Linking vector favourable environmental conditions with serological evidence of widespread Bluetongue virus exposure in livestock in Ecuador

Alfredo Acosta
alfredo.acosta@sva.se
University of São Paulo
Maritza Barrera
Universidad Técnica de Manabí
David Jarrín
Agencia de regulación y control fito y zoosanitario-Agrocalidad
Alexander Maldonado
Agencia de regulación y control fito y zoosanitario-Agrocalidad
Johanna Salas
Agencia de regulación y control fito y zoosanitario-Agrocalidad
Guilherme Camargo
University of São Paulo
Beatriz Mello
University of São Paulo
Alexandra Burbano
Agencia de regulación y control fito y zoosanitario-Agrocalidad
Euclides DelaTorre
Agencia de regulación y control fito y zoosanitario-Agrocalidad
Bernd Hoffman
Friedrich-Loeffler-Institut
Klaas Dietze
Friedrich-Loeffler-Institut

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Abstract

Despite knowledge of Bluetongue disease (BT) in Latin America, little information is available on the actual spread and overall burden. As a vector-borne disease, high-risk areas for BT will coincide with favourable environmental conditions for the prevailing vector. In Ecuador, information on the presence of BTV is limited to singled out virological findings. In this study, we obtained serological evidence for BT virus exposure derived from the passive surveillance system of national veterinary services aimed at detecting reproductive-vesicular diseases, including BT, for differential diagnosis. Bioclimatic factors relevant for Culicoides development as the main vector and the host abundance in parish level were taken as risk factors and analysed using a logistic regression model. Results reveal widespread evidence of bluetongue virus exposure that geographically matches favourable vector ecosystems between 12°C and 32°C. The variables relevant for the prediction of BTV riskiest areas include cattle population, maximum temperature of the warmest month, minimum temperature of the coldest month, temperature seasonality, and precipitation of the driest month. This analysis, the first of its kind for an Andean country with diverse ecosystems, can inform initial strategic approaches for targeted surveillance and control measures considering a one-health approach.

1. INTRODUCTION

Bluetongue disease BT in Latin America remains relatively underexplored, with limited information on its spread. Given its vector-borne nature, BT prevalence is expected to align with favourable environmental conditions for its primary vector. In Ecuador, BTV presence has been limited, highlighting a gap in comprehensive surveillance. We hereby aim to provide scientific grounds for future targeted surveillance and control strategies.

Bluetongue (BT) is a noncontagious disease affecting domestic and wild ruminants caused by the Bluetongue virus (BTV), which belongs to the genus *Orbivirus* in the *Reoviridae* family. The virus is capable of infecting cattle, sheep, deer, goats and camelids[1,2] and is transmitted by insects from the genus *Culicoides* As the disease causes substantial economic losses and is a major concern for international trade[3], it is notifiable to the World Organization for Animal Health (WOAH). Many countries have adopted regulatory control measures addressing Bluetongue; however, the effectiveness of these measures depends on the capacities and resources of their veterinary services, including laboratory facilities[4].

The disease has multiple manifestations that depend on the host and viral factors, and its clinical presentation ranges from salivation to depression, dyspnea, and asymptomatic to mild fever, as well as abortion and death[1]. According to the phylogenetic analysis of the more variable region of the BTV genome (Seg-2 region), at least 26 distinct serotypes have been identified around the World, each of which is able to cause disease[5]. In South America, BTV serotypes 1 to 4, 6 to 10, 14, 17 and 24 have been found previously in Argentina[6], Brazil, Colombia, Guyana, and Peru[7]. In Ecuador the identified serotypes in cattle are 9, 13 and 18[8].

Among the wild species, collared peccaries (*Tayassu tajacu*) have been found to be infected in Brazil[9] and Peru, marsh deer (*Blastocerus dichotomus*), pampas deer (*Ozotoceros bezoarticus*) and Tapir (*Tapirus terrestris*) in Brazil[10]; grey brocket (*Mazama gouazoubira*) in Bolivia, guanaco (*Lama guanicoe*) and vicuna (*Vicugna vicugna*) in Argentina[11]. Currently, there is no available information on BT in wildlife in continental Ecuador and the virus is absent in the Galapagos islands[12].

According to the WOAH, midges (genus *Culicoides*) are the only significant competent vector of BTV. They are also vectors of vesiculovirus (vesicular stomatitis)[13], Schmallenberg virus, African horse sickness virus, Aino virus and Akabane virus[14]. As a vector-borne disease, the natural distribution and prevalence of BT are governed mainly by ecological factors modulating vector populations (e.g., rainfall, temperature, humidity, and soil characteristics).

Transmission mainly occurs through the bite of infected midges (females)[15]. BTV requires a minimum temperature between 10°C and 15°C to replicate inside the *Culicoides* vector, as RNA polymerase activity is positively influenced by temperature[2]. Higher temperatures may increase the biting rate, favouring vector host transmission[15]. The temperature that maximises the chance of a midge surviving and consuming a blood meal are 23°C, and 13°C is the temperature that results in the greatest expected number of lifetime midge bites[16]. The inventory of *Culicoides* fauna in Ecuador comprises 70 species, including *C. insignis and C. paraensis*[17].

