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Original Article

Predicting suitable spatial niches in the Philippines for *Ascaris lumbricoides* using bioclimatic envelope models

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Abstract
Introduction: Recent studies on the spatial distribution of *A. lumbricoides* in the Philippines have used the data available from the nationwide parasitological survey in the early 2000s. This study developed an updated predictive map of the spatial distribution of ascariasis occurrences in the Philippines using data from 2000–2020 to identify high-risk areas for ascariasis.
Methodology: Data were acquired from WorldClim and included 19 bioclimatic variables. Additionally, the geographical distribution of species occurrence records was obtained through literature and known medical reports for ascariasis cases. The spatial distribution was mapped using QGIS after running the occurrence and environmental layers in the software Maxent.
Results: The predictive map revealed a high percentage of occurrences of ascariasis in Central Luzon, Calabarzon, Western Visayas, Bicol Region, and Central Visayas. The average training area under the receiver operating characteristic curve (AUC) for the replicate runs was 0.873. Analysis of variable contribution showed the highest percentage predictive contribution of the mean temperature during the warmest quarter (49.4%), annual range of temperature (10.9%), and mean temperature during the driest quarter (10.9%).
Conclusions: The species predictive map generated in this study can identify bioclimatic variables associated with the high prevalence of *A. lumbricoides*. Since extensive parasitological surveys can be costly and time-consuming, predictions on *A. lumbricoides* distribution can fill the gap in areas lacking data. Consequently, a detailed understanding of the distribution of *A. lumbricoides* will assist in identifying high-risk areas for effective public health intervention, especially in underfunded regions in the Philippines.

Key words: ascariasis; AUC; modeling; NTD; parasitology.

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Introduction
Ascariasis is the most common helminthic infection affecting humans worldwide, causing an estimated 800 million to 1.2 billion cases and more than estimated of 60,000 deaths annually [1]. *A. lumbricoides* is the most prevalent species among the soil-transmitted helminthiasis (STH), worldwide. Approximately 807–1,121 million people were infected by *A. lumbricoides* globally. This neglected tropical disease is prevalent in areas specifically in the tropical and subtropical regions of the world. Ascariasis is reported to be prevalent in more than 100 countries worldwide, and those vulnerable to this specific kind of infection are the people with low-income economic status.

Humans can get infected by *A. lumbricoides* by ingesting embryonated eggs. The embryonated egg of *A. lumbricoides* measures about 55 µm × 40 µm and is usually round. Fertilized eggs possess a thicker shell than unfertilized eggs. In some cases, the fertilized egg has a mammillated layer; and sometimes, it is absent and called a decorticated egg [2]. Meanwhile, the unfertilized eggs of *A. lumbricoides* measure approximately 90 µm × 40 µm, which are relatively larger and more oblong than the embryonated eggs. However, the shell is thinner than that of fertilized eggs. On the other hand, the adult stage of *A. lumbricoides* measures about 22 to 35 cm long and is cream with shades of light pink. The male adult worm is slender and smaller than the female. Male adult worms measure not more than 30 cm, while the female adult worms are larger, thicker (pencil lead-wise), and longer than male adult worms [2].

It is necessary to identify the prevalence of parasitic diseases in different areas in the Philippines, as it would provide the data necessary to evaluate the effectiveness of measures undertaken by the government. This data would help in deducing which areas require the greatest concern. Prevalence data are insufficient in the Philippines, where intestinal helminths are endemic [3]. Most previous research on the prevalence of *A. lumbricoides* in the Philippines coincides with the assessment of *Trichuris trichiura*, *Necator americanus*, and *A. duodenale*. In addition, these focus on a small-scale approach, merely investigating species occurrence on a town, city, or provincial level. This includes the evaluation of the prevalence of STH egg contamination in soil samples randomly collected within villages and select towns (i.e., house yards, empty lots, and school grounds) in Bay, Los Baños, Calamba, and Calauan Laguna [4]. Of the 1480 soil samples gathered, 31% contained STH eggs. *A. lumbricoides* contamination accounted for the second-highest prevalence (11%). In another cross-sectional study in Laguna, Philippines, STH infections in school-aged children (grades 4 and 5), from 10 elementary schools were tested by comparing the diagnostic results derived by the Kato-Katz technique with those derived from multiplex quantitative polymerase chain reaction (qPCR) [5]. In the same year, a cross-sectional survey and stool examination (Kato-Katz technique) involving 10,434 individuals in Northern Samar, Philippines, found a prevalence rate of 40.2% for *A. lumbricoides* [6]. Bayesian multinomial geostatistical models estimated 89,400 *A. lumbricoides* and *T. trichiura* co-infections in school-aged children in Luzon alone [7]. Visayas followed with 38,300 and Mindanao with 20,200 estimated co-infections [7]. A recent study identified the prevalence of infection with at least one type of STH in school-aged children (Grades 3 to 5) from public elementary schools in Pamplona (25.99%) and Sanchez-Mira (19.40%), which are school districts in Cagayan Valley [8]. The results show a 7.11% overall prevalence of heavy-intensity infection with *A. lumbricoides*.

