,360 km^2 (Choowong et al., 2009). The climatic pattern within Prachuap Khiri Khan province is divided into three seasons: the hot season (mid-February to mid-May), the rainy season (mid-May to mid-October) and the dry season (mid-October to mid-February). In addition, rains can last through until November.

The insect collections were operated continuously between 1800 hours and 0600 hours using four Center for Disease Control miniature light traps with different light sources: an incandescent light, an ultraviolet light-emitting diode (UV-LED) light, a 4 W UV fluorescent light and a 4 W white fluorescent light. The experiment was conducted for 1 night/mth from November 2020 to October 2021. Traps were hung on tripods, 1.5 m above the ground around the horse stable and 10 or 15 m apart from each other. To reduce any position-specific effect, all traps were rotated to the next trap position after each sampling (González et al., 2016). Captured *Culicoides* specimens were preserved using 95% ethanol until processing. *Culicoides* female specimens were identified to species by the wing pattern (Wirth and Hubert, 1989; Dyce et al., 2007; Bellis et al., 2015). Weather parameters were obtained from the Thai Meteorological Department Service at Hua Hin (Station 500202), as shown in Fig. 1.

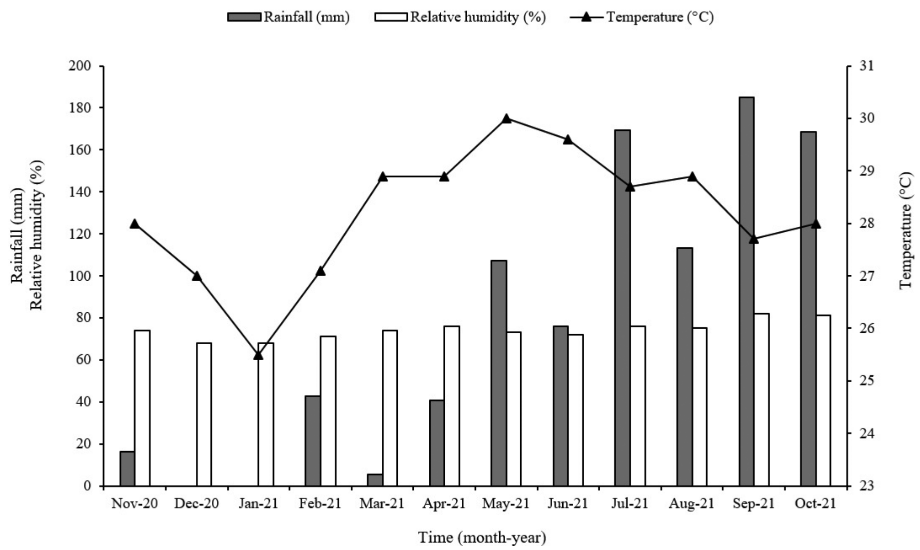

Fig. 1 Monthly total rainfall, mean temperature and mean relative humidity during survey in Hua Hin district, Prachuap Khiri Khan province, Thailand from November 2020 to October 2021

The data were tested for normality and data were log-transformed [log (n+1)] when needed. Then the data on monthly numbers of females of *C. imicola* and *C. oxystoma* were analyzed using a one-way analysis of variance and the least significant difference (LSD) post hoc test was used for mean comparisons. Pearson's correlation coefficient (r) was calculated to estimate relationships between abundances of females for *C. imicola* and *C. oxystoma* and weather parameters. All statistical tests were considered significant at $p < 0.05$. The data analyses were performed using the R statistical software version 4.1.2 (R Core Team, 2018).

Results

In total, 12,583 specimens of the *Culicoides* genus were collected, with 10,849 (86.2%) being females and 1,734 (13.8%) males, as shown in Table 1. The highest total number of *Culicoides* specimens was collected in the light traps baited with the 4 W UV fluorescent light (n = 7,667), followed by the 4 W white fluorescent light (n = 2,635), the UV-LED light (n = 2,047) and the incandescent light (n = 234). The three most-abundant species were *C. imicola* 4,706 (43.4%), *C. oxystoma* 2,652 (24.4%) and *C. peregrinus* 1,810 (16.7%). Another 20 *Culicoides* species were identified: *C. tainanus*, *C. actoni*, *C. fulvus*, *C. flavipunctatus*, *C. huffi, C. innoxius, C. orientalis*. *C. brevitarsis*, *C. asiana, C. similis, C. clavipalpis, C. geminus, C. halonostictus, C. guttifer, C. arakawae, C. sumatrae, C. griffithi, C. brevipalpis, C. shortti* and *C. homotomus*.