Rainfall is also a determinant of the survival and activity of midgets, and the abundance of the vector is often related to rainfall (and suitable temperatures). After rainfall, their feeding frequency[18–20]. Rainfall also governs the availability of larval habitat, survival, and dispersal of adults. The pupae of most species will float if submerged; however, the pupae of some species, such as *C. imicola*, can be drowned if inundated[20].

The long-distance spread can also be attributed to animal movements in the case of insufficient veterinary control. Little evidence for contact transmission has been found only in goats, sheep and deer, and transplacental infection has been reported in cattle, sheep, and elk[14].

Knowledge of BTV dispersion in Latin America is limited mostly to serological surveillance and few molecular characterization reports, and risk analysis or systematic surveillance that could guide prevention and control strategies is lacking. In Ecuador, BTV is not targeted by a specific surveillance approach but is included as a differential diagnosis of vesicular diseases in the foot and mouth disease (FMD) surveillance programme. Serological findings have been reported in the national surveillance system, scientific reports[8,12,21], as well as in international reporting systems since 2015 (https://wahis.woah.org/#/home/).

In this paper, we present the first analysis of ecological factors such as temperature and rainfall dependency of past detections of antibodies against BTV in Ecuador. We hereby provide scientific grounds for future targeted surveillance and control strategies addressing BT.

2. RESULTS

The results reveal widespread evidence of bluetongue virus exposure that geographically matches favourable vector ecosystems between 12°C and 32°C. We explored the bioclimatic variables dependency on natural regions and the distribution of the serological evidence between provinces. The variables relevant for the prediction of BTV riskiest areas include cattle population, maximum temperature of the warmest month, minimum temperature of the coldest month, temperature seasonality, and precipitation of the driest month.

2.1 Descriptive analysis of surveillance for BTV in Ecuador

Surveillance of BTV has been carried out by the National Veterinary Service (NVS) within the active and passive national surveillance strategy since the first official occurrence in the country in 2014 (https://wahis.woah.org/, accessed on 01 June 2023). General surveillance (passive) is based on the reporting of clinical symptoms such as fever, vesicular lesions, a drop in performance or abortions. Between November 2014 and December 2022, a total of 5,015 reports were received from 647 parishes around the country, representing 62,2% of the total 1,040 parishes in Ecuador (Fig. 1). The reported herds were examined by official veterinarians considering the clinical manifestations and records on the farms. Depending on this first anamnesis, suspected diagnosis can be derived to confirm brucellosis, infectious bovine rhinotracheitis, anaplasmosis, bovine viral diarrhea, leucosis, BT, neosporosis, FMD, and others.

Following the notification, out of the 5,015 reports, 381 farms with BT compatible signs were sampled for laboratory confirmation. Of these farms, 324 were seropositive for BTV. Most of the farms involved cattle (n = 378; 99,2%), followed by sheep (n = 2; 0,5%) and goats (n = 1; 0,3%). From a total of 5,901 samples obtained from these farms, a total of 5,161 animals had positive diagnoses for BTV antibodies (Table 1). BTV antibodies were not detected in other species in the database, such as Andean camelids (llama), deer, and buffalo. Wildlife species were not tested in the analysed period.

Table 1
Reports, positive diagnoses, and prevalence for bluetongue virus antibodies in cattle, sheep, and goats of Ecuador between the years 2014 and 2022.

Year	Positive farms/Sampled farms				Positive animals/Sampled animals				Apparent prevalence (%)			
	C	S	G	**T**	C	S	G	**T**	C	S	G	**T**
2014	1			**1**	43			**43**	100			**100**
2015	34/36	0/1	1/1	**35/38**	1,001/1,024	0/48	5/15	**1,006/1,087**	97.8		33.3	**92.5**
2016	72/81	1/1		**73/82**	1,577/1,767	10/15		**1,587/1,782**	89.2	66.7		**89.1**
2017	48/55			**48/55**	773/850			**773/850**	90.9			**90.9**
2018	123/149			**123/149**	1,345/1,590			**1,345/1,590**	84.6			**84.6**
2019	23/28			**23/28**	176/253			**176/253**	69.6			**69.6**
2020	15/19			**15/19**	157/187			**157/187**	84.0			**84.0**
2021	6/8			**6/8**	74/109			**74/109**	67.9			**67.9**
2022	0/1			**1**	0/17			**0/17**	0			**0.0**
TOTAL	322/378	1/2	1/1	**324/380**	5,146/5,823	10/63	5/15	**5,161/5,901**	88.4	15.9	33.3	**87.5**

C = Cattle; S = Sheep; G = Goats; T = Total.

The occurrence of BTV antibodies on farms increased from 2016 (n = 82; 21.6%) to 2018 (n = 149; 39.2%), peaked in 2016, and significantly decreased in 2019–2022 (Table 1).

The Administrative levels in Ecuador are province, canton, and parish. Provinces are also grouped in four main geographic regions: the coastal, the highlands, the amazon, and the Galapagos Islands (Fig. 1).