Species distribution models are essential for understanding the extent of neglected tropical diseases and creating effective policies and programs for disease intervention. The results of modeling studies enable policymakers to estimate the number of people infected within a certain geographical area and determine suitable interventions and their costs. Extensive parasitological surveys can be costly and time-consuming; therefore, modeling studies have been utilized by the World Health Organization (WHO) in predicting global STH distribution and estimating populations that require deworming [9]. Ecological niche models (ENMs) are a group of approaches that integrate occurrence data with environmental data to present a correlative model of the environmental circumstances that satisfy the ecological requirements of a species and predict its habitat suitability [10,11]. ENMs are generally utilized under one of several instances. They can be used to estimate the relative suitability of a habitat documented to be inhabited by the species, to estimate the relative suitability of habitat within geographic regions not documented to be inhabited by the species, to estimate shifts in the suitability of habitat over time based on a particular circumstance for environmental change, and, finally, to predict estimates of the species niche [11,12]. The maximum entropy (MaxEnt) model is one of the models that only requires the present location of the species [13]. In addition to the species location, the model also requires environmental information for the entire area of research; thus, giving MaxEnt an advantage over other models [11]. Continuous and categorical data can be used in this model. Moreover, MaxEnt can generate an explicit map of the possible suitability area. It also includes a jackknife test function for evaluating the environmental layer considered relevant. Finally, using occurrence data can analyze environmental information and is simple to execute as an interface application. This method provides a large amount of information that enables the classification of the potential distribution of species and additional information, including variable significance and probability of occurrence maps [14]. Throughout several studies, MaxEnt has proven to perform better than other models. Nonetheless, several flaws have been discovered. MaxEnt may underestimate the likelihood of occurrence inside areas where the species is known to exist, thus overestimating it in areas where it does not exist [15,16]. Another disadvantage is that this model makes it difficult to optimize the specifics of climate data, which are the most critical variables controlling species distribution, and this could significantly reduce the model's predictive ability [17].

This study extended the existing knowledge on ascariasis by providing key insights and updated information on *A. lumbricoides* distribution in the Philippines. The species predictive map, after incorporating bioclimatic variables into the species occurrences, can identify the bioclimatic variables associated with the high prevalence of *A. lumbricoides*. Since extensive parasitological surveys can be costly and time-consuming, predictions on *A. lumbricoides* distribution produced by the study can fill the gap in areas where data are still lacking. Consequently, a detailed understanding of the distribution of *A. lumbricoides* will assist in identifying high-risk areas in the Philippines. Through this, policymakers can estimate the number of people infected within a certain area and develop evidence-based, effective control strategies against ascariasis to prevent potential outbreaks. The results of this study can also assist in evaluating the success of past intervention strategies in the Philippines.

Methodology

Study design

Data collection was conducted from June 2021 to September 2021. Based on previously published protocols [18,19], a stratified cluster sampling method was utilized in regions with a recorded prevalence of ascariasis. The Philippines was stratified into 17 regions using this design. Representative cities and municipalities served as clusters for every region in the Philippines from which data were collected. Bioclimatic variables for the Philippines were also collected from geographical information system (GIS) and collated in .asc format. Certain bioclimatic variables determine species distribution, and the optimum combination of these variables enables a specific species to survive in particular places [13]. The occurrence and distribution patterns of *A. lumbricoides* in the Philippines can be influenced by several bioclimatic factors, both explicitly or implicitly [20]. The interaction among bioclimatic variables influencing a species' overall suitability in a given area was highlighted in the study. The MaxEnt modeling algorithm revealed the relationship between the species' known range from its data occurrence and bioclimatic variables to determine potential species distribution. The predictability of the generated distribution map was evaluated using the area under the curve (AUC) values generated by the MaxEnt analysis, as done by other studies [16,19].