During the entire study period, *C. imicola* individuals were present, indicating all-year-round occurrence, with three seasonal abundance peaks: the highest in November (dry season), another in March (hot season) and the third during June–September (rainy season). The lowest number was observed in April (Fig. 2). In addition, *C. oxystoma,* occurred throughout the year, with the first of the two seasonal peaks being a large peak during July–September (rainy season) and the second, smaller one in January (dry season), while low numbers occurred during February–April (Fig. 2).

Variation in the abundance levels of *C. imicola* and *C. oxystoma* was observed within three different seasons (hot, rainy, dry), as shown in Fig. 3. The highest numbers of *C. imicola* were collected in the dry season, whereas the highest numbers of *C. oxystoma* were collected in the rainy season. During the dry and hot seasons, *C. imicola* was highest in numbers, followed by *C. oxystoma*; however, the number of *C. oxystoma* collected was higher than for *C. imicola* during the rainy season. Both species were trapped in lower numbers during the hot season. However, there were no significant differences in the mean numbers of *C. imicola* (F-test value = 1.084; degrees of freedom, df = 2, 9; p = 0.379) and *C. oxystoma* (F-test value = 4.215, df = 2, 9; p = 0.051) collected among seasons.

Pearson's correlation tests showed non-significant correlation between the abundance of *C. imicola* and the following parameters: rainfall (r = -0.091, p = 0.778); temperature (r = -0.221, p = 0.49); and relative humidity (r = 0.007; p = 0.983). Rainfall and relative humidity were not significantly correlated with the number of *C. oxystoma* collected (r = 0.551, p = 0.063; r = 0.232, p = 0.468, respectively), and neither was temperature (r = -0.189, p = 0.556).

Table 1 Total numbers of *Culicoides* specimens collected using four light sources in Hua Hin district, Prachuap Khiri Khan province, Thailand from November 2020 to October 2021

Species	2020		2021										Total	%
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct		
Culicoides imicola	1,753	690	115	159	515	16	63	303	275	62	510	245	4,706	43.4
Culicoides oxystoma	198	136	406	26	44	36	185	213	581	197	404	226	2,652	24.4
Culicoides peregrinus	625	268	9	18	13	21	14	41	362	67	211	161	1,810	16.7
Culicoides tainanus	0	1	0	0	0	9	3	47	57	3	115	88	323	3.0
Culicoides actoni	103	33	3	15	2	0	4	5	11	4	1	4	185	1.7
Culicoides fulvus	98	11	3	1	2	0	3	6	23	1	11	7	166	1.5
Culicoides flavipunctatus	28	5	0	4	0	0	1	5	11	6	25	54	139	1.3
Culicoides huffi	2	9	2	5	7	6	18	3	4	6	2	49	113	1.0
Culicoides innoxius	13	8	4	8	4	0	6	4	20	0	29	6	102	0.9
Culicoides orientalis	0	0	0	0	0	0	3	19	5	0	36	20	83	0.8
Culicoides brevitarsis	7	10	5	7	2	1	1	3	3	0	3	0	42	0.4
Culicoides asiana	3	1	0	0	19	0	1	7	3	1	5	1	41	0.4
Culicoides similis	1	7	2	1	4	3	2	1	1	4	0	3	29	0.3
Culicoides clavipalpis	1	0	1	0	1	1	2	0	10	2	2	0	20	0.2
Culicoides geminus	0	0	0	0	0	0	1	4	13	2	0	0	20	0.2
Culicoides halonostictus	0	0	3	0	0	2	2	1	4	6	0	0	18	0.2
Culicoides guttifer	2	1	0	1	0	0	0	0	0	3	1	4	12	0.1
Culicoides arakawae	2	1	1	0	0	0	0	0	0	1	0	6	11	0.1
Culicoides sumatrae	0	0	0	0	0	3	0	5	0	0	0	1	9	0.1
Culicoides griffithi	1	0	0	0	0	0	0	0	5	0	0	0	6	0.1
Culicoides brevipalpis	3	1	0	0	0	0	0	0	0	1	0	0	5	0.0
Culicoides shortti	0	1	0	1	0	0	0	0	0	0	0	0	2	0.0
Culicoides homotomus	0	0	0	1	0	0	0	0	0	0	0	0	1	0.0
Culicoides spp.	52	41	19	14	40	16	5	33	57	13	44	20	354	3.3
Female	2,892	1,224	573	261	653	114	314	700	1,445	379	1,399	895	10,849	86.2
Male	383	208	36	65	57	28	125	107	295	106	226	98	1,734	13.8
Total	3,275	1,432	609	326	710	142	439	807	1,740	485	1,625	993	12,583	