Differences in the number of farms testing positive for BT antibodies and the apparent prevalence rates were evident among provinces. Within the coastal region, Guayas, Esmeraldas and Los Rios, exhibited particularly elevated rates, similar to Morona, Orellana and Zamora in the amazon region. Conversely, provinces in the Highlands region such as Carchi, Chimborazo and Azuay exhibited the lowest rates. Specifically, Napo, Loja and Santo Domingo provinces recorded the highest number of farms with positive test results (Table 2, Fig. 1).

Table 2
Overview of farms with positive diagnoses and the apparent on-farm prevalence of BTV antibodies in ruminants between 2014 and 2022 in different provinces of Ecuador.

Province	ID	Positive farms	Animals on the farms	Samples	BTV+	Apparent prevalence
Morona Santiago	14	29	705	657	657	100.0
Orellana	22	19	444	293	293	100.0
Guayas	09	3	207	35	35	100.0
Zamora Chinchipe	19	21	519	413	410	99.3
Esmeraldas	08	7	483	124	123	99.2
Los Rios	12	9	1972	357	354	99.2
Sucumbios	21	12	408	257	253	98.4
El Oro	07	9	286	115	111	96.5
Santo Domingo	23	40	6,719	836	805	96.3
Napo	15	48	746	526	487	92.6
Pastaza	16	13	256	230	205	89.1
Cotopaxi	05	10	83	83	69	83.1
Bolivar	02	37	568	426	345	81.0
Loja	11	40	803	477	364	76.3
Manabi	13	14	3,267	199	151	75.9
Pichincha	17	13	718	348	253	72.7
Imbabura	10	16	574	95	60	63.2
Canar	03	9	531	133	76	57.1
Tungurahua	18	9	118	106	55	51.9
Azuay	01	10	142	140	49	35.0
Chimborazo	06	8	66	27	5	18.5
Carchi	04	5	41	41	1	2.4
Total		381	19,656	5,918	5,161	76.7

2.2 Ideal temperature conditions for vector survival

Although Ecuador is located in a tropical region crossed by the equator line, there are extensive areas with cold temperatures. Mainly because the temperature is modified by the Andean Mountains, which extends from north to south and reach altitudes greater than 6,200 metres, there are also important cities at altitudes greater than 2,500 m, as well as important animal populations at higher altitudes, especially dairy farms (Fig. 2A).

The mean parish temperature at which BTV antibodies were detected was 20.62°C (IQR = 5.2°C), and the temperature at which BTV antibodies were not detected was 18.37°C (IQR = 11.4°C). It is possible to observe higher temperatures in the eastern (amazon region) and western (coastal region) under ideal conditions for the survival and proliferation of *Culicoides spp.* vectors.

The analysis of parishes with ideal survival conditions for *Culicoides spp.* revealed that 54% (561 of 1,040) of the parishes had ideal temperature conditions, indicating that 73% of the national area (180.800 km^2) provided ideal conditions for vector survival (minimum temperature of 12°C and maximum temperature of 32°C). When increasing the minimum temperature by 3°C, as the expected mean warming over drylands[22] due to global warming, there would be an increase up to 80% of the national area (198.188) and 637 parish (61.25%) (SM).

The mean annual precipitation of parishes with observed BTV antibody detection was 1,983 mm (IQR = 1,576 mm), and that of parishes without BTV antibody detection averaged 1,373 mm (IQR = 853.79 mm). It is possible to observe greater precipitation in the (amazon region) and in the central-northwestern (coastal region) which could contribute with the survival and proliferation of the *Culicoides spp.* vectors (Fig. 2C).

The minimum total parish precipitation with registered outbreaks was 513 mm. In Spain the annual rainfall favourable for the survival of midges was approximately 600 mm, and in Africa, it was between 300 and 750 mm[23]. Parishes with lower annual rainfall are located on the Pacific coast without any outbreaks within the temperature range but with lower precipitation.

The cattle population in Ecuador was analysed considering that the occurrence of BTV strongly depends on host abundance. According to the 2021 vaccination campaign against FMD, the number of vaccinated animals was 4.65 million. The province of Manabi (northwestern coastal) is home to the largest cattle population, with 0.97 million animals; Pichincha (northcentral highlands, with its capital Quito) and Esmeraldas (northwestern coastal border to Colombia) have 0.37 and 0.36 million cattle, respectively (Fig. 2D). The median observed parish cattle population was 2,323.6 (Q1: 838.8, Q3: 5,353.8), and the maximum was 121,853.0, corresponding Manabi (where is located the largest livestock market called *El Carmen*). The parish median of cattle density (animals/km^2) was 22.26 (Q1:8.32, Q3:47,28), and the maximum corresponded to 808.75 in Tungurahua (central highlands, *Pelileo*) (SM).

The provinces with the highest animal densities were Carchi (border with Colombia), Tungurahua, and Cotopaxi in the central highlands, with densities of 81.2, 72.1 and 63.6 (animals/km^2), respectively (Table 3).

