

Article

Long-Term Climatic Changes in Small Ruminant Farms in Greece and Potential Associations with Animal Health

Eleni I. Katsarou ¹, Daphne T. Lianou ¹, Elias Papadopoulos ²  and George C. Fthenakis ^{1,*}

¹ Veterinary Faculty, University of Thessaly, 43100 Karditsa, Greece; elekatsarou@vet.uth.gr (E.I.K.); dlianou@vet.uth.gr (D.T.L.)

² Laboratory of Parasitology and Parasitic Diseases, School of Veterinary Medicine, Faculty of Health Sciences, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece; eliaspap@vet.auth.gr

* Correspondence: gcf@vet.uth.gr

Abstract: The objectives of this work were (a) to present the changes in climatic parameters from 1989 to 2019, in 444 locations throughout Greece, where small ruminant farms have been based and (b) to present associations of the changes in the climatic parameters with clinical data related to small ruminant health. Climatic variables (1989–2019) were obtained for 444 locations with small ruminant farms throughout Greece. During this period, significant increases were noted in temperature-related parameters (annually 0.05 °C for average temperature and 0.14 °C for temperature range) and precipitation (annually 0.03 mm). There were significant differences in climatic conditions between locations of farms in accord with the management system applied therein, as well as in accord with the breed of animals on the farms (e.g., higher average temperature in locations with Greek breeds, higher temperature range in locations with imported breeds). There were significant associations of temperature-related parameters with the annual frequency of cases of neonatal hypothermia seen at a veterinary teaching hospital, as well as with the average proportion of *Haemonchus contortus* larvae in faecal samples and the frequency of cases of *H. contortus* resistance reported by a veterinary parasitology laboratory.

Keywords: agricultural environment; climate; climate change; epg counts; goat; *Haemonchus*; neonatal hypothermia; Trichostrongylidae; pregnancy toxemia; resistance; sheep



Citation: Katsarou, E.I.; Lianou, D.T.; Papadopoulos, E.; Fthenakis, G.C. Long-Term Climatic Changes in Small Ruminant Farms in Greece and Potential Associations with Animal Health. *Sustainability* **2022**, *14*, 1673. <https://doi.org/10.3390/su14031673>

Academic Editors: Ana Kaić and Nikolina Kelava Ugarković

Received: 4 January 2022

Accepted: 29 January 2022

Published: 31 January 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Greece has a high number of sheep and goats, around 8,400,000 sheep and 3,600,000 goats [1], which account for approximately 6.5% and 22.0%, respectively, of total numbers of small ruminants in Europe [2]. The milk production from these animals amounts to 645,000 and 350,000 tonnes annually [2,3], respectively, 90% of which is used for cheese production. Despite the importance of small ruminant farming for the country, specific climatic changes in the environment of sheep and goat farms have not been reported. Moreover, the potential effects of these changes on small ruminant health have not been reported.

Changes in the environment of sheep and goats can affect their health and welfare and, consequently, their productivity. A variety of climatic factors can affect small ruminants, although greater importance has been given to the potential effects of temperature. Relevant studies have focused on the adverse effects of high temperatures and the mechanisms to counteract these potential adverse effects, e.g., thermoregulatory mechanisms of the animals [4,5]. Increased environmental temperatures can result in decreased milk production [6,7], as well as in reduced weight and quality of meat of sheep and goats [8,9]. Moreover, climatic factors may have an effect on pathogens or on hosts. For example, nematode infections of sheep and goats are facilitated by increased temperatures, which represent the most significant determinant of development of free-living nematodes on pasture [10], thus increasing infection potential of grazing animals [11].

The objectives of this work were (a) to present the changes in climatic parameters from 1989 to 2019, in 444 locations throughout Greece, where small ruminant farms have been based, and (b) to present associations of the changes in the climatic parameters with clinical data related to small ruminant health.

2. Materials and Methods

2.1. Small Ruminant Farms

As part of an extensive countrywide investigation into sheep and goat diseases, 444 small ruminant farms were visited in all 13 administrative regions of Greece (Figure 1). Farms were included in the study on a convenience basis (willingness of farmers to receive a visit by university staff), as described previously [12].



Figure 1. Location of 444 small ruminant farms around Greece, in which climatological measurements were evaluated from 1989 to 2019.

2.2. Data Management and Analysis

2.2.1. Data Extraction

During the visit on each farm, data on farm location were collected using hand-held Global Positioning System Garmin units. The geo-references were resolved to the specific farm level.

Climatic variables were derived from ‘The POWER (Prediction of Worldwide Energy Resources) Project’ (NASA Langley Research Center (LaRC), Hampton, VA, USA), which provides meteorological datasets from NASA research for the support of agricultural needs. The following settings were used for obtaining the data: user community, ‘agroclimatology’;

temporal average, ‘monthly & annual’; latitude/longitude, ‘geo-references of each farm’; time extent, ‘start date 1989–end date 2019’; output file format, ‘ASCII’. Data for the following parameters were extracted: temperature at 2 m (T2M), temperature of Earth skin (TS), minimum temperature at 2 m (T2Min), maximum temperature at 2 m (T2Max), temperature range at 2 m (T2Ran), relative humidity at 2 m (RH2m), precipitation (PREC) and wind speed at 10 m (WS10m).

For the evaluations, the annual averages provided by the above platform for every year from 1989 to 2019 ($n = 31$) were taken into account. For the assessment of potential seasonal effects, the respective monthly averages provided were computed to a seasonal average, as follows: $(\text{month}_1 + \text{month}_2 + \text{month}_3)/3$. To calculate the seasonal average for winter, the monthly average of December of the preceding year was taken into account.

The 13 administrative regions of Greece were clustered into four main parts of the country: North, Central, South and Islands of the country. For the evaluation of the management system applied on the farms (intensive, semi-intensive, semi-extensive, extensive), the classification of the European Food Safety Authority [13] was used.

Data on clinical cases on three reproductive disorders, namely (a) pregnancy toxemia, (b) clinical mastitis and (c) neonatal hypothermia, were taken from the Department of Obstetrics and Reproduction of the Veterinary Faculty of the University of Thessaly, located in the veterinary teaching hospital. The Department is a certified training centre of the European College of Small Ruminant Health Management, under the policies and procedures of the European Board of Veterinary Specialisation; it receives first-opinion and referral cases and provides consultancy services at small ruminant farms. Standard procedures, with a combination of clinical or paraclinical techniques, were employed for the diagnosis of these cases (e.g., measurement of β -hydroxybutyrate value in blood, bacteriological examination of milk). For the present evaluation, only cases from farms in central Greece, where the Veterinary Faculty is located, were taken into account, as they accounted for >80% of all clinical cases seen during the study period.

The results of parasitological examinations on clinical samples included (a) overall average eggs per gram (epg) counts in examined faecal samples from small ruminants, (b) overall average proportion of *Haemonchus contortus* larvae found in coprocultures of examined faecal samples from small ruminants and (c) frequency of cases of *H. contortus* resistance in small ruminants, as reported after the examination of clinical samples by the Laboratory of Parasitology and Parasitic Diseases of the Faculty of Veterinary Medicine of the Aristotle University of Thessaloniki. The Laboratory receives and processes samples and provides consultancy services at small ruminant farms. Standard parasitological techniques were employed for processing the samples received (e.g., McMaster technique, coprocultures, faecal egg count reduction test). For the present evaluation, only results of samples from farms in northern Greece were taken into account, as these accounted for >85% of all samples processed during the study period.

2.2.2. Statistical Analysis

Data were entered into Microsoft Excel and analysed using SPSS v. 21 (IBM Analytics, Armonk, NY, USA). Basic descriptive analysis was performed.

Repeated measures mixed-effect linear regression was used to evaluate the significance of changes regarding the various climatic variables in each location throughout the period 1989–2019. Models were adjusted for repeated measures within each location. Differences in changes regarding the various climatic parameters were also assessed on a seasonal basis, separately for autumn, winter, spring and summer. Regression slopes were also calculated for the various study periods and compared as appropriate.

Analysis of covariance was used to evaluate differences in changes regarding the various climatic parameters between the four main parts of the country and between the various management systems applied on the farms; analysis was performed for two time periods, specifically 1989 to 2019 and 2014 to 2019.

Comparisons of differences were also performed between locations in accord with the animal species farmed (sheep or goats), as well as with the various breeds (indigenous or imported) of sheep or goats. In total, twelve breeds were seen on sheep farms (indigenous breeds: Boutsko, Chios, Friesarta, Karagouniko, Kefallinia, Local (this referred to a variety of small-scale breeds, not always related between them and each one prevailing only in some areas of the country with limited geographic dissemination), Mytilini, Sfakia; imported breeds: Assaf, Awassi, Friesian, Lacaune) and seven breeds were seen on goat farms (indigenous breeds: Kefallinia, Indigenous Greek (*Capra prisca*), Skopelos; imported breeds: Alpine, Damascus, Murciano-Granadina, Saanen) [14].

The potential associations of the annual frequency of (a) pregnancy toxaemia, (b) clinical mastitis and (c) neonatal hypothermia with the various climatic parameters was assessed by using analysis of correlation. For this analysis, only climatic data from locations in the central part of the country were taken into account. For pregnancy toxaemia and neonatal hypothermia, only data for winter (when the last stage of gestation of small ruminants in Greece takes place) were used; for clinical mastitis, data for winter and spring (when the lactation period of small ruminants in Greece occurs) were used. The potential association of the parasitological data with the various climatic parameters was assessed by using analysis of correlation. For this analysis, only climatic data from locations in the north part of the country were taken into account. Additionally, and specifically for the evaluation of potential correlations of climatic data with the frequency of cases of *H. contortus* resistance, the study period was divided into two stages: up to the end of 2011 and from 2012 onwards. Separate correlation analyses were performed for each of these two periods; then, the results of the evaluation of the two periods were compared between them.