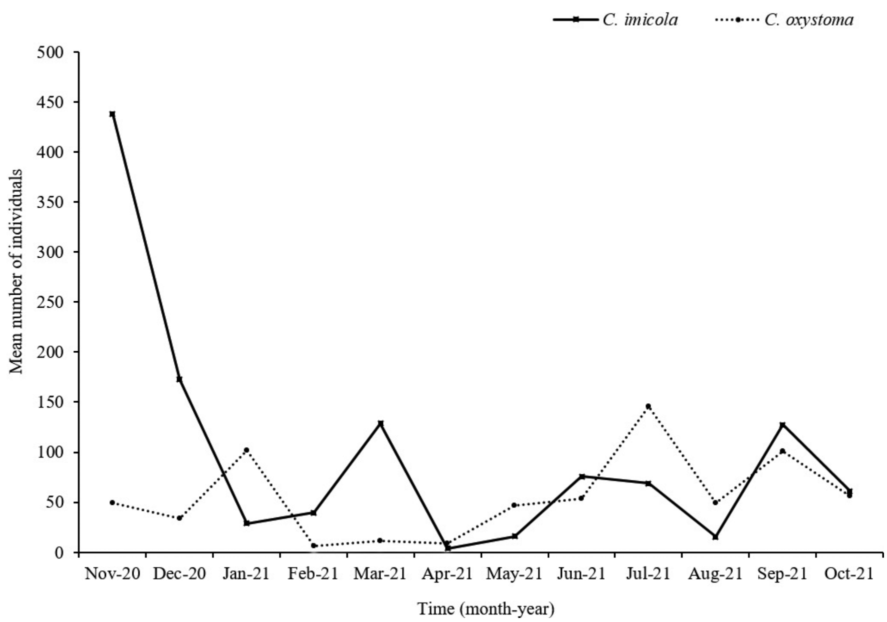

Fig. 2 Seasonal abundance of *Culicoides imicola* and *Culicoides oxystoma* collected in Hua Hin district, Prachuap Khiri Khan province, Thailand from November 2020 to October 2021