Table 3
Cattle population density and annual minimum temperature by province in Ecuador in 2023.

Province	Cattle population	Density (animals/Km2)	Min. Temp. (C')
Manabi	977,503	42.37	18.63
Pichincha	375,447	41.52	7.3
Esmeraldas	368,251	33.77	20.73
Guayas	297,254	26.07	19.13
Chimborazo	260,321	46.75	5.07
Cotopaxi	258,187	63.64	6.5
Santo Domingo	209,653	63.08	17.65
Loja	195,233	20.42	12.85
Azuay	176,345	30.11	7.59
Morona Santiago	165,256	16.6	14.64
Carchi	159,168	81.23	7.4
Bolivar	157,692	40.07	9.18
El Oro	156,984	35.81	17.03
Canar	142,555	63.2	7.77
Zamora Chinchipe	135,054	17.13	13.75
Tungurahua	132,964	72.07	5.81
Sucumbios	129,918	13.5	17.24
Imbabura	104,340	31	7.45
Los Rios	83,768	11.47	19.32
Orellana	75,939	18.44	19.13
Napo	49,519	8.28	10.34
Pastaza	25,345	9.94	16.85
Santa Elena	19,693	4.46	19.21
Total	4’656,389	34.38	

2.3 Modelling bio climate variables.

Each pair of bioclimatic variables included in the model had a correlation < 0.54. Of the 13 variables, 6 were significant in distinguishing the parish where the outbreaks were present. The model presented an error of 0.14, a high adjustment (Holsem test = 0.9) and an acceptable fit (AUC:0.77) (Table 4).

Table 4
Logistic model results.

Variable	β	OR	CI95		Pr(>|Z|)	Sig
Precipitation of wettest month	6.56E-03	1.007	1.004	– 1.009	5.69E-08	***
Population of cattle	6.52E-05	1.000	1.000	-1.000	1.55E-06	***
Max temp of warmest month	3.08E-01	1.360	1.156	-1.601	2.09E-04	***
Min temp of coldest month	-2.76E-01	0.759	0.648	-0.889	6.17E-04	***
Temperature seasonality	-1.55E-03	0.998	0.997	-0.999	1.94E-03	**
Precipitation of driest month	2.38E-03	1.002	1.000	-1.005	9.10E-02	.
AIC: 744, R2:0.217, AUC: 0.78, error: 0.14, Holsem: 0.97						

The maximum temperature of the warmest months increased the odds of vector presence in Ecuadorian parishes (OR 1.36); the minimum temperature of the coldest month (OR 0.76) showed the opposite (protective) effect related to the ideal temperature range window (Fig. 2B), contrasting the Andean colder zones and the coastal and amazon warmer zones. The precipitation of the wettest months, the population of cattle and the rest of the variables showed high significance in the model; however, these variables had very small effects (low odds).

Collinearity analysis revealed values under 1.8 between the analysed variables. There was 1 observation with a significant influence on model fitting (excluded on final fit), according to the Bonferroni outlier test (p = 0.004); additionally, there was no correlation between the residuals.

The suitability of sites in Ecuador for the occurrence of BTV based on modelling the bioclimatic variables is shown in Fig. 3. The analysis revealed a high probability of occurrence in transition zones from the highlands to the amazon in the central-eastern provinces of the country (Napo, Orellana), and in the central-western provinces (Santo Domingo) and southwestern (Loja).

3. DISCUSSION

Widespread BTV exposure in Ecuadorian cattle emphasises the necessity for enhanced surveillance systems, given the underestimated impact of Bluetongue disease (BT) on producers and veterinary services. Climatic conditions significantly influence vector abundance, warranting targeted control measures. This analysis, the first of its kind for an Andean country with diverse ecosystems, can inform initial strategic approaches for risk-based surveillance and control measures, adopting a comprehensive one-health approach.

With the limited available information on the prevalence of BT in Latin America, the overall impact of the disease is most likely underestimated by producers and veterinary services alike. Considering the effects of BTV on cattle production, such as a relative reduction in milk production, postponed gestation, no gestation, and abortion[24], there is therefore a need for scientific evidence supporting the need to understand and control BT in the region.

The evidence of widespread BTV exposure in Ecuadorian cattle was derived from the results of untargeted passive surveillance supporting brucellosis and FMD surveillance programs. The lack of a BT case definition in the NVS system and the fact that BT is only addressed as a differential diagnosis within the general surveillance is a major constraint leading most likely to an underestimation of the overall disease burden.

The presented analysis of prevailing climatic conditions and their expected impact on vector abundance is in line with current knowledge[25]. The mean parish temperature at which the outbreaks occurred in this study was 20.1°C, which is in line with other temperature-dependent transmission studies[26] in which the temperature ranged from 15°C to 26°C. The identification and prioritization of parish, as performed in this paper, could be valuable for informing animal health decision-making, identifying possible at-risk areas of spread, focusing on specific surveillance of BTV or even on animal movement to avoid the transport of positive animals[27] and implementing preventive and control measures in large livestock markets[28] around the country.