In all analyses, statistical significance was defined at $p \leq 0.05$.

3. Results

3.1. Changes in Climatic Parameters from 1989 to 2019

3.1.1. Overall Changes

The changes in climatic parameters from 1989 to 2019, for two temperature-related measurements in the locations of the 444 farms, were significant ($p < 0.0001$ for the average temperature at 2 m and the average temperature of Earth skin and $p \geq 0.17$ for the other parameters) (Table 1). The changes in average precipitation were also significant ($p = 0.004$), but no significant changes in relative humidity ($p = 0.12$) and wind speed ($p = 0.32$) were noted (Tables 1 and S1, Figures 2–4 and S1–S5).

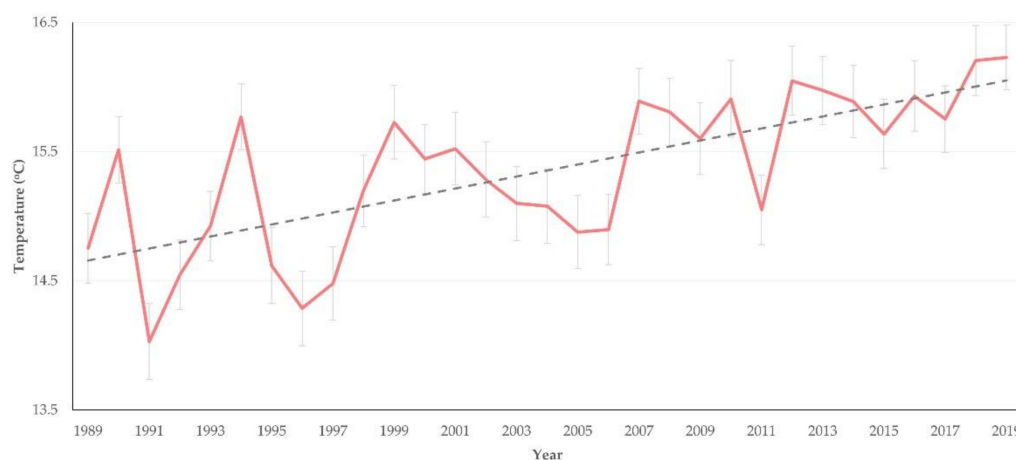
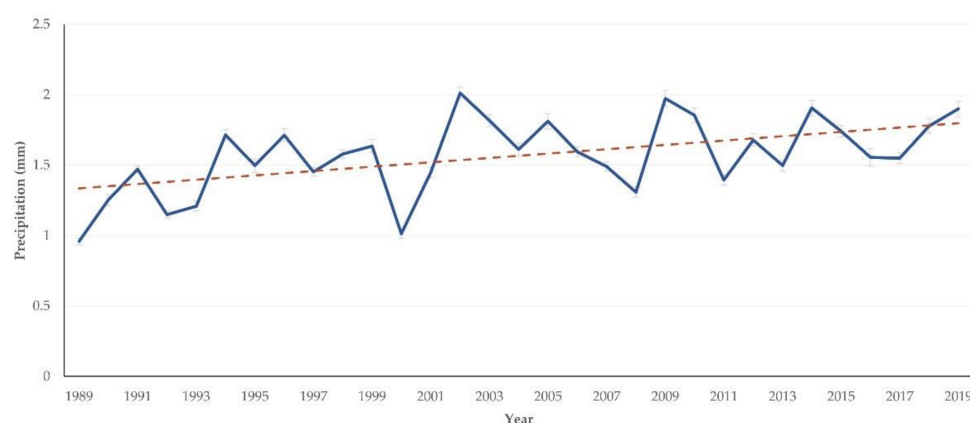
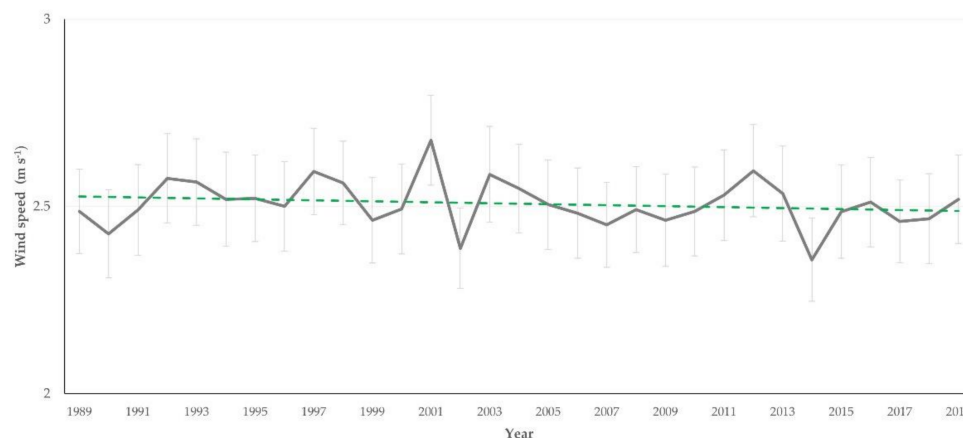


Figure 2. Annual average temperature at 2 m from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece (dashed line is the respective trendline; slope: 0.046, $p < 0.0001$).

Table 1. Annual average values of climatic parameters among locations of 444 small ruminant farms throughout Greece in 1989 and 2019.

Climatic Parameters	Annual Average ($\pm$ s.e. ¹)		Overall Change	Average Annual Change	Slope ($\pm$ s.e.)	<i>p</i>
	1989	2019				
Average temperature at 2 m (T2m) (°C)	14.8 $\pm$ 0.3	16.2 $\pm$ 0.2	9.9%	0.05	0.046 $\pm$ 0.008	<0.0001
Average temperature of Earth skin (TS) (°C)	15.3 $\pm$ 0.3	16.7 $\pm$ 0.3	9.6%	0.05	0.044 $\pm$ 0.008	<0.0001
Minimum temperature at 2 m (T2mMin) (°C)	−2.8 $\pm$ 0.6	−4.6 $\pm$ 0.8	−62.3%	0.06	0.011 $\pm$ 0.038	0.77
Maximum temperature at 2 m (T2mMax) (°C)	34.7 $\pm$ 0.3	37.2 $\pm$ 0.3	7.4%	0.08	0.046 $\pm$ 0.033	0.17
Temperature range at 2 m (T2mRan) (°C)	37.5 $\pm$ 0.8	41.8 $\pm$ 1.0	11.6%	0.14	0.035 $\pm$ 0.050	0.49
Average relative humidity at 2 m (RH2m) (%)	66.5 $\pm$ 0.4	68.4 $\pm$ 0.3	2.9%	0.06	0.062 $\pm$ 0.039	0.12
Average precipitation (PREC) (mm)	0.96 $\pm$ 0.02	1.90 $\pm$ 0.06	98.1%	0.03	0.015 $\pm$ 0.005	0.004
Average wind speed at 10 m (WS10m) (m s ^{−1})	2.5 $\pm$ 0.1	2.5 $\pm$ 0.1	1.3%	<0.01	−0.001 $\pm$ 0.001	0.32

¹ Standard error of the mean.**Figure 3.** Annual average precipitation from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece (dashed line is the respective trendline; slope: 0.015, *p* = 0.004).**Figure 4.** Annual average wind speed at 10 m from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece (dashed line is the respective trendline; slope: −0.001, *p* = 0.32).

3.1.2. Changes between Locations in the Four Parts of the Country

There were significant differences between locations of farms in the four parts of the country for all the climatic parameters ($p < 0.0001$ for all comparisons), with the exception of average precipitation ($p = 0.85$) (Figures 5–7, Table S2).

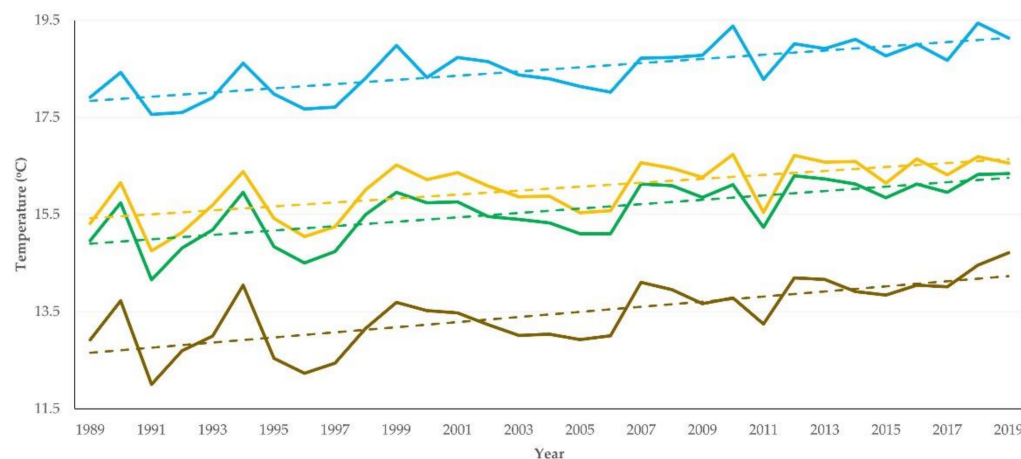


Figure 5. Annual average temperature at 2 m from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece, in accord with the part of the country where these were located (green: central part, blue: islands, brown: north part, orange: south part; dashed lines are respective trendlines; respective slopes: 0.045, 0.043, 0.053, 0.041, $p > 0.37$ for all comparisons).