Collection and selection of species occurrence data

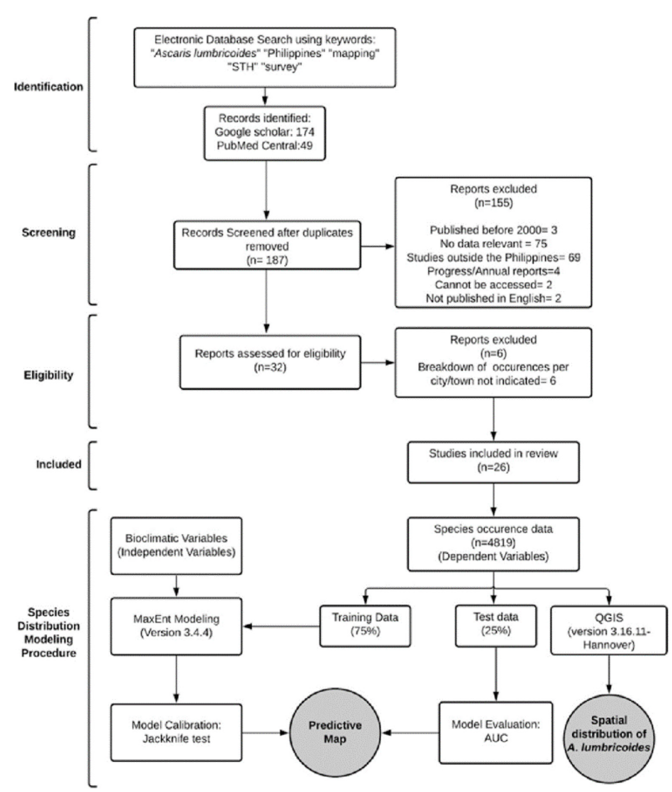
The occurrence records of *A. lumbricoides* were acquired through a systematic literature review following the Preferred Reporting Items for systematic reviews and meta-analyses (PRISMA) guidelines [21] performed by the second to the sixth authors. Search queries "*Ascaris lumbricoides*," "Philippines," "mapping," "STH," and "survey" were searched on Google Scholar and PubMed Central. The references of the related studies that can potentially provide the desired data were evaluated. In the case of unpublished confidential data, a request was made to access data from research institutions in the Philippines, such as the Research Institute for Tropical Medicine. After the collection of occurrence records, data screening and assessment of eligibility were conducted to ensure that the data collected met the criteria for the study design (Figure 1). The data included were the occurrences of ascariasis recorded only in the Philippines. Hence, studies focusing on multiple STH will exclude data involving parasitic infections other than ascariasis. Moreover, only data from 2000 to the present were included. Occurrence records were converted into geographic coordinates (Global Coordinate System) using PhilAtlas and Google Earth. Data calibration was performed using R studio.

Species distribution modeling

The spatial distribution of the collected ascariasis cases with their respective geographical coordinate was plotted over the environmental shapefile layers of the Philippines (PHL_adm0) and its city/municipal boundaries (PHL_adm2) using QGIS 3.16.11. MaxEnt software version 3.4.4 was utilized to model the species distribution of *A. lumbricoides* in the Philippines using maximum entropy modeling. The retrieved data set included presence-only species occurrence as a count variable and environmental measurement variables. The species occurrence and environmental data were converted into ASCII format for model construction in MaxEnt. The data layers in MaxEnt represented the bioclimatic variables. A predicted species distribution map of *A. lumbricoides* was generated using MaxEnt. The generated model visualized the potential distribution of *A. lumbricoides* in the Philippines and the suitability of conditions in different regions.

The bioclimatic data were the independent variables

Figure 1. Experimental flowchart.