Temperature and precipitation are related to the biting rate of *Culicoides* spp., the time required for oogenesis, oviposition, the time needed to digest the blood meal, and the BTV replication rate[29]. Environmental conditions are one of the key aspects for implementing a successfully surveillance and control strategy. In this paper, we used average temperatures and rainfall, but further studies could improve the temperature resolution using monthly data to establish temporal and seasonal implications.

Several species of *Culicoides* described in Ecuador have public health implications because they have been reported as possible agents of skin zoonosis (*C. insignis, C. pachymerus, and C. paraensis*), filariasis (*C. pifanoi*), allergic dermatitis (*C. acotylus, C. fluvialis, and C. leopoldoi*) and mansonellosis (*C. guttatus*); others have been reported to carry DNA from *Leshmania brasiliensis* and *Amazonensis* (*C. foxi*, *C. insignis*, and *C. filarifer*)[17]. Giving rise to the importance of improving the knowledge of the vector not only for veterinarian interest but also as a public health concern and wildlife affectation that could be better addressed considering one-health approach.

Knowledge of the risk areas for BTV vectors could inform recommendations for vector control as an attempt to reduce virus transmission by reducing vector-host contact[30], and implementing the use of sticky resting boxes as a tool for monitoring the presence of *Culicoides*[31], insecticides[32,33], are often discussed as options; however, their widespread implementation and effects must be carefully assessed for economic and environmental sustainability.

Finally factoring in the host, the population of cattle is a risk factor for BTV presence but only as a cofactor with Temperature-precipitation seasonality, and annual precipitation matching the optimal ranges for *Culicoides* development. This is exemplified clearly when we look at parishes with high population of cattle (high density), without seropositivity findings, located in the highland central zone with low temperatures, showing that the climate factors are determinant. However, the option for vaccination[34] of susceptible species of cattle and small ruminants against circulating BTV serotypes provides a suitable tool to protect animals and avoid further spread[35,36]. The results presented here can inform targeted vaccination strategies to prevent the spread of BT via the transport of animals from high-risk zones.

Currently, understanding the precise areas where *Culicoides* are most likely to be present, associated to climate conditions such as temperature and precipitation, is of paramount importance. Furthermore, it is necessary to undertake further studies of elucidate the impact of climate change[37–39], rise in the temperature (SM) will affect the distribution of vector habitads[40]. This will not only modify the current situation but also inform future predictions.

In the South American context, is crucial, to explore the hitherto uncharted role of wildlife in virus maintenance[9,10], including its effects on various populations[41].

4. MATERIALS AND METHODS

Passive surveillance data from the Veterinary Service were analysed from farms screened for BTV antibodies using c-ELISA. Descriptive analysis was then conducted on historical surveillance data. Ideal temperature conditions for Culicoides vector survival were assessed using bioclimatic variables; Finally, logistic regression determined the influence of environmental factors on parish BTV status.

4.1 Surveillance data

We analysed the passive surveillance information of suspicious and confirmed events from the Veterinary Service database from 2014 to 2022. The analysed dataset was obtained from the official system (www.sistemas.agrocalidad.gob.ec/sizse) accessed on 01.04.2023). The information was registered by official veterinarians accessing the institutional system when visiting the farms. Cadastral records are updated each semester when bovines are vaccinated against FMD, and movement records between farms and traders update the individual farm records. The farms were sampled by the official veterinarians according to internal procedures. Serum samples were screened for the presence of BTV antibodies using a bluetongue antibody test kit, c-ELISA (VMRD, Pullman WA, USA), which was performed according to the manufacturer's instructions. The test was positive if the sample produced more than 60% inhibition. All samples were analysed in the national reference laboratory.

4.2 Descriptive analysis of BTV surveillance in Ecuador

During the 2014–2022 period, the NVS collected information on vesicular and reproductive diseases and their differentials via passive surveillance. BTV was included in the differential diagnoses registering large datasets of information about the disease. We performed a descriptive epidemiological analysis on the available historical information.

4.3 Ideal temperature conditions for vector survival

We analysed the relationships between the ideal survival temperature ranges of *Culicoides spp.* and the maximum and minimum parish temperatures at the best geographic resolution (parish), to identify the geographic locations that provided optimal survival conditions for the *vector.*

The ideal temperature ranges are defined by a minimum temperature threshold of 12°C, which maximizes the likelihood of a BTV-infected midge surviving its extrinsic incubation period[16], as well as the apparent absence of virus replication below 15°C[20]. Maximum temperatures were set at 34°C, representing the anticipated limit of infective life[42] and 33°C, beyond which negative effects on oviposition[43].

Bioclimatic variables were obtained at a spatial resolution of 2.5 arc-minutes (~ 5 km^2); and the extracted values from a raster object at the locations of the spatial vector data were analysed using Raster (R package V3.5)[44]. The official map layers were obtained from the Institute of Statistics and Census of Ecuador (http://www.geoportaligm.gob.ec/, accessed on 1 February 2023). The temperature and precipitation data were extracted from WorldClim (https://worldclim.com/, accessed on 1 January 2023). Analyses were computed using R V.4.2 (https://cran.r-project.org/, accessed on 1 February 2023).