Figure 6. Annual average precipitation from 1989 to 2019 (**left**) or 2014 to 2019 (**right**) among locations of 444 small ruminant farms throughout Greece, in accord with the part of the country where these were located (green: central part, blue: islands, brown: north part, orange: south part; dashed lines are respective trendlines; for 1989–2019, respective slopes: 0.018, 0.006, 0.018, 0.014, $p > 0.37$ for all comparisons; for 2014–2019, respective slopes: 0.041, 0.055, -0.100 , 0.082, $p < 0.07$ for comparisons between the north part and other parts of the country and $p > 0.50$ for all other comparisons).

There were no significant differences between locations in the four parts of the country in the change in the various parameters from 1989 to 2019 ($p > 0.07$ for all comparisons). Moreover, there were no significant differences between locations in the four parts of the country in the change in the various parameters from 2014 to 2019 ($p \geq 0.08$ for all comparisons), with the exception of the average precipitation. For this parameter, there was a tendency for significant difference between the north and other parts of the country ($p < 0.07$, $p > 0.50$ for all other comparisons) (Figures 5–7, Table S3).

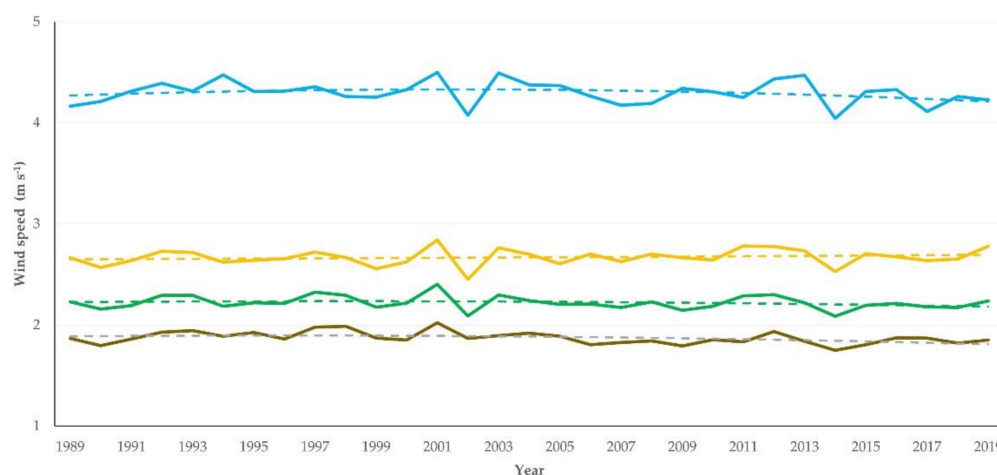


Figure 7. Annual average wind speed at 10 m from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece, in accord with the part of the country where these were located (green: central part, blue: islands, orange: south part, brown: north part; dashed lines are respective trendlines; respective slopes: -0.001 , -0.002 , -0.003 , 0.002 , $p > 0.07$ for all comparisons).

3.1.3. Changes between Locations in Accord with the Management System Applied on Farms

There were significant differences between locations of farms in accord with the management system applied therein for all the climatic parameters ($p < 0.025$ for all comparisons), with the exception of the average precipitation ($p = 0.91$) (Table 2, Figures 8–10).

Table 2. Average ($\pm$ standard error of the mean) overall values of climatic parameters from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece, in accord with the management system applied on the farms.

Management System Applied on Farms	Average Temperature at 2 m ($^{\circ}\text{C}$)	Average Temperature of Earth Skin ($^{\circ}\text{C}$)	Minimum Temperature at 2 m ($^{\circ}\text{C}$)	Maximum Temperature at 2 m ($^{\circ}\text{C}$)	Temperature Range at 2 m ($^{\circ}\text{C}$)	Average Relative Humidity (%)	Average Precipitation (mm)	Average Wind Speed at 10 m (m s^{-1})
Intensive ($n = 52$)	14.5 ± 0.1	14.9 ± 0.1	-6.2 ± 0.4	38.2 ± 0.3	44.4 ± 0.5	68.4 ± 0.4	1.55 ± 0.05	2.2 ± 0.01
Semi-intensive ($n = 180$)	14.8 ± 0.1	15.2 ± 0.1	-5.8 ± 0.4	38.3 ± 0.3	44.2 ± 0.5	67.8 ± 0.4	1.59 ± 0.05	2.2 ± 0.01
Semi-extensive ($n = 168$)	15.6 ± 0.1	16.2 ± 0.1	-3.6 ± 0.3	37.3 ± 0.3	40.9 ± 0.4	68.9 ± 0.3	1.60 ± 0.06	2.7 ± 0.01
Extensive ($n = 44$)	16.5 ± 0.1	17.2 ± 0.1	-1.2 ± 0.3	36.7 ± 0.3	37.9 ± 0.4	69.3 ± 0.3	1.59 ± 0.05	3.1 ± 0.01

There were no significant differences between locations of farms in accord with the management system applied therein in the change in the various parameters from 1989 to 2019 and from 2014 to 2019 ($p > 0.36$ for all comparisons) (Table S4). Moreover, there were no significant differences between locations of farms in accord with the management system applied therein in the change in the various parameters during these periods, when the analyses were performed on a seasonal basis ($p > 0.15$ for all comparisons).

3.2. Associations of Climatic Parameters with Animal Species and Breeds

3.2.1. Associations with the Animal Species Farmed

There were no significant differences between locations of farms with sheep or goats for all the climatic parameters ($p > 0.09$ for all comparisons) (Figure S6), with the exception of the average wind speed. For this parameter, there were consistently significantly higher values in the locations of goat farms in comparison to locations of sheep farms ($p < 0.0001$) (Figure 11); moreover, the average wind speed in all locations studied throughout all the years covered was significantly higher on goat farms than on sheep farms: $2.60 \pm 0.03 \text{ m s}^{-1}$ versus $2.49 \pm 0.02 \text{ m s}^{-1}$, respectively ($p = 0.001$).

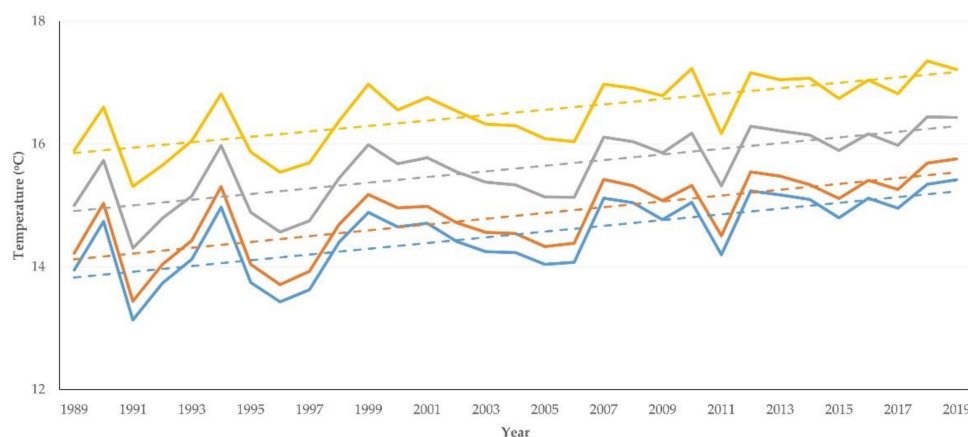


Figure 8. Annual average temperature at 2 m from 1989 to 2019 among 444 locations of small ruminant farms throughout Greece, in accord with the management system applied on these farms (blue: intensive, orange: semi-intensive, grey: semi-extensive, yellow: extensive management system; dashed lines are respective trendlines; respective slopes: 0.047, 0.047, 0.046, 0.044, $p > 0.80$ for all comparisons).

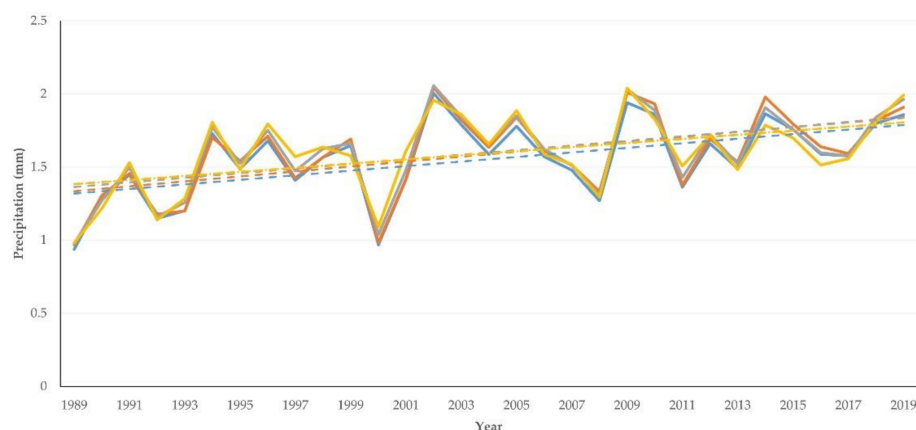


Figure 9. Annual average precipitation from 1989 to 2019 among 444 locations of small ruminant farms throughout Greece, in accord with the management system applied on the farms (blue: intensive, orange: semi-intensive, grey: semi-extensive, yellow: extensive management system; dashed lines are respective trendlines; respective slopes: 0.016, 0.017, 0.016, 0.014, $p > 0.67$ for all comparisons).

There were no significant differences between locations of farms with sheep or goats in the change in the various parameters from 1989 to 2019 and from 2014 to 2019 ($p > 0.36$ for all comparisons).