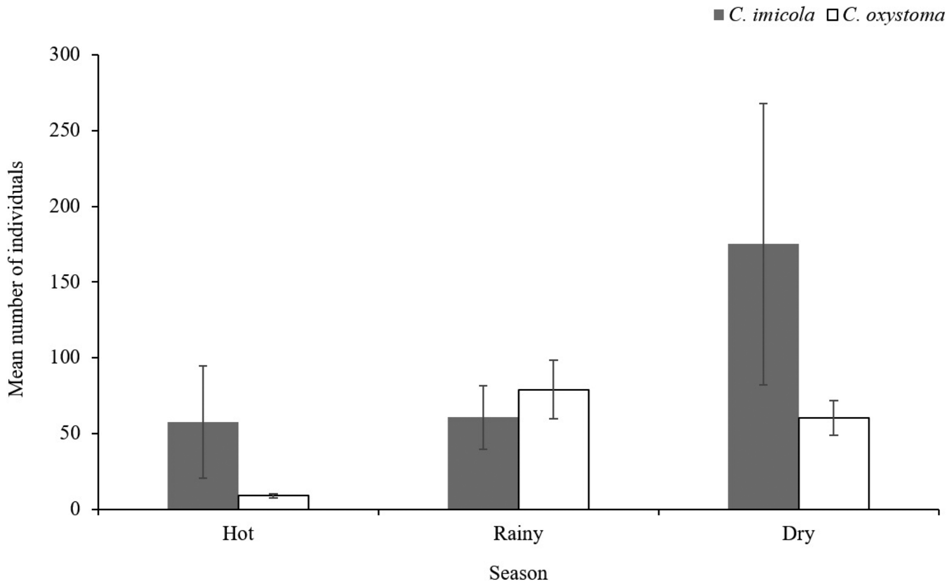

Fig. 3 Mean numbers ± SE of *Culicoides imicola* and *Culicoides oxystoma* collected using four light sources during three seasons in Hua Hin district, Prachuap Khiri Khan province, Thailand from November 2020 to October 2021; no statistical difference ($p > 0.05$) was observed between seasons within a species

Discussion

During the survey, the two predominant species were *C. imicola* and C. *oxystoma*. Similar findings were reported in Senegal (Diarra et al., 2015) and India (Archana et al., 2016). Furthermore, *C. imicola* is the proven field vector of AHSV in South Africa (Rawlings et al., 1997; Venter et al., 2000, 2009) and is suggested to be the main vector of bluetongue virus (BTV), which infects domestic and wild ruminants in Africa and the Mediterranean (Venter et al., 1998; Mellor et al., 2000; Venter et al., 2006b; Nolan et al., 2008). *C. oxystoma* has been implicated in the transmission of several bovine arboviruses to livestock, such as Akabane in Japan (Kurogi et al., 1987; Yanase et al., 2005) and epizootic hemorrhagic disease virus in Israel (Morag et al., 2012). It is thought to be a potential vector of BTV in India (Dadawala et al., 2012) and China (Di et al., 2021). In Senegal, *C. oxystoma* has been suggested as a possible vector of the AHS and BT viruses (Fall et al., 2015b). These two species may be potential vectors involved in AHS transmission in Thailand. However, its vector competence is unknown under natural environmental conditions in Thailand.

In general, the seasonal abundance of vectors on livestock farms is likely to be linked to the efficiency of virus transmission and the occurrence of outbreaks (Miranda et al., 2014). In the current study, the seasonal abundance of the two predominant species in Hua Hin district, Prachuap Khiri Khan province suggested that they were found every month of the year. The results were similar to those reported by Diarra et al. (2015) who found that *C. imicola* and *C. oxystoma* were present throughout the year in the Niayes area, Senegal. Furthermore, the former species was found in Nigeria (Herniman et al., 1983), Israel and Zimbabwe (Braverman et al., 1985), where the species was reported throughout the year. Although seasonal difference in abundance of *C. imicola* was not supported by the statistical tests, the abundance tended to be high during November and December (dry season), whereas *C. oxystoma* tended to have a period peak in abundance between July and September (rainy season), while these two species were present in relatively low numbers during the hot season. This was similar to the findings in a study conducted by Diarra et al. (2014) in the Niayes area, Senegal, where it was reported that the highest abundance of *C. imicola* was found in the cold dry season (February) and of *C. oxystoma* in the rainy season (August–October). In India, the seasonal prevalence *revealed* the highest numbers of *Culicoides* species (including *C. imicola* and *C. oxystoma*) in the rainy season and *low numbers* in *summer, except for C. oxystoma* whose low numbers coincided with the winter season (Archana et al., 2014; Sathiyamoorthy et al., 2021). The variations in the abundance peaks for the collected *Culicoides* species might have been due to variations in the sites and species (Diarra et al., 2014).