4.4 Modelling bioclimate variables

To determine the influence of environmental variables on the *Culicoides* parish distribution, we considered 12 bioclimatic variables (supplemental material SM) as risk factors in the model and the host population (cattle). Climate data were obtained from the spatial resolution climate surfaces for global land areas[45]. The variables included in the model (Table 5) were chosen based on their correlation values $|r| < 0.7$. Variance inflation factors were calculated into the model to avoid multi-collinearity of environmental variables $|vif| < 10$[46]. The evaluation of variables was based on the association of each explanatory variable with the binary outcome parish BTV status (antibodies detected yes/no) using logistic regression[47]. We used a manual backwards exploratory selection of variables and then a forward stepwise selection[48]. The goodness of fit of the final model was measured using conditional R2, ROC and Hosmer-Lemeshow tests[49].

Table 5
Variables analysed in the model.

Variables	Description
bio_1	Annual mean temperature
Bio_4	Temperature seasonality (sd x 100)
Bio_5	Max temperature of warmest month
Bio_6	Min temperature of coldest month
Bio_8	Mean temperature of wettest quarter
Bio_9	Mean temperature of driest quarter
Bio_12	Annual precipitation
Bio_13	Precipitation of wettest month
Bio_14	Precipitation of driest month
Bio_15	Precipitation seasonality (sd x 100)
Bio_18	Precipitation of warmest quarter
Bio_19	Precipitation of coldest quarter

Declarations

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AUTHOR CONTRIBUTIONS

Conceptualization, A.A., K.D. and B.H.; investigation, M.B., D.J., A.M., J.S. E.D.; writing original draft, A.A., B.G., G.C., coding A.A. B.G., G.C.; visualization, A.A. B.G., G.C.; writing review and editing A.B., E.D.; All authors have read and agreed to the published version of the manuscript.

ADDITIONAL INFORMATION

Supplementary material is available: SM.

The author(s) declare no competing interest.

DATA AVAILABILITY STATEMENT

The datasets generated during and/or analysed during the current study are available in the [BTV] repository, [https://github.com/alfredojavier55/BTV11].