3.2.2. Associations with the Breeds of Sheep or Goats on the Farms

There were significant differences between locations of farms with Greek or imported breeds (for sheep and goats) for all temperature-related parameters ($p \leq 0.01$ for all comparisons, except for the maximum temperature in locations of sheep farms ($p = 0.16$)) (Figure 12). However, no such significances were noted for average relative humidity, average precipitation or average wind speed at 2 m ($p \geq 0.06$ for all comparisons, except for the wind speed in locations of sheep farms ($p < 0.0001$)). Details are in Table 3.

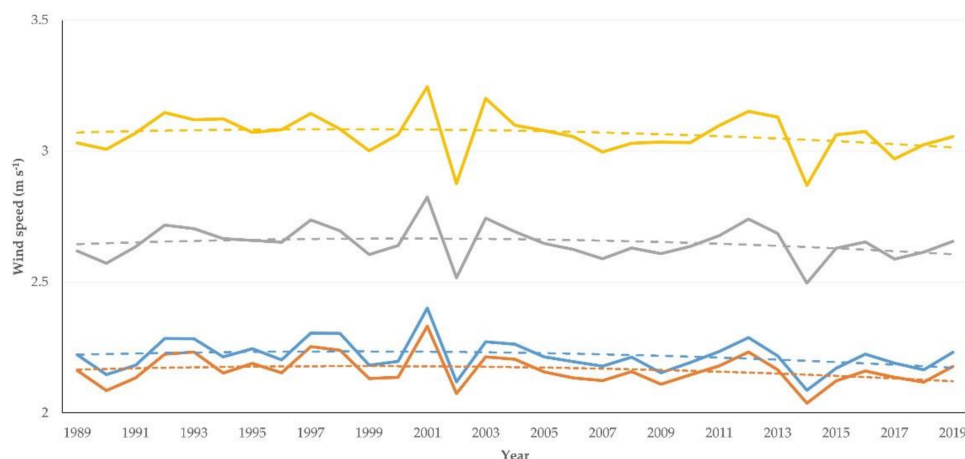


Figure 10. Annual average wind speed at 10 m from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece, in accord with the management system applied on the farms (blue: intensive, orange: semi-intensive, grey: semi-extensive, yellow: extensive management system; dashed lines are respective trendlines; respective slopes: -0.002 , -0.001 , -0.001 , -0.002 , $p > 0.44$ for all comparisons).

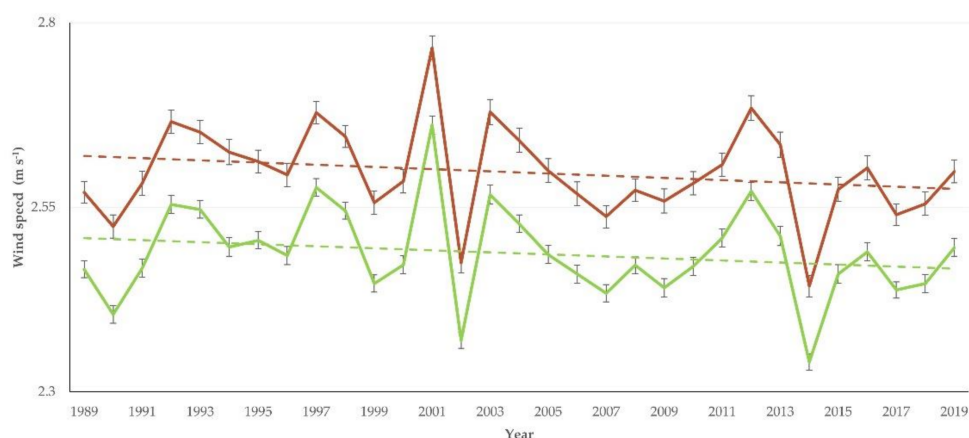


Figure 11. Annual average wind speed at 2 m from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece, in accord with the animal species farmed in the respective locations (green: sheep, brown: goats; bars show standard error of the mean; dashed lines are respective trendlines; respective slopes: -0.001 , -0.001 , $p = 0.96$).

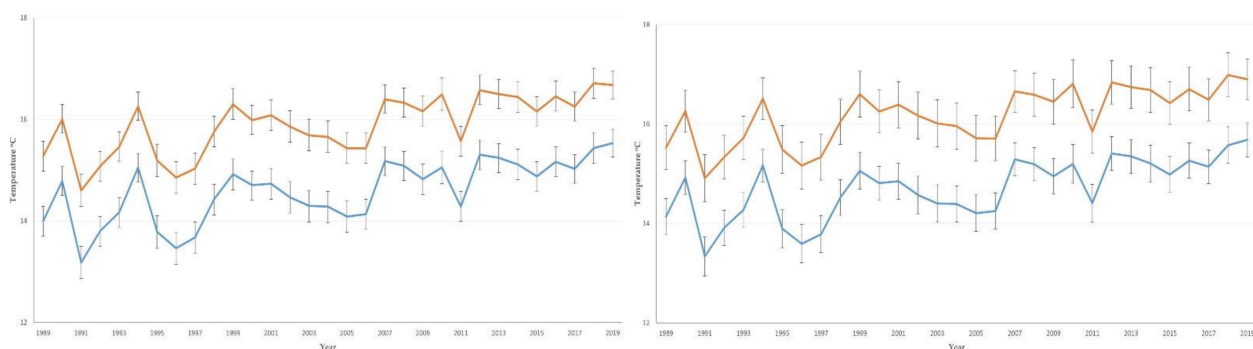


Figure 12. Annual average temperature at 2 m from 1989 to 2019 among locations of 325 sheep (left) and 119 goat (right) farms, in accord with the breeds on these farms (orange: Greek breeds, blue: imported breeds; bars show standard error of the mean).

Table 3. Average ($\pm$ standard error of the mean) overall values of climatic parameters from 1989 to 2019 among locations of 325 sheep farms and 119 goat farms throughout Greece, in accord with the breeds of animals on the farms.

Animal Breedson Farms	Average Temperature at 2 m (°C)	Average Temperature of Earth Skin (°C)	Minimum Temperature at 2 m (°C)	Maximum Temperature at 2 m (°C)	Temperature Range at 2 m (°C)	Average Relative Humidity (%)	Average Precipitation (mm)	Average Wind Speed at 10 (m s ⁻¹)
Sheep farms								
Greek breeds	15.9 $\pm$ 0.1 *	16.4 $\pm$ 0.1 *	−2.9 $\pm$ 0.3 *	36.1 $\pm$ 1.3	40.4 $\pm$ 0.4 *	68.5 $\pm$ 0.3	1.58 $\pm$ 0.05	2.7 $\pm$ 0.01 *
Imported breeds	14.6 $\pm$ 0.1 *	15.0 $\pm$ 0.1 *	−6.1 $\pm$ 0.4 *	38.1 $\pm$ 0.3	44.2 $\pm$ 0.5 *	68.3 $\pm$ 0.4	1.61 $\pm$ 0.05	2.2 $\pm$ 0.01 *
Goat farms								
Greek breeds	16.2 $\pm$ 0.1 *	16.8 $\pm$ 0.1 *	−2.1 $\pm$ 0.3 *	37.0 $\pm$ 0.3 *	39.1 $\pm$ 0.4 *	69.2 $\pm$ 0.3	1.65 $\pm$ 0.05	2.6 $\pm$ 0.01
Imported breeds	14.7 $\pm$ 0.1 *	15.1 $\pm$ 0.1 *	−6.3 $\pm$ 0.4 *	38.1 $\pm$ 0.3 *	44.3 $\pm$ 0.5 *	68.3 $\pm$ 0.4	1.57 $\pm$ 0.05	2.6 $\pm$ 0.01

* $p < 0.01$ for marked comparisons.

There were no significant differences between locations of farms with Greek or imported breeds in the change in the various parameters ($p > 0.09$ for locations with sheep farms and $p > 0.46$ for locations with goat farms).

3.3. Potential Associations with Small Ruminant Health

The annual frequencies of cases of (a) pregnancy toxæmia, (b) clinical mastitis and (c) neonatal hypothermia during the study period, attended at the Department of Obstetrics and Reproduction of the Veterinary Faculty of the University of Thessaly, are in Table S5.

There was a positive correlation of the annual frequency of cases of pregnancy toxæmia with the average wind speed at 10 m ($p = 0.009$), as well as a tendency for an inverse correlation with the average temperature at 2 m ($p = 0.07$) (Figure S7) and for positive correlation with the average relative humidity at 2 m ($p = 0.06$) (Figure S8). There was no correlation between the annual frequency of cases of clinical mastitis and the various climatic parameters ($p > 0.25$ for all comparisons) (Figure S9). There was an inverse correlation of annual frequency of cases of neonatal hypothermia with the average temperature at 2 m ($p = 0.039$) and the minimum temperature at 2 m ($p = 0.017$) (Figure 13) and a positive correlation with temperature range at 2 m ($p = 0.030$) and wind speed at 10 m ($p = 0.017$) (Figure 14). Details are in Tables 4 and S6.