Temperature, humidity and rainfall are crucial factors influencing the activity, richness, abundance and survival of *Culicoides* populations (Silva and Carvalho, 2013; Gusmão et al., 2019). For example, temperature had a positive correlation with *C. imicola* abundance in Spain (Ortega et al., 1997) and on Réunion Island (Grimaud et al., 2019). The greatest numbers of *C. imicola* were recorded for daily minimum and maximum temperatures of 18°C and 38°C, respectively (Ortega et al., 1997). In Senegal, the abundance of *C. oxystoma* was positively correlated with temperature and relative humidity, while being negatively correlated with the interaction between temperature and rainfall; in contrast, the abundance of *C. imicola* was negatively correlated with relative humidity and rainfall (Diarra et al., 2015). Changes in climatic conditions, such as rainfall, which help to lower the temperature and increase the humidity and produce more suitable breeding sites, favor increasing *Culicoides* abundance (Gusmão et al., 2019). However, high rainfall may lead to a decrease in temperature and inhibit the activity of some *Culicoides* species (Diarra et al., 2015). In the current study, *C. imicola* and *C. oxystoma* were active in the study area throughout the year with no significant differences between seasons. Furthermore, *temperature* and *relative humidity* did not seem to influence the abundance levels for both *C. imicola* and *C. oxystoma,* while *rainfall although* seemed to be correlated with *C. oxystoma* abundance but without statistical support. There are probably other environmental factors that influence the abundance of arthropod vectors (including *Culicoides* species) comprising abiotic or biotic factors, such as climatic variables, animal host populations and vector larval habitats (Tabachnick, 2010). More research is necessary to better understand the abiotic and biotic factors affecting *Culicoides* abundance and distribution in AHS-affected areas in Thailand.

The current study has provided information on occurrence of *C. imicola* and *C. oxystoma*, which may be potential vectors for AHSV outbreak in Thailand. Thus, entomological surveillance should monitor the presence of these predominant species to prevent the emergence of new diseases (Gusmão et al., 2019).

Ethics statements

Animal care and all experimental procedures were approved by the Institutional Animal Care and Use Committee, Faculty of Veterinary Medicine, Kasetsart University, Bangkok, Thailand (Approval no. ACKU63-VET-043).

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

This work was partially supported by the Center for Advanced Studies for Agriculture and Food, Institute for Advanced Studies, Kasetsart University, Bangkok, Thailand under the Higher Education Research Promotion and National Research University Project of Thailand, Office of the Higher Education Commission, Ministry of Education, Thailand. Financial support was received from the Faculty of Veterinary Medicine, Kasetsart University. Dr Glenn Bellis, Department of Agriculture, Australia assisted with *Culicoides* identification.

References

Archana, M., D'Souza, P.E., Prasad, C.R., Byregowda, S.M. 2014. Seasonal prevalence of different species of in Bangalore rural and urban districts of South India. Vet. World 7: 517–521.

Archana, M., D'Souza, P.E. Prasad, C.R., Byregowda, S.M. 2016. Prevalence of different species of *Culicoides* in Bangalore rural and urban districts of South India. J. Parasit. Dis. 40: 591–604. doi.org/10.1007/s12639-014-0544-1

Backer, J.A., Nodelijk, G. 2011. Transmission and control of African horse sickness in the Netherlands: A model analysis. PLoS One 6: e23066. doi.org/10.1371/journal.pone.0023066

Bellis, G.A., Halling, L., Anderson, S.J. 2015. Pictorial key to adult female *Culicoides* Latreille, 1809 (Diptera: Ceratopogonidae) from the Northern Territory, Western Australia and South Australia. Austral. Entomol. 54: 28–59. doi.org/10.1111/aen.12099

Borkent, A. 2005. The biting midges, the Ceratopogonidae (Diptera). In: Marquardt, W.C. (Ed.). Biology of Disease Vectors, 2nd ed. Elsevier Academic Press. San Diego, CA, USA, pp. 113–126.

Borkent, A. 2014. The pupae of the biting midges of the world (Diptera: Ceratopogonidae), with a generic key and analysis of the phylogenetic relationships between genera. Zootaxa 3879: 1–327. doi.org/10.11646/zootaxa.3879.1.1

Braverman, Y., Linley, J.R., Marcus, R., Frish, K. 1985. Seasonal survival and expectation of infective life of *Culicoides* spp. (Diptera: Ceratopogonidae) in Israel, with implications for bluetongue virus transmission and a comparison of the parous rate in *C. imicola* from Israel and Zimbabwe. J. Med. Entomol. 22: 476–484. doi.org/10.1093/jmedent/22.5.476

Bunpapong, N., Charoenkul, K., Nasamran, C., et al. 2021. African horse sickness virus serotype 1 on horse farm, Thailand, 2020. Emerg. Infect. Dis. 27: 2208–2211. doi: 10.3201/eid2708.210004