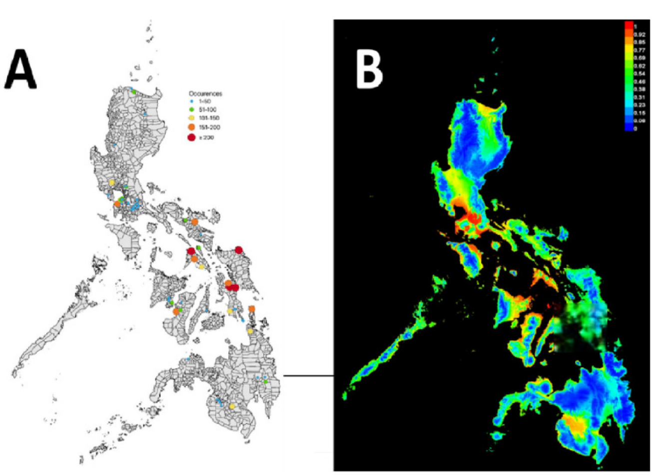


in the study, while the occurrence records of *A. lumbricoides* were the dependent variables. The bioclimatic and occurrence data were subjected to MaxEnt software for model construction. Presence data were divided into 25% test and 75% training data, which is widely followed in studies using MaxEnt [22–24]. During MaxEnt analysis, 75% of occurrence records were used to build the model. This allowed the remaining 25% to test whether the predictions generated were better than random ones [24]. Analysis of variable contribution was conducted to assess the importance of the bioclimatic variables contributing to the distribution of *A. lumbricoides*. The percent predictive contribution of the environmental variables was available, indicating which variables mattered most [25]. In addition to the table of analysis of variable contribution, the Jackknife test was used in MaxEnt to assess the relative importance of each bioclimatic variable contributing to the species distribution model (SDM) [25]. The area under the receiver operating characteristic curve (AUC) value of the area under the receiver operating characteristics (ROC) curve within MaxEnt was used to assess the model's accuracy.

Data visualization and analyses

The SDM generated in MaxEnt was visualized using a map that showed the potential distribution of *A. lumbricoides* in the Philippines and the suitability of conditions in different regions. Once the map was created, the correlation between the environmental variables and species occurrences was revealed by MaxEnt. This determined which environmental variables could be associated with high species occurrence.

Figure 2 A. Recorded occurrence of *A. lumbricoides* based on the systematic literature scanning of public records in the Philippines and **B.** predictive map of potential distribution of *A. lumbricoides* using bioclimatic envelopes employed in the MaxEnt software.



Two statistical measures were utilized to assess the influence of the environmental variables on the SDM: the table of analysis of variable contribution and the Jackknife test. A table of analysis of variable contribution was produced to assess the importance of the environmental variables contributing to the *A. lumbricoides* distribution. This included the percent predictive contribution of each variable. A high percent contribution value indicated a strong influence of a certain variable on the SDM. The importance of variables increased with increasing percentage values. Similar to the table of analysis of variable contribution, the Jackknife test calculates the model gain for each variable used [25]. Based on the analysis, a species response curve of the relationship between *A. lumbricoides* habitat suitability and environmental variables was generated. Based on the chart, the model gain was determined based on the value provided: low potential (< 0.2), moderate potential (0.2 to 0.4), good potential (0.4 to 0.6), and high potential (> 0.6) [27].

Predictive accuracy is a fundamental issue linked to SDMs [11,25]. For this reason, the threshold-independent evaluation index (AUC) is used to assess model performance [15,25]. AUC is one of the traditional methods of model performance evaluation. A plot of sensitivity (true positives) against 1-specificity (false positives) over a range of threshold values between 0 to 1 is used [10,28]. Simply put, this statistical tool measures the model's performance by comparing the model's predictive ability with a random prediction [29]. An AUC value of less than 0.5 denotes low predictive capacity. Values from 0.75 to 1 are considered useful, with those nearest to 1 have the highest predictive capacity [30].