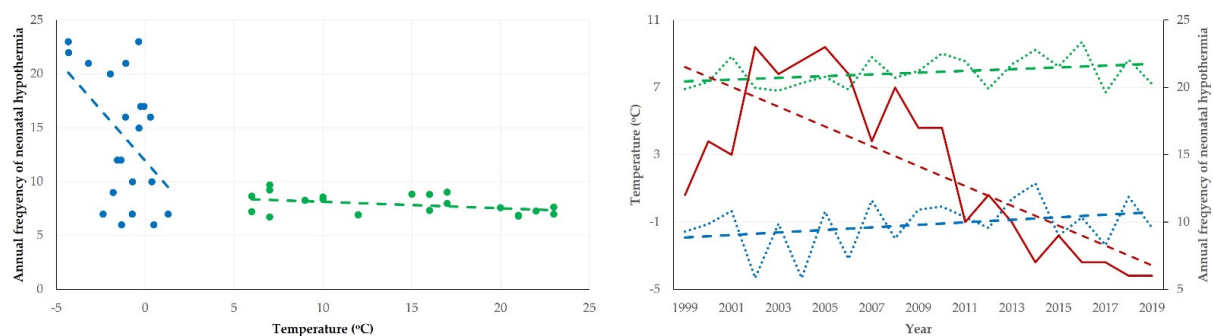


Figure 13. Left diagram: scatterplot of annual average temperature at 2 m (green dots) and annual minimum temperature at 2 m (blue dots) in the central part of Greece versus annual frequency of cases of neonatal hypothermia attended at the Department of Obstetrics and Reproduction of the Veterinary Faculty of the University of Thessaly. Right diagram: annual average temperature at 2 m (green dotted line) and annual minimum temperature at 2 m (blue dotted line), from 1999 to 2019, in the central part of Greece versus annual frequency of cases of neonatal hypothermia attended at the Department of Obstetrics and Reproduction of the Veterinary Faculty of the University of Thessaly (red solid line) (dashed lines are respective trendlines; $r = -0.393$, $p = 0.039$ and $r = -0.463$, $p = 0.017$, respectively).

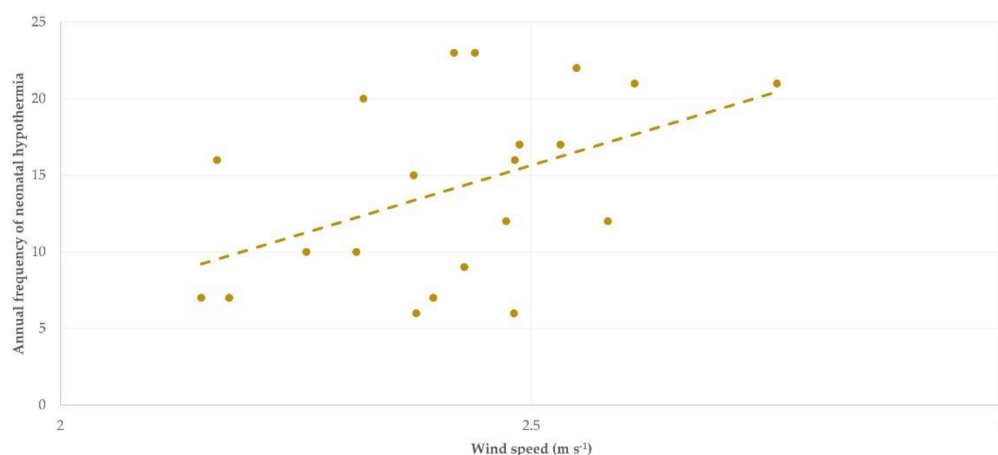


Figure 14. Scatterplot of annual average of wind speed at 10 m in the central part of Greece versus the annual frequency of cases of neonatal hypothermia attended at the Department of Obstetrics and Reproduction of the Veterinary Faculty of the University of Thessaly (dashed line is respective trendline; $r = 0.466$, $p = 0.017$).

The parasitological results of (a) average epg counts in faecal samples, (b) average proportion of *H. contortus* larvae in coprocultures of faecal samples and (c) frequency of cases of *H. contortus* resistance during the study period, as reported by the Laboratory of Parasitology and Parasitic Diseases of the Faculty of Veterinary Medicine of the Aristotle University of Thessaloniki are in Table S7.

There was no correlation between the average epg counts in faecal samples and climatic parameters ($p > 0.11$ for all comparisons) (Figure S10). There was a positive correlation of the average proportion of *H. contortus* larvae in coprocultures of faecal samples with average temperature at 2 m ($p < 0.0001$) and average Earth skin temperature ($p = 0.0004$) (Figures 15 and S11), whilst no correlation was seen with the other parameters ($p \geq 0.07$ for all comparisons). Moreover, there was a positive correlation of the frequency of cases of *H. contortus* resistance with average temperature at 2 m ($p = 0.0003$) and average Earth skin temperature ($p = 0.0007$) (Figures 16 and 17), whilst no correlation was seen with the other parameters ($p > 0.11$ for all comparisons). Details are in Tables 5 and S8.

Table 4. Correlation coefficients (r) of the annual frequency of cases of (a) pregnancy toxemia, (b) clinical mastitis and (c) neonatal hypothermia attended at the Department of Obstetrics and Reproduction of the Veterinary Faculty of the University of Thessaly with the various climatic parameters that prevailed in the central part of Greece.

Climatic Parameters	Pregnancy Toxaemia	Clinical Mastitis	Neonatal Hypothermia
Average temperature at 2 m (T2m)	−0.326	0.026	−0.393 *
Average temperature of Earth skin (TS)	−0.268	0.015	−0.350
Minimum temperature at 2 m (T2mMin)	−0.304	0.086	−0.463 *
Maximum temperature at 2 m (T2mMax)	−0.244	0.154	0.007
Temperature range at 2 m (T2mRan)	0.122	0.053	0.418 *
Average relative humidity at 2 m (RH2m)	0.359	0.023	0.345
Average precipitation (PREC)	0.134	0.004	0.072
Average wind speed at 10 m (WS10m)	0.516 *	−0.127	0.466 *

* $p < 0.05$.

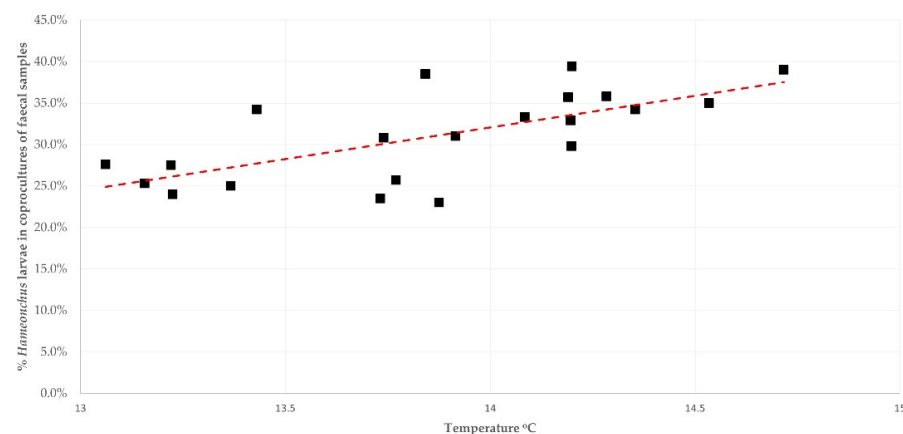


Figure 15. Scatterplot of annual average Earth skin temperature in the north part of Greece versus the annual average proportion of *Haemonchus contortus* larvae in coprocultures from faecal samples as reported by the Laboratory of Parasitology and Parasitic Diseases of the Faculty of Veterinary Medicine of the Aristotle University of Thessaloniki (dashed line is respective trendline; $r = 0.678$, $p = 0.0004$).

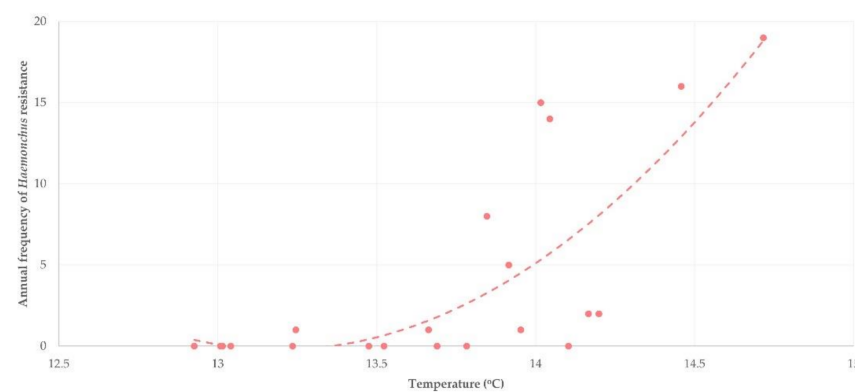


Figure 16. Scatterplot of annual average temperature at 2 m in the north part of Greece versus the annual frequency of cases of *Haemonchus contortus* resistance as reported by the Laboratory of Parasitology and Parasitic Diseases of the Faculty of Veterinary Medicine of the Aristotle University of Thessaloniki (dashed line is respective trendline; $r = 0.684$, $p = 0.0003$).

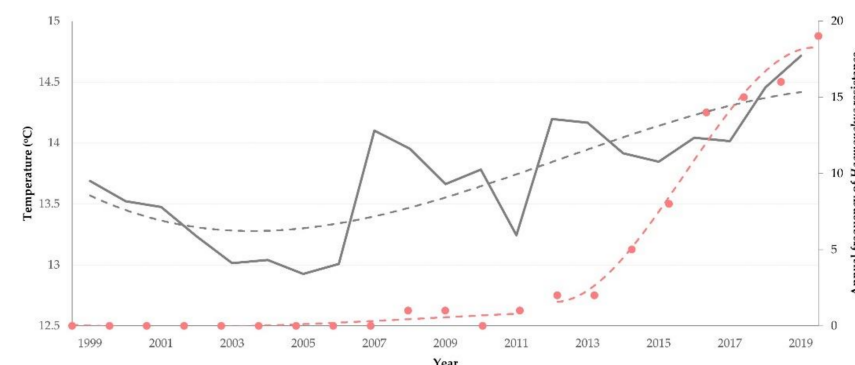


Figure 17. Annual average temperature at 2 m in the north part of Greece (grey continuous line) versus the annual frequency of cases of *Haemonchus contortus* resistance as reported by the Laboratory of Parasitology and Parasitic Diseases of the Faculty of Veterinary Medicine of the Aristotle University of Thessaloniki (pink dots) from 1999 to 2019 (dashed lines are respective trendlines; slopes of the annual frequency of cases of *H. contortus* resistance: 0.071 for the period 1999 to 2011, 2.679 for the period 2012 to 2019, $p < 0.0001$).