Carpenter, S., Mellor, P.S., Fall, A.G., Garros, C., Venter, G.J. 2017. African horse sickness virus: history, transmission, and current status. Annu. Rev. Entomol. 62: 343–358. doi.org/10.1146/annurev-ento-031616-035010

Castillo-Olivares, J. 2021. African horse sickness in Thailand: Challenges of controlling an outbreak by vaccination. Equine Vet. J. 53: 9–14. doi.org/10.1111/evj.13353

Choocherd, S., Pattanatanang, K., Chimnoi, W., Kamyingkird, K., Tongyoo, P., Phasuk, J. 2022. Preliminary study on comparative efficacy of four light sources for trapping *Culicoides* spp. (Diptera: Ceratopogonidae) in Prachuap Khiri Khan province, Thailand. J. Econ. Entomol. 115: 1719–1723. doi.org/10.1093/jee/toac117

Choowong, M., Songmuang, R., Phantuwongraj, S., Daorerk, V., Charusiri, P., Numee, L. 2009. Monitoring beach morphology changes and coastal sediment balance from Prachuap Khiri Khan, Thailand. BEST. 2: 1–10.

Dadawala, A.I., Biswas, S.K., Rehman, W., et al. 2012. Isolation of bluetongue virus serotype 1 from *Culicoides* vector captured in livestock farms and sequence analysis of the viral genome segment-2. Transbound. Emerg. Dis. 59: 361–368. doi.org/10.1111/j.1865-1682.2011.01279.x

Di, D., Chen-xi, L., Zong-jie, L., et al. 2021. Detection of arboviruses in *Culicoides* (Diptera: Ceratopogonidae) collected from animal farms in the border areas of Yunnan province, China. J. Integr. Agric. 20: 2491–2501. doi.org/10.1016/S2095-3119(21)63613-4

Diarra, M., Fall, M., Fall, A.G., et al. 2014. Seasonal dynamics of *Culicoides* (Diptera: Ceratopogonidae) biting midges, potential vectors of African horse sickness and bluetongue viruses in the Niayes area of Senegal. Parasit. Vectors 7: 147. doi.org/10.1186/1756-3305-7-147

Diarra, M., Fall, M., Lancelot, R., et al. 2015. Modelling the abundances of two major *Culicoides* (Diptera: Ceratopogonidae) species in the Niayes area of Senegal. PLoS One 10: e0131021. doi.org/10.1371/journal.pone.0131021

Du Toit, R.M. 1944. The transmission of blue-tongue and horse sickness by *Culicoides*. Onderstepoort J. Vet. Sci. Anim. Ind. 19: 7–16.

Dyce, A.L., Bellis, G.A., Muller, M.J. 2007. Pictorial Atlas of Australasian *Culicoides* Wings (Diptera: Ceratopogonidae). Australian Biological Resources Study. Canberra, Australia.

Fall, M., Diarra, M., Fall, A.G., et al. 2015a. *Culicoides* (Diptera: Ceratopogonidae) midges, the vectors of African horse sickness virus—a host/vector contact study in the Niayes area of Senegal. Parasit. Vectors 8: 39. doi.org/10.1186/s13071-014-0624-1

Fall, M., Fall, A.G., Seck, M.T., et al. 2015b. Circadian activity of *Culicoides oxystoma* (Diptera: Ceratopogonidae), potential vector of bluetongue and African horse sickness viruses in the Niayes area, Senegal. Parasitol. Res. 114: 3151–3158. doi.org/10.1007/s00436-015-4534-8

Grimaud, Y., Guis, H., Chiroleu, F., et al. 2019. Modelling temporal dynamics of *Culicoides* Latreille (Diptera: Ceratopogonidae) populations on Reunion Island (Indian Ocean), vectors of viruses of veterinary importance. Parasit. Vectors 12: 562. doi.org/10.1186/s13071-019-3812-1

González, M., Alarcón-Elbal, P.M., Valle-Mora, J., Goldarazena, A. 2016. Comparison of different light sources for trapping *Culicoides* biting midges, mosquitoes and other dipterans. Vet. Parasitol. 226: 44–49. doi.org/10.1016/j.vetpar.2016.06.020