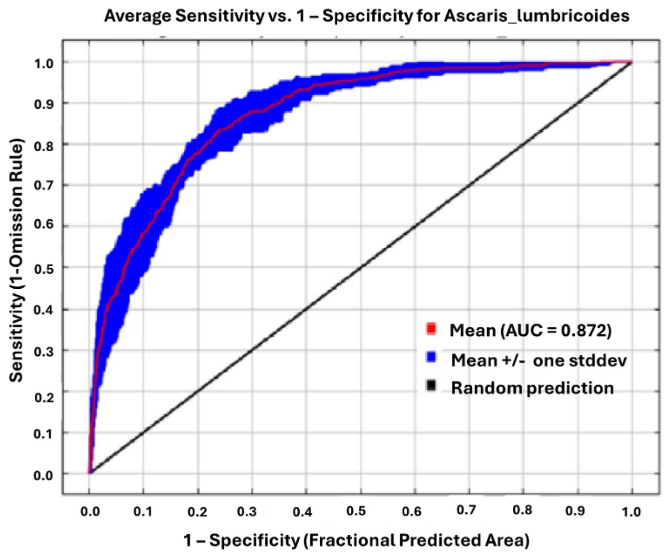
Results

The spatial distribution of ascariasis mapped in QGIS (Figure 2A) showed that most recorded cases occurred in Southern Luzon and Visayas.

In contrast, the predictive map generated by MaxEnt (Figure 2B) revealed the highest percent predictive contribution of ascariasis occurrences in Region IV-A (CALABARZON) and Region VII (Central Visayas), as represented by the red-shaded regions shown in the heat map. A high percent predictive contribution is also associated with Region III (Central Luzon), Region V (Bicol Region), and Region VI (Western Visayas), which are shaded in orange. Lastly, Region XII (SOCCSKSARGEN) and Bangsamoro Autonomous Region in Muslim Mindanao (BARMM) show a relatively high percent predictive contribution since they contain orange- and yellow-shaded zones.

The average training AUC for the replicate runs was 0.872, and the standard deviation was 0.017. An AUC value of 0.75 to 1 is useful as it confers a high predictive capacity (Figure 3). Analysis of variable contribution (Table 1) showed the highest percent predictive contribution in mean temperature of warmest quarter (49.4%); followed by temperature annual range (10.9%), mean temperature of driest quarter (10.9%), max temperature of warmest month (8%), and annual mean temperature (7.7%).

Figure 3. Receiver operating curve showing the average training area under receiver operating curve (AUC) of 0.872 for the replicate runs.



Discussion

Evaluation of spatial distribution and bioclimatic models

Previous studies reveal that sample size influences species distribution model performance, with fewer records resulting in poor results. The researchers used MaxEnt because it circumvents this problem by providing adequate power for predicting distributions with as few as < 10 records [30]. AUC is the most generally utilized statistical tool in MaxEnt to evaluate the model's predictive capacity. The *A. lumbricoides* model generated from MaxEnt obtained a high AUC value (0.872 ± 0.017) and predicted areas of low to high probability of *A. lumbricoides* occurrences based on the presence data and bioclimatic variables provided. A total of 58 presence data of ascariasis occurrences recorded in different municipalities and cities were used for this study. A large amount of presence data is preferred since a MaxEnt model with greater accuracy may be produced with more presence records. Using a small sample size over a large area may lead to model overestimation [31,32].

QGIS was used to generate a spatial distribution map of ascariasis occurrences. This map was used to visualize and present the number of ascariasis cases in the Philippines from 2000 to 2021. The QGIS map showed high ascariasis occurrences in Eastern Visayas, Bicol Region, and Calabarzon. However, some places in the map produced in QGIS, particularly region 8, were not included in the risk areas in the predictive map generated in MaxEnt. This can be explained by the fact that MaxEnt generated a predictive map based on the bioclimatic factors in the study area regardless of the number of cases in every coordinate evaluated by the software. MaxEnt presents a predictive map showing areas with a higher percentage of predictive contribution to ascariasis occurrences than the spatial distribution map generated from QGIS. These include Central Visayas, Central Luzon, Western Visayas, Soccsksargen, and Barmm. MaxEnt attributes a high percent predictive contribution to areas containing the most influential bioclimatic variables for predicting occurrences of ascariasis.

Table 1. Estimates of relative contributions of the environmental variables to the Maxent model.