Table 5. Correlation coefficients (r) of (a) annual average epg counts in faecal samples, (b) annual average proportion of *Haemonchus contortus* larvae in coprocultures of faecal samples and (c) annual frequency of cases of *H. contortus* resistance as reported by the Laboratory of Parasitology and Parasitic Diseases of the Faculty of Veterinary Medicine of the Aristotle University of Thessaloniki with the various climatic parameters that prevailed in the north part of Greece.

Climatic Parameters	epg Counts in Faecal Samples	% <i>H. contortus</i> Larvae in Coprocultures of Faecal Samples	Cases of <i>H. contortus</i> Resistance
Average temperature at 2 m (T2m)	−0.156	0.726 *	0.684 *
Average temperature of Earth skin (TS)	−0.157	0.678 *	0.651 *
Minimum temperature at 2 m (T2mMin)	0.270	0.281	0.066
Maximum temperature at 2 m (T2mMax)	−0.091	−0.126	−0.277
Temperature range at 2 m (T2mRan)	−0.271	−0.299	−0.197
Average relative humidity at 2 m (RH2m)	0.022	−0.151	−0.165
Average precipitation (PREC)	0.136	0.127	0.058
Average wind speed at 10 m (WS10m)	−0.142	−0.338	−0.172

* $p < 0.05$.

4. Discussion

4.1. Climatic Conditions in the Locations of Small Ruminant Farms

Climatic conditions and changes can affect livestock welfare, as they may contribute to the dissemination of pathogens, influence the quality of feed provided and modify environmental conditions during housing and grazing. Among the effects in climatic changes caused by small ruminant production, one may include the contamination of waterways, land degradation and release of greenhouse emissions. The animal production sector has contributed to greenhouse gas emissions and is now facing the consequences [15]. Nevertheless, in Greece, awareness of the importance of climate change has led to a decrease in CH₄ emissions by livestock from 2000 to 2016, from 3200 Gg to 2800 Gg of CO₂ equivalent [16].

The increase in temperature in Greece for the past 30 to 40 years has already been reported [17]. Relevant studies have focused on urban environments [18], forested areas [19] and cultivated lands [20]. The findings of the current study, which presents data for locations of small ruminant farms (i.e., the primary animal production activity in the country), also indicate a progressive increase in temperature in the respective locations throughout the country.

Farms under extensive management are mainly low input holdings, with basic buildings providing little protection to animals from adverse weather conditions; hence, such farms would be more frequently located in areas with milder weather conditions (e.g., higher temperatures). In contrast, farms under intensive management contain high-quality buildings (e.g., with insulation), which can provide better protection to animals, and thus are located in areas with low temperatures. Furthermore, the differences in the temperature of the locations in accord with the breeds of animals on the farms may reflect the possibility of animals of indigenous Greek breeds to tolerate higher temperatures. In sheep and goats, there are genetic differences in heat stress adaptations and, consequently, tolerance to high temperatures [21,22], which are mediated through a complex network of genes [23,24]. In general, local breeds of small ruminants (or their crosses) are considered to have better tolerance to local climate conditions (including temperature) than imported breeds, with relevant results also reported from various regions globally, e.g., Africa [25], Brazil [26] and India [27]. One may thus postulate that in small ruminants, adaptations to locally prevailing temperatures shaped the spatial distribution of some gene variants, which might have underpinned adaptive variation [28]. Possibly, farming animals of indigenous breeds in locations with higher temperatures than those of locations of farms of animals of imported breeds may contribute to the lower milk production of the indigenous

animals [14], given that in small ruminants, milk production is inversely associated with exposure to high environmental temperatures [29,30].

With regard to precipitation changes in Greece, the present results differ significantly from previous relevant reports—both Pakalidou and Karacosta [31], who studied an urban environment, and Stefanidis et al. [32], who studied the environment at water enclosures, did not report significant changes in precipitation over the years. This difference can possibly be explained by the diversity of locations assessed in the present study. The tendency of a change in the pattern of precipitation recorded in recent years is noteworthy, warranting close monitoring. This tendency reflected primarily a pattern of more intense changes in precipitation in the north part of the country. This may reflect the influence of air masses moving from Northern Europe and Russia, which affect more strongly the northern part of Greece. Nevertheless, no differences were identified between locations of farms in relation to management system or animal breeds therein.

Finally, the difference in wind speed between locations of sheep and goat farms may possibly reflect the fact that goat farms are located at higher elevations than sheep farms (333.5 m versus 243.0 m for average altitude of locations of the respective farms, $p = 0.002$ [Lianou unpublished results]).

4.2. Potential Associations of Climatic Changes with Small Ruminant Health

For the assessment and highlighting of possible associations of the occurrence of clinical problems of small ruminants over a 20-year period with climatic changes, we used as examples four different pathological conditions of sheep and goats, specifically, pregnancy toxaemia, clinical mastitis, neonatal hypothermia and trichostrongylid infections.

Pregnancy toxaemia is a frequent metabolic disorder of sheep, caused by metabolic imbalance during pregnancy, predisposed by the increased number of borne fetuses [33]. The findings did not provide strong evidence of association of the frequency of the disorder with the climatic changes observed. There was only a significant association with the wind speed, which reflects the consequences of heat loss (on average 9%) recorded in sheep with the increase in air speed [34]. Furthermore, there was some tendency for an inverse association of the frequency of the disease with the gradual increase in the temperature. Pregnant sheep exposed to low environmental temperatures have increased energy demands due to the undesirable environmental conditions [35], and moreover, they have reduced feed intake [35], which can further contribute to development of the disorder. Low environmental temperatures can also result in hypoglycaemia, which is a prime feature of pregnancy toxaemia [36]. Potentially, the increased wind speed and the low temperatures can also have indirect effects; for example, they can impede easy access of farmers to their animals, reducing the care provided to them, or they can result in freezing of water within pipes, thus stopping the availability of water to the animals, which in turn would lead to reduced feed intake, precipitating a metabolic imbalance and finally the development of the disorder [37]. As environmental temperatures have been found to increase gradually over the years, the energy requirements of the ewes would have been decreased [38], thus contributing to a lower risk of the development of pregnancy toxaemia. We consider, however, that the decrease in cases recorded was primarily the result of improved health management on the farms, which resulted from an increase in available scientific knowledge and updated training of farmers. The progressive increase in environmental temperature could have contributed only to some extent, as discussed above. This is reflected in the lack of a significant association and the presence of only a tendency with the reduction in the frequency of the disorder.

No significant associations were found between environmental factors and the frequency of mastitis. Mastitis is mainly predisposed by management or genetic factors [39,40], and environmental effects may be of limited importance for the development of the disease. In a relevant study, it was found that only short-term temperatures changes [41] may have an effect on the development of subclinical mastitis.

With regard to neonatal hypothermia, there was a clear association of the environmental changes with the reduction in the frequency of cases seen. Neonatal hypothermia is a complex syndrome, developing when newborns lose more heat than they can produce and absorb [42]. Directly after birth, newborns may be suddenly exposed to low temperatures with the dramatic difference from 39 °C within the uterus to −5 to 10 °C in the external environment in parturitions taking place during the winter, which contributes to a sharp increase in heat demand by newborns. Therapeutic management of the disorder includes the placement of the affected lambs and kids in a protected place, with optimum environmental conditions [42], and in this respect, the ‘Moredun box’ has been devised, wherein affected animals can be placed for protection and to promote the increase in their body temperature. Even if the condition can be prevented with management changes on the farms, environmental temperature still has a key role in the development of this disorder [42]. This becomes evident in the stronger association with the increase in the minimum temperature, given that temperatures below 5 °C are the ones that cause the greatest heat loss by newborns and predispose them to the development of the problem. Hence, it can be expected that a progressive rise in the environmental temperature over the years would have contributed to decreasing the risk of the disorder. Again, improved health management on farms should not be overlooked and it certainly has contributed to the reduction in the frequency of the disorder. However, we postulate that given the nature and the pathogenesis of the disorder, the climatic changes recorded throughout the study period have also played a role in the reduction in the frequency of clinical cases seen.

Gastrointestinal nematode infections are particularly influenced by climatic factors. This is due to the fact that increased temperature, in the presence of appropriate humidity, facilitates the development of parasitic forms and their dissemination in the grazing areas. In low temperatures (e.g., winter), parasitic larvae have a slow development and may even be destroyed [11]. Thus, it was originally expected that average epg counts in clinical samples would have increased throughout the study period, but this was not found in the laboratory results of clinical samples. Possibly, this can be explained by the fact that over the years, farmers have increased the number of anthelmintic treatments performed [43]; it is also noteworthy that new anthelmintic drugs have been developed, some licensed for administration during the lactation period with a withdrawal period of zero days for milk, offering new potential for the timing of their administration. This overcame a significant limitation in the administration of anthelmintic drugs with a long withdrawal period for milk, given that in Greece, dairy production systems prevail on small ruminant farms, and led to greater flexibility and improved efficacy of anthelmintic regimes applied on small ruminant farms.

However, the proportion of *H. contortus* larvae in faecal samples was found to increase during the study period, in clear association with the increase in environmental temperature. This nematode is considered a predominant parasite of sheep and goats in areas with warm climatic conditions, in which infection with *H. contortus* is enabled and facilitated [44]. The increased infections by this parasite are in line with the extension of the geographical distribution of the parasite in temperate climates in the Northern Hemisphere [45]. Given that *H. contortus* can cause serious disease in affected animals (e.g., anaemia, ill-thrift), farmers may increase the number of anthelmintic treatments to their animals (as discussed above), which in turn increases the risk for developing anthelmintic resistance. This was depicted by the increase in the cases of resistance of the parasite, also in association with the increasing temperatures.