Gusmão, G.M.C., Brito, G.A., Moraes, L.S., Bandeira, M.C.A., Rebêlo, J.M.M. 2019. Temporal variation in species abundance and richness of *Culicoides* (Diptera: Ceratopogonidae) in a tropical equatorial area. J. Med. Entomol. 56: 1013–1018. doi.org/10.1093/jme/tjz015

Herniman, K.A.J., Boorman, J.P.T., Taylor, W.P. 1983. Bluetongue virus in a Nigerian dairy cattle herd. 1. Serological studies and correlation of virus activity to vector population. J. Hyg. Lond. 90: 177–193. doi.org/10.1017/S0022172400028849

King, S., Rajko-Nenow, P., Ashby, M., Frost, L., Carpenter, S., Batten, C. 2020. Outbreak of African horse sickness in Thailand, 2020. Transbound. Emerg. Dis. 67: 1764–1767. doi.org/10.1111/tbed.13701

Kurogi, H., Akiba, K., Inaba, Y., Matumoto, M. 1987. Isolation of Akabane virus from the biting midge *Culicoides oxystoma* in Japan. Vet. Microbiol. 15: 243–248. doi.org/10.1016/0378-1135(87)90078-2

Long, M.T., Guthrie, J. 2014. African horse sickness. In: Sellon, D.C., Long, M.T. (Eds.). Equine Infectious Diseases, 2nd ed. Elsevier Inc. Missouri, MI, USA, pp. 181–183.

Mellor, P.S., Boorman, J., Baylis, M. 2000. *Culicoides* biting midges: Their role as arbovirus vectors. Annu. Rev. Entomol. 45: 307–340. doi.org/10.1146/annurev.ento.45.1.307

Miranda, M.A., Rincón, C., Borràs. D. 2014. Seasonal abundance of *Culicoides imicola* and *C. obsoletus* in the Balearic Islands. Vet. Ital. 40: 292–295.

Morag, N., Saroya, Y., Braverman, Y., Klement, E., Gottlieb, Y. 2012. Molecular identification, phylogenetic status and geographic distribution of *Culicoides oxystoma* (Diptera: Ceratopogonidae) in Israel. PLoS One 7: e33610. doi.org/10.1371/journal.pone.0033610

Nelson, E., Thurston, W., Pearce-Kelly, P., Jenkins, H., Cameron, M., Carpenter, S., Guthrie, A., England, M. 2022. A qualitative risk assessment for bluetongue disease and African horse sickness: The risk of entry and exposure at a UK zoo. Viruses 14: 502. doi.org/10.3390/v14030502

Nolan, D.V., Dallas, J.F., Piertney, S.B., Mordue (Luntz), A.J. 2008. Incursion and range expansion in the bluetongue vector *Culicoides imicola* in the Mediterranean basin: A phylogeographic analysis. Med. Vet. Entomol. 22: 340–351. doi.org/10.1111/j.1365-2915.2008.00744.x

Ortega, M.D., Lloyd, J.E., Holbrook, F.R. 1997. Seasonal and geographical distribution of *Culicoides imicola* Kieffer (Diptera: Ceratopogonidae) in southwestern Spain. J. Am. Mosq. Control Assoc. 13: 227–232.

Paweska, J.T., Prinsloo, S., Venter, G.J. 2003. Oral susceptibility of South African *Culicoides* species to live-attenuated serotype-specific vaccine strains of African horse sickness virus (AHSV). Med. Vet. Entomol. 17: 436–447. doi.org/10.1111/j.1365-2915.2003.00467.x

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. http://www.R-project.org/, 25 July 2022.

Rawlings, P., Pro, M.J., Pena, I., Ortega, M.D., Capela, R. 1997. Spatial and seasonal distribution of *Culicoides imicola* in Iberia in relation to the transmission of African horse sickness virus. Med. Vet. Entomol. 11: 49–57. doi.org/10.1111/j.1365-2915.1997.tb00289.x

Sanders, C.J., Shortall, C.R., Gubbins, S., et al. 2011. Influence of season and meteorological parameters on flight activity of *Culicoides* biting midges. J. Appl. Ecol. 48: 1355–1364. doi.org/10.1111/j.1365-2664.2011.02051.x

Sathiyamoorthy, N., Ponnudurai, G., Senthilvel, K., Rani, N., Ramya, K. 2021. Prevalence of *Culicoides* species in livestock farms in relation to season, Namakkal, Tamil Nadu. The Pharma Innovation Journal 10: 166–170.