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Figures

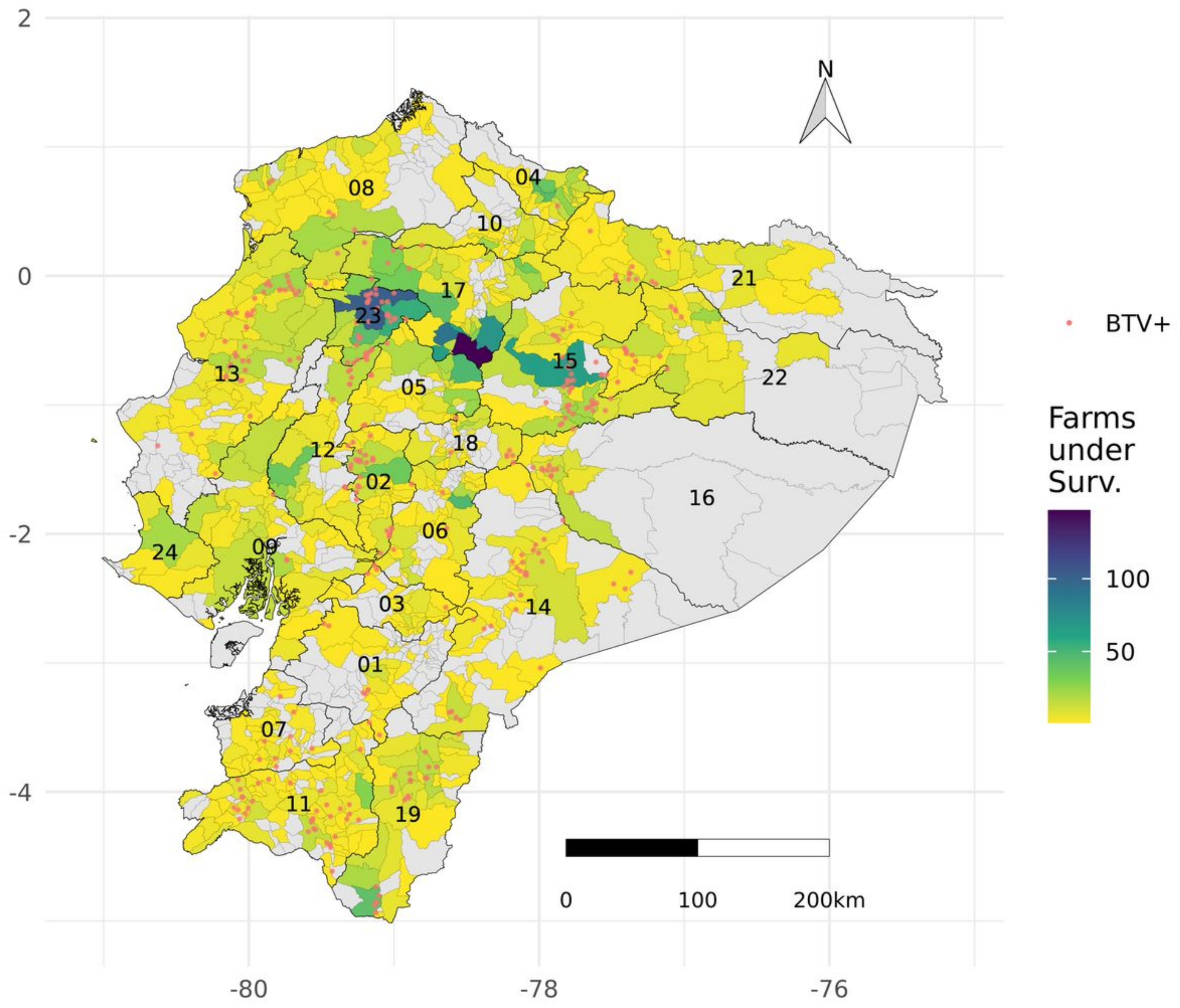

Figure 1

Surveillance of bluetongue in Ecuador. Detection of BTV seropositive farms in Ecuador (red dots), with parishes on a coloured scale representing the overall number of farms under surveillance that reported disease suspicion to the NVS between 2014 and 2022, 23 provinces are identified by their political id and their boundaries are black, parish boundaries on grey (Galapagos islands are omitted).