5. Conclusions

We presented examples for four different pathological conditions of sheep and goats regarding the potential effects of long-term climatic changes on the health of these animals. There were differences between the pathological conditions in the potential effects of climatic changes in their occurrence. Despite the associations found in selected pathological conditions with some climatic factors, during complex pathophysiological processes, environmental factors may, from time to time, have some effect, but other interactions also play a significant role in disease processes. The findings indicate that there is a need for more in-depth research into the response of animals to challenges from the environment.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su14031673/s1>: Table S1. Annual average values of climatic parameters among locations of 444 small ruminant farms throughout Greece from 1989 to 2019; Table S2. Average overall values of climatic parameters from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece, in accord with the part of the country; Table S3. Slope of change in the annual values of climatic parameters from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece, in accord with the part of the country; Table S4. Slope of change in the annual values of climatic parameters from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece, in accord with the management system applied on the farms; Table S5. Annual frequency of cases (a) pregnancy toxemia, (b) clinical mastitis and (c) neonatal hypothermia in small ruminants, from 1989 to 2019, attended at the Department of Obstetrics and Reproduction of the Veterinary Faculty of the University of Thessaly; Table S6. Significance (p values) of the correlations between the annual frequency of cases of (a) pregnancy toxemia, (b) clinical mastitis and (c) neonatal hypothermia attended at the Department of Obstetrics and Reproduction of the Veterinary Faculty of the University of Thessaly with the various climatic parameters that prevailed in the central part of Greece; Table S7. Annual (a) overall average epg counts in faecal samples from small ruminants, (b) overall average proportion of *Haemonchus contortus* larvae found in coprocultures of samples from small ruminants and (c) frequency of cases of *H. contortus* resistance in small ruminants, as detected at the Laboratory of Parasitology and Parasitic Diseases of the Faculty of Veterinary Medicine of the Aristotle University of Thessaloniki; Table S8. Significance (p values) of the correlations between (a) annual average epg counts in faecal samples, (b) annual average proportion of *Haemonchus contortus* larvae in coprocultures of faecal samples and (c) annual frequency of cases of *H. contortus* resistance, as reported by the Laboratory of Parasitology and Parasitic Diseases of the Faculty of Veterinary Medicine of the Aristotle University of Thessaloniki with the various climatic parameters that prevailed in the north part of Greece; Figure S1. Annual average temperature of Earth skin from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece; Figure S2. Annual average annual minimum temperature at 2 m from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece; Figure S3. Annual average annual maximum temperature at 2 m from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece; Figure S4. Annual average range of temperature at 2 m from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece; Figure S5. Annual average relative humidity at 2 m from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece; Figure S6. Annual average temperature at 2 m from 1989 to 2019 among locations of 444 small ruminant farms throughout Greece, in accord with the animal species farmed in the respective locations; Figure S7. Scatterplot of annual average temperature at 2 m in the central part of Greece versus the annual frequency of cases of pregnancy toxemia attended at the Department of Obstetrics and Reproduction of the Veterinary Faculty of the University of Thessaly; Figure S8. Scatterplot of annual average of relative humidity at 2 m in the central part of Greece versus the annual frequency of cases of pregnancy toxemia attended at the Department of Obstetrics and Reproduction of the Veterinary Faculty of the University of Thessaly; Figure S9. Scatterplot of annual average temperature at 2 m in the central part of Greece versus the annual frequency of cases of clinical mastitis attended at the Department of Obstetrics and Reproduction of the Veterinary Faculty of the University of Thessaly; Figure S10. Scatterplot of annual average Earth skin temperature in the north part of Greece versus the annual average epg counts in faecal samples from small ruminants as reported by the Laboratory of Parasitology and Parasitic Diseases of the Faculty of Veterinary Medicine of the Aristotle University of Thessaloniki; Figure S11. Annual average Earth skin temperature in the north part of Greece (grey bars) and annual

average % of *Haemonchus contortus* larvae in coprocultures from faecal samples from small ruminants as reported by the Laboratory of Parasitology and Parasitic Diseases of the Faculty of Veterinary Medicine of the Aristotle University of Thessaloniki (black line), from 1999 to 2019.

Author Contributions: Conceptualisation, E.I.K. and G.C.F.; methodology, E.I.K. and G.C.F.; formal analysis, E.I.K. and G.C.F.; investigation, E.I.K., D.T.L., E.P. and G.C.F.; resources, G.C.F.; data curation, E.I.K.; writing—original draft preparation, E.I.K. and G.C.F.; writing—review and editing, E.I.K., D.T.L., E.P. and G.C.F.; visualisation, E.I.K.; supervision, G.C.F.; project administration, G.C.F. All authors read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable. The protocols of the study were approved by the academic board of the Veterinary Faculty of the University of Thessaly, meetings 34/03.04.19 and 82/04.11.20.

Informed Consent Statement: Not applicable.

Data Availability Statement: Most data presented in this study are in the main text or in the Supplementary Materials.

Acknowledgments: The climatic data were obtained from the NASA Langley Research Center (LaRC) POWER Project funded through the NASA Earth Science/Applied Science Program. The help received by the veterinarians, who selected the small ruminant farms and arranged the visits for collection, is gratefully acknowledged.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Hellenic Statistical Authority. Farm Structure Surveys. Available online: <https://www.statistics.gr> (accessed on 12 October 2021).
2. Pulina, G.; Milán, M.J.; Lavín, M.P.; Theodoridis, A.; Morin, E.; Capote, J.; Thomas, D.L.; Francesconi, A.H.D.; Caja, G. Current production trends, farm structures, and economics of the dairy sheep and goat sectors. *J. Dairy Sci.* **2018**, *101*, 6715–6729. [CrossRef] [PubMed]
3. Hellenic Agricultural Organisation—Demeter. Deliveries of Ovine and Caprine Milk by Region and Regional Authority and Average Milk Price—Calendar Year 2019. Cumulative Data Updated. Available online: https://www.elgo.gr/images/ELOGAK_files/Statistics/2020/AIGO_%CE%A0%CE%B1%CF%81%CE%B1%CE%B4%CF%8C%CF%83%CE%B5%CE%B9%CF%82_%CE%A0%CF%81%CF%8C%CE%B2%CE%B5%CE%B9%CE%BF%CF%85_%CE%BA%CE%B1%CE%B9_%CE%93%CE%AF%CE%B4%CE%B9%CE%BD%CE%BF%CF%85_%CE%93%CE%AC%CE%BB%CE%B1%CE%BA%CF%84%CE%BF%CF%82_2019.pdf (accessed on 12 October 2021).
4. Hamzaoui, S.; Salama, A.; Albanell, E.; Such, X.; Caja, G. Physiological responses and lactational performances of late-lactation dairy goats under heat stress conditions. *J. Dairy Sci.* **2013**, *96*, 6355–6365. [CrossRef] [PubMed]
5. Chedid, M.; Jaber, L.S.; Giger-Reverdin, S.; Duvaux-Ponter, C.; Hamadeh, S.K. Water stress in sheep raised under arid conditions. *Can. J. Anim. Sci.* **2014**, *94*, 243–257. [CrossRef]
6. Brasil, L.H.d.A.; Wechesler, F.S.; Baccari Júnior, F.; Gonçalves, H.C.; Bonassi, I.A. Thermal stress effects on milk yield and chemical composition and thermoregulatory responses of lactating alpine goats. *Rev. Bras. Zootec.* **2000**, *29*, 1632–1641. [CrossRef]
7. Peana, I.; Fois, G.; Cannas, A. Effects of heat stress and diet on milk production and feed and energy intake of sarda ewes. *Ital. J. Anim. Sci.* **2007**, *6*, 577–579. [CrossRef]
8. Kadim, I.; Mahgoub, O.; Al-Kindi, A.; Al-Marzooqi, W.; Al-Saqri, N. Effects of transportation at high ambient temperatures on physiological responses, carcass and meat quality characteristics of three breeds of omani goats. *Meat Sci.* **2006**, *73*, 626–634. [CrossRef]
9. Archana, P.; Sejian, V.; Ruban, W.; Bagath, M.; Krishnan, G.; Aleena, J.; Manjunathareddy, G.; Beena, V.; Bhatta, R. Comparative assessment of heat stress induced changes in carcass traits, plasma leptin profile and skeletal muscle myostatin and hsp70 gene expression patterns between indigenous osmanabadi and salem black goat breeds. *Meat Sci.* **2018**, *141*, 66–80. [CrossRef] [PubMed]
10. Reynecke, D.P.; Waghorn, T.S.; Oliver, A.M.B.; Miller, C.M.; Vlassoff, A.; Leathwick, D.M. Dynamics of the free-living stages of sheep intestinal parasites on pasture in the North Island of New Zealand. 2. Weather variables associated with development. *N. Z. Vet. J.* **2011**, *59*, 287–292. [CrossRef]
11. Taylor, R.L.; Coop, R.; Wall, R. *Veterinary Parasitology*, 4th ed.; Wiley-Blackwell: Oxford, UK, 2015.
12. Lianou, D.T.; Chatziprodromidou, I.P.; Vasileiou, N.G.C.; Michael, C.K.; Mavrogianni, V.S.; Politis, A.P.; Kordalis, N.G.; Billinis, C.; Giannakopoulos, A.; Papadopoulos, E.; et al. A detailed questionnaire for the evaluation of health management in dairy sheep and goats. *Animals* **2020**, *10*, 1489. [CrossRef] [PubMed]