Searle, K.R., Barber, J., Stubbins, F., et al. 2014. Environmental drivers of *Culicoides* phenology: How important is species-specific variation when determining disease policy? PLoS One 9: e111876. doi.org/10.1371/journal.pone.0111876

Shere, J. 2021. Addition of Malaysia to the list of regions considered affected with African horse sickness. Fed. Regist. 86: 66516–66517.

Silva, F.S., Carvalho, L.P.C. 2013. A population study of the *Culicoides* biting midges (Diptera: Ceratopogonidae) in urban, rural, and forested sites in a Cerrado area of northeastern Brazil. Ann. Entomol. Soc. Am. 106: 463–470. doi.org/10.1603/AN12047

Tabachnick, W.J. 2010. Challenges in predicting climate and environmental effects on vector-borne disease episystems in a changing world. J. Exp. Biol. 213: 946–954. doi.org/10.1242/jeb.037564

Thepparat, A., Bellis, G., Ketavan, C., Ruangsittichai, J., Sumruayphol, S., Apiwathnasorn, C. 2015. Ten species of *Culicoides* Latreille (Diptera: Ceratopogonidae) newly recorded from Thailand. Zootaxa 4033: 48–56. doi.org/10.11646/zootaxa.4033.1.2

Venter, G.J., Graham, S.D., Hamblin, C. 2000. African horse sickness epidemiology: Vector competence of South African *Culicoides* species for virus serotypes 3, 5 and 8. Med. Vet. Entomol. 14: 245–250. doi.org/10.1046/j.1365-2915.2000.00245.x

Venter, G.J., Koekemoer, J.J.O., Paweska, J.T. 2006a. Investigations on outbreaks of African horse sickness in the surveillance zone of South Africa. Rev. Sci. Tech. 25: 1097–1109.

Venter, G.J., Mellor, P.S., Paweska, J.T. 2006b. Oral susceptibility of South African stock associated *Culicoides* species to bluetongue virus. Med. Vet. Entomol. 20: 329–334. doi.org/10.1111/j.1365-2915.2006.00635.x

Venter, G.J., Paweska, J.T., Van Dijk, A.A., Mellor, P.S., Tabachnick, W.J. 1998. Vector competence of *Culicoides bolitinos* and *C. imicola* (Diptera: Ceratopogonidae) for South African bluetongue virus serotypes 1, 3 and 4. Med. Vet. Entomol. 12: 378–385. doi.org/10.1046/j.1365-2915.1998.00116.x

Venter, G.J., Wright, I.M., Van Der Linde, T.C., Paweska, J.T. 2009. The oral susceptibility of South African field populations of *Culicoides* to African horse sickness virus. Med. Vet. Entomol. 23: 367–378. doi.org/10.1111/j.1365-2915.2009.00829.x

Wilson, A., Mellor, P.S., Szmaragd, C., Mertens, P.P.C. 2009. Adaptive strategies of African horse sickness virus to facilitate vector transmission. Vet. Res. 40: 16. doi.org/10.1051/vetres:2008054

Wirth, W.W., Hubert, A.A. 1989. The *Culicoides* of Southeast Asia (Diptera: Ceratopogonidae). The American Entomological Institute. Florida, FL, USA.

Yanase, T., Kato, T., Kubo, T., Yoshida, K., Ohashi, S., Yamakawa, M., Miura, Y., Tsuda, T. 2005. Isolation of bovine arboviruses from *Culicoides* biting midges (Diptera: Ceratopogonidae) in southern Japan: 1985–2002. J. Med. Entomol. 42: 63–67. doi.org/10.1093/jmedent/42.1.63

Zientara, S., Weyer, C.T., Lecollinet, S. 2015. African horse sickness. Rev. Sci. Tech. 34: 315–327.