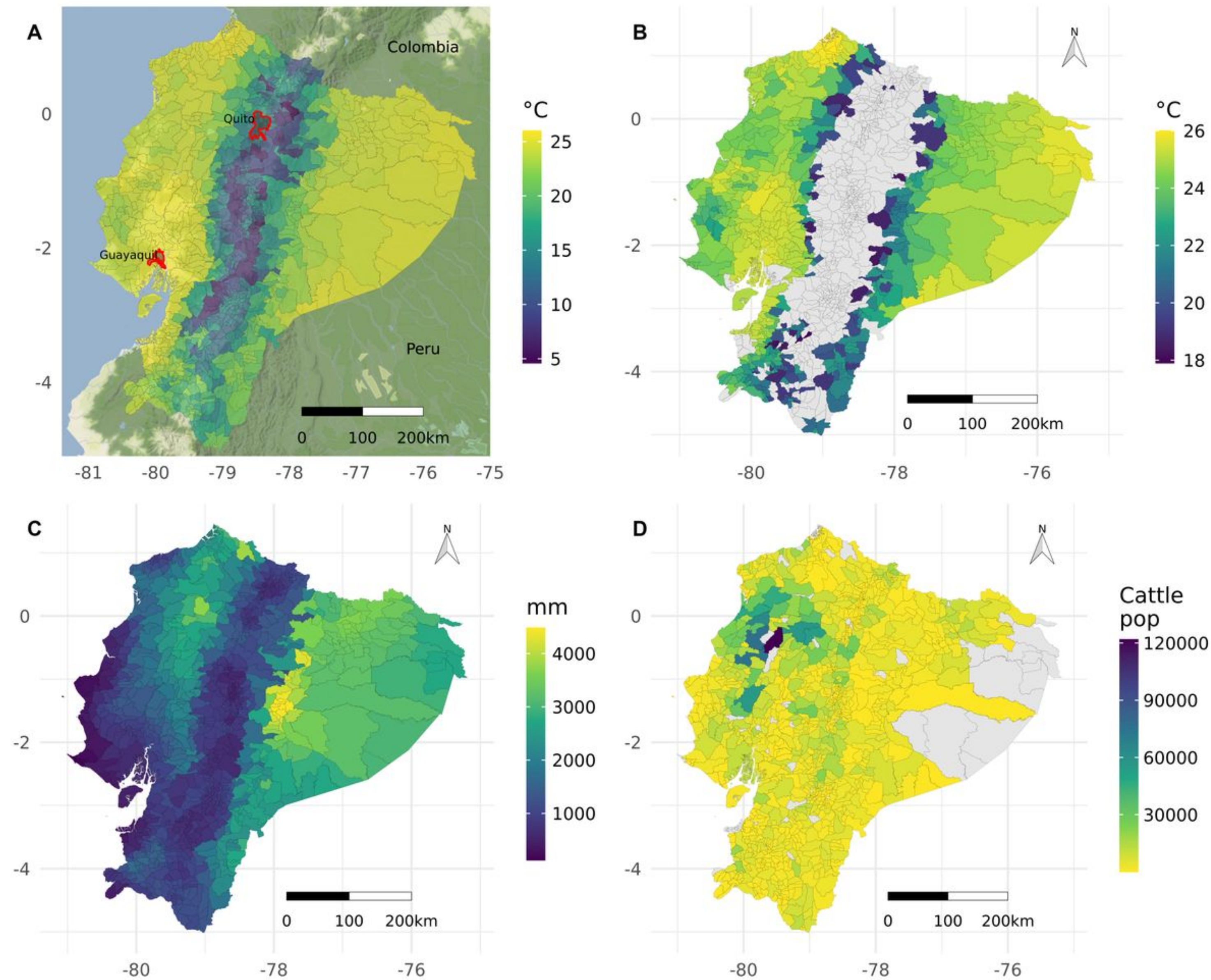

Figure 2

Overview of environmental characteristics and host species related to the bluetongue presence in Ecuador at the parish level. (A) Maximum temperature of the warmest month. Metropolitan areas of the largest cities (highlighted in red): Guayaquil is located in the coastal region, and Quito (the capital) is situated in the highland region. (B) Annual mean temperature. The optimal temperature range for vectors corresponds to temperatures a minimum of 12 °C and a maximum of 32 °C. Parishes with the least likely presence of Culicoides outside this optimal temperature range are shown in grey. (C) Annual precipitation in mm shows the highest values in the central amazon region and the north-western coastal region. (D) Cattle population in 2023 shows the highest populations observed in parishes corresponding to Manabi and Santo Domingo provinces.

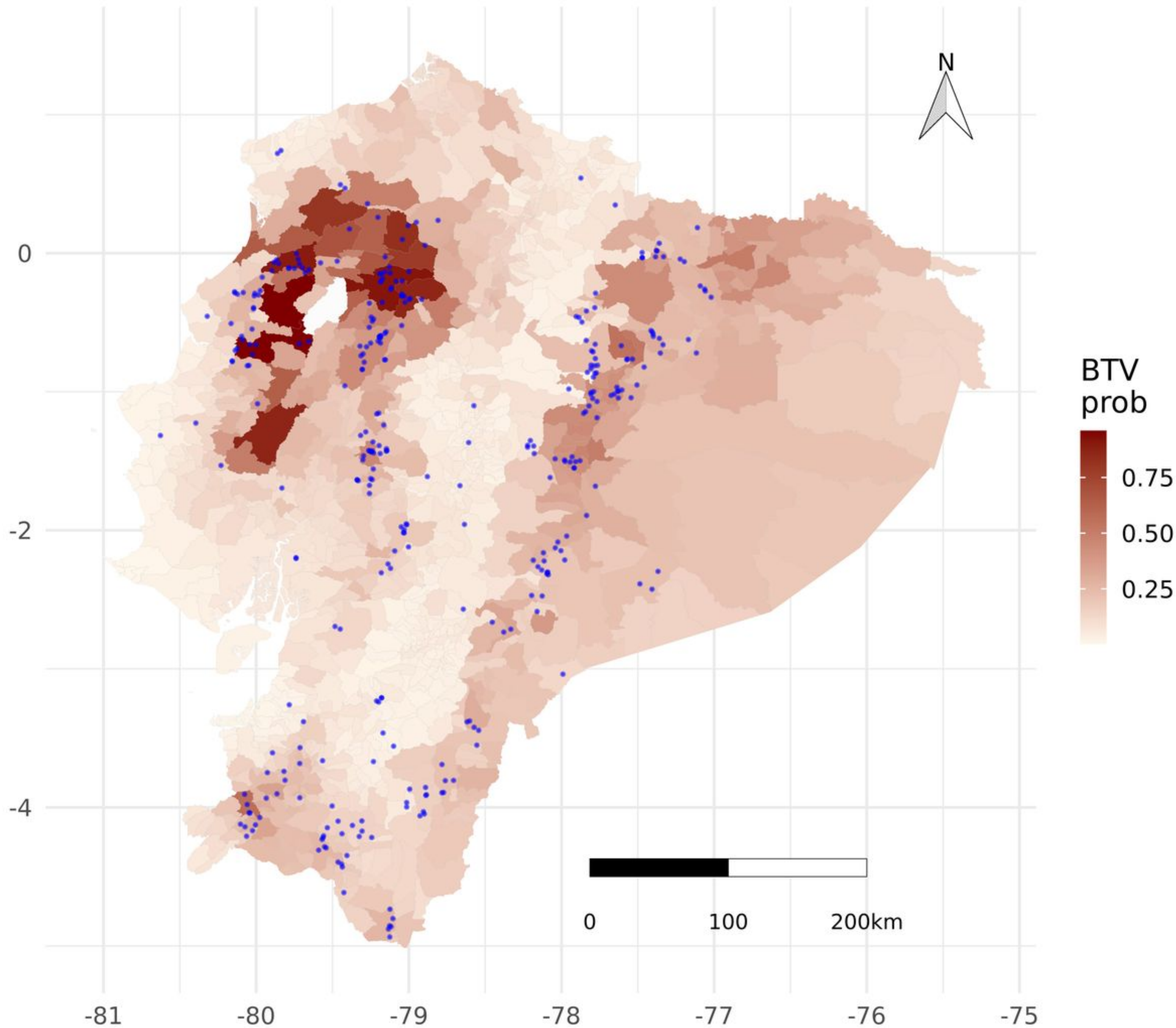

Figure 3

Probability map of the occurrence of BTV in Ecuador. According to the results from the model based on bioclimatic variables and host population, the locations of farms with serological findings of BTV+ can be seen as blue dots.

Supplementary Files

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- Supplementarymaterial.docx