13. European Food Safety Authority. Scientific opinion on the welfare risks related to the farming of sheep for wool, meat and milk production. *EFSA J.* **2014**, *12*, 3933–4060.
14. Lianou, D.T.; Michael, C.K.; Vasileiou, N.G.C.; Liagka, D.V.; Mavrogianni, V.S.; Caroprese, M.; Fthenakis, G.C. Association of breed of sheep or goats with somatic cell counts and total bacterial counts of bulk-tank milk. *Appl. Sci.* **2021**, *11*, 7356. [\[CrossRef\]](#)
15. Food and Agriculture Organization of the United Nations. *Livestock Solutions for Climate Change*; FAO: Rome, Italy, 2017.
16. Food and Agriculture Organization of the United Nations. *Transforming the Livestock Sector through the Sustainable Development Goals*; FAO: Rome, Italy, 2018.
17. Mamara, A.; Argiriou, A.A.; Anadranistakis, M. Recent trend analysis of mean air temperature in Greece based on homogenized data. *Theor. Appl. Climatol.* **2016**, *126*, 543–573. [\[CrossRef\]](#)
18. Kapsomenakis, J.; Kolokotsa, D.; Nikolaou, T.; Santamouris, M.; Zerefos, S.C. Forty years increase of the air ambient temperature in Greece: The impact on buildings. *Energy Convers. Manag.* **2013**, *74*, 353–364. [\[CrossRef\]](#)
19. Chrysopolitou, V.; Apostolakis, A.; Avtzis, D.; Avtzis, N.; Diamandis, S.; Kemitzoglou, D.; Papadimos, D.; Perlerou, C.; Tsiaoussi, V.; Dafis, S. Studies on forest health and vegetation changes in Greece under the effects of climate changes. *Biodivers. Conserv.* **2013**, *22*, 1133–1150. [\[CrossRef\]](#)
20. Cartalis, C.; Nikitopoulou, T.; Proedrou, M. Climate changes and their impact on agriculture in Greece: A critical aspect for medium- and long-term environmental policy planning. *Int. J. Environ. Pollut.* **2002**, *17*, 211–219. [\[CrossRef\]](#)
21. Berihulay, H.; Abied, A.; He, X.; Jiang, L.; Ma, Y. Adaptation mechanisms of small ruminants to environmental heat stress. *Animals* **2019**, *9*, 75. [\[CrossRef\]](#) [\[PubMed\]](#)
22. Sawyer, G.; Narayan, E.J. A review on the influence of climate change on sheep reproduction. In *Comparative Endocrinology of Animals*; Narayan, E., Ed.; Intechopen: Zagreb, Croatia, 2019. [\[CrossRef\]](#)
23. Ramón, M.; Carabaño, M.J.; Díaz, C.; Kapsona, V.V.; Banos, G.; Sánchez-Molano, E. Breeding strategies for weather resilience in small ruminants in Atlantic and Mediterranean climates. *Front. Genet.* **2021**, *12*, 692121. [\[CrossRef\]](#)
24. Serranito, B.; Cavalazzi, M.; Vidal, P.; Taurisson-Mouret, D.; Ciani, E.; Bal, M.; Rouvellac, E.; Servin, B.; Moreno-Romieux, C.; Tosser-Klopp, G.; et al. Local adaptations of Mediterranean sheep and goats through an integrative approach. *BioRxiv* **2021**. [\[CrossRef\]](#)
25. Marshall, K.; Gibson, J.P.; Mwai, O.; Mwacharo, J.M.; Haile, A.; Getachew, T.; Mrode, R.; Kemp, S.J. Livestock genomics for developing countries—African examples in practice. *Front. Genet.* **2019**, *10*, 297. [\[CrossRef\]](#)
26. McManus, C.; Lima Dallago, B.S.; Lehugeur, C.; Ribeiro, L.A.; Hermuche, P.; Guimarães, R.F.; de Carvalho Junior, O.A.; Paiva, S.R. Patterns of heat tolerance in different sheep breeds in Brazil. *Small Rumin. Res.* **2016**, *144*, 290–299. [\[CrossRef\]](#)
27. Singh, M.; More, T.; Rai, A.K. Heat tolerance of different genetic groups of sheep exposed to elevated temperature conditions. *J. Agric. Sci.* **1980**, *94*, 63–67. [\[CrossRef\]](#)
28. Lv, F.H.; Agha, S.; Kantanen, J.; Colli, L.; Stucki, S.; Kijas, J.W.; Joost, S.; Li, M.H.; Marsan, P.A. Adaptations to climate-mediated selective pressures in sheep. *Mol. Biol. Evol.* **2014**, *31*, 3324–3343. [\[CrossRef\]](#) [\[PubMed\]](#)
29. Finocchiaro, R.; van Kaam, J.B.C.H.M.; Portolano, B.; Misztal, I. Effect of heat stress on production of Mediterranean dairy sheep. *J. Dairy Sci.* **2005**, *88*, 1855–1864. [\[CrossRef\]](#)
30. Contreras-Jodar, A.; Salama, A.A.; Hamzaoui, S.; Vailati-Riboni, M.; Caja, G.; Llor, J.J. Effects of chronic heat stress on lactational performance and the transcriptomic profile of blood cells in lactating dairy goats. *J. Dairy Res.* **2018**, *85*, 423–430. [\[CrossRef\]](#)
31. Pakalidou, N.; Karacosta, P. Study of very long-period extreme precipitation records in Thessaloniki, Greece. *Atmos. Res.* **2018**, *208*, 106–115. [\[CrossRef\]](#)
32. Stefanidis, K.; Varlas, G.; Papadopoulos, A.; Dimitriou, E. Four decades of surface temperature, precipitation, and wind speed trends over lakes of Greece. *Sustainability* **2021**, *13*, 9908. [\[CrossRef\]](#)
33. Fthenakis, G.C.; Arsenos, G.; Brozos, C.; Fragkou, I.A.; Giadinis, N.D.; Giannenas, I.; Mavrogianni, V.S.; Papadopoulos, E.; Valasi, I. Health management of ewes during pregnancy. *Anim. Reprod. Sci.* **2012**, *130*, 198–212. [\[CrossRef\]](#)
34. Hocquette, J.F.M.; Vermorel, M.; Bouix, J. Effects of cold, wind and rain on energy-expenditure and thermoregulation of ewes from 7 genetic types. *Gen. Sel. Evol.* **1992**, *24*, 147–169. [\[CrossRef\]](#)
35. Webster, A.J.F.; Hicks, A.M.; Hays, F.L. Cold climate and cold temperature induced changes in the heat production and thermal insulation of sheep. *Can. J. Physiol. Pharmacol.* **1969**, *47*, 553–562. [\[CrossRef\]](#)
36. Dzadzovski, I.; Celeska, I.; Ulchar, I.; Janevski, A.; Kirovski, D. Influence of the season on the metabolic profile in Chios sheep. *Mak. Vet. Rev.* **2015**, *38*, 183–188. [\[CrossRef\]](#)
37. Panousis, N.; Brozos, C.; Fthenakis, G.C.; Karatzias, C. Pregnancy toxemia of ewes. A literature review. *J. Hell. Vet. Med. Soc.* **2001**, *52*, 89–96. [\[CrossRef\]](#)
38. Wilkes, M.J. Understanding Physiological Drivers of Resilience in Sheep. Ph.D. Thesis, University of Adelaide, School of Animal and Veterinary Sciences, Roseworthy, SA, Australia, 2017.
39. Oget, C.; Tosser-Klopp, G.; Rupp, R. Genetic and genomic studies in ovine mastitis. *Small Rumin. Res.* **2019**, *176*, 55–64. [\[CrossRef\]](#)
40. Vasileiou, N.G.C.; Mavrogianni, V.S.; Petinaki, E.; Fthenakis, G.C. Predisposing factors for bacterial mastitis in ewes. *Reprod. Domest. Anim.* **2019**, *54*, 1424–1431. [\[CrossRef\]](#) [\[PubMed\]](#)
41. Vasileiou, N.G.V.; Giannakopoulos, A.; Cripps, P.J.; Ioannidi, K.S.; Chatzopoulos, D.C.; Gougoulis, D.A.; Billinis, C.; Mavrogianni, V.S.; Petinaki, E.; Fthenakis, G.C. Study of potential environmental factors predisposing ewes to subclinical mastitis in Greece. *Comp. Immunol. Microbiol. Inf. Dis.* **2019**, *62*, 40–45. [\[CrossRef\]](#)

42. Henderson, D.C. Neonatal conditions. In *Diseases of Sheep*, 3rd ed.; Martin, W.B., Aitken, I.D., Eds.; Blackwell Science: Oxford, UK, 2000; pp. 58–65.
43. Karteri, O.F.; Papadopoulos, E.; Vasileiou, N.G.C.; Mavrogianni, V.S.; Fthenakis, G.C. Practices in controlling helminth infections of small ruminants by veterinarians in clinical practice in Greece. In *Proceedings of the 25th International Conference of the World Association for the Advancement of Veterinary Parasitology*, Liverpool, UK, 16–21 August 2015; p. 303.
44. Arsenopoulos, K.V.; Fthenakis, G.C.; Katsarou, E.I.; Papadopoulos, E. Haemonchosis: A challenging parasitic infection of sheep and goats. *Animals* **2021**, *11*, 363. [[CrossRef](#)]
45. Sargison, N.D.; Wilson, D.J.; Bartley, D.J.; Penny, C.D. Haemonchosis and teladorsagiosis in a Scottish sheep flock putatively associated with the overwintering of hypobiotic fourth stage larvae. *Vet. Parasitol.* **2007**, *147*, 326–331. [[CrossRef](#)]