Code	Environmental variables	Contribution (%)	Permutation importance
Bio10	Mean temperature in the warmest quarter	49.4	35.1
Bio7	Temperature annual range	10.9	15.7
Bio9	Mean temperature in the driest quarter	10.9	8.8
Bio5	Max temperature in the warmest month	8.0	11.0
Bio1	Annual mean temperature	7.7	7.6
Bio18	Precipitation in the warmest quarter	3.3	4.0
Bio15	Seasonal precipitation	3.0	2.1
Bio17	Precipitation in the driest quarter	2.8	6.9
Bio19	Precipitation in the coldest quarter	1.2	4.8
Bio13	Precipitation in the wettest quarter	1.1.	1.1
Bio8	Mean temperature in the wettest quarter	0.7	0.3
Bio11	Mean temperature in the coldest quarter	0.4	2.2
Bio14	Precipitation in the driest month	0.3	0.0
Bio12	Annual precipitation	0.2	0.3
Bio16	Precipitation in the wettest quarter	0.2	0.1

Most influential bioclimatic variables

The analysis of the variable contribution table is congruent in revealing temperature-related variables and the top five influential bioclimatic variables. Although a slight difference was noted in the top five influential variables of the analysis of variable contribution table, which included temperature annual range (bio 7) while jackknife test results included mean temperature of the wettest quarter (bio8), four temperature-related variables are consistent in the results of both tests, supporting their contribution as the most influential factors. The analysis of the variable contribution table and jackknife tests support that the mean temperature of the warmest quarter (bio10) was the most influential variable. Regarding the other four temperature-related variables, the results do not have a consistent order of importance, implying that these variables are influential; however, the importance of each variable compared to the others cannot be determined.

Temperature is a strong predictor of *A. lumbricoides* distribution due to its effect on egg development in the soil. When fertilized eggs are passed in feces, an incubation period in the soil is required to molt, embryonate, and acquire infectivity. The eggs deposited in the soil are resistant to adverse conditions, but are very sensitive to environmental temperatures [33]. Considering that the Philippines is a tropical country, it is characterized by varying relatively high temperatures. The climate is divided into a wet season from May to November and a dry season from December to April. The dry season combines a cool, dry season from December to February and a hot, dry season from March to May. The annual mean temperature of 26.6 °C (excluding Baguio at an elevation of 1,500 m) and an average temperature range of 25 to 32°C [34], which falls within the optimal temperature of 20–30°C to allow rapid development of fertilized *A. lumbricoides* eggs [34]. Maxent suggested that the most influential bioclimatic variable was the mean temperature of warmest quarter (bio10). Warmer months in the Philippines occur from March to October, with a mean monthly temperature of 26 to 28 °C [35]. The warmest month is May, with a mean temperature of 28.3 °C, while the highest temperature recorded was 53° C [36]. It is important to note that although a suitable condition of warm soil is needed by *A. lumbricoides* eggs, they cannot survive temperatures above 38°C [34]. This suggests that temperature changes greatly affect *A. lumbricoides* egg development. Particularly, extreme temperatures in the warmest month (May) can cease the development of *Ascaris* eggs in the soil. The occurrence of the wet and dry seasons is particularly important because temperature increases more easily in dry soil than wet soil [37]. Hence, this affects seasonal changes in soil temperature linked to *A. lumbricoides* egg development in soil. However, the dry season in the Philippines is a combination of a cool, dry season from December to February and a hot, dry season from March to May. This means that during the dry season, soil temperature can increase during the hot, dry season or decrease during the cool, dry season. The cool, dry months occur in December to February with a monthly temperature of 25 to 26 °C, and January is the coolest month with a mean temperature of 25.5 °C [35], which still falls within the optimal temperature for *A. lumbricoides* survival and development (20–30°C). However, a temperature below 15.5°C is lethal [34].

Compared to variables related to temperature, precipitation had a lower percent predictive contribution in the model. Nevertheless, precipitation is also likely to affect *A. lumbricoides* egg development. A positive correlation has previously been shown between ascariasis incidence and precipitation, such that the highest rate of egg development was observed under the highest soil humidity [38]. In this case, precipitation likely contributed to soil moisture, accelerating egg development [39]. Precipitation also moves mature eggs from the soil, contaminating food and water sources, thereby increasing the risk of infection. In contrast, it has been shown that ascariasis prevalence was significantly higher in dry areas [40–44]. In this case, the regions that experienced extreme drought also had higher cases of ascariasis due to limited access to sanitation facilities [8, 45–47]. Precipitation likely has a lower percentage predictive contribution than temperature because organic matter such as feces protects *A. lumbricoides* eggs from moisture loss even in dry environments with low precipitation [48]. Additionally, the shell of *A. lumbricoides* eggs can also restrict water loss [48–49]. Therefore, precipitation alone cannot predict the prevalence of ascariasis, and temperature must also be considered.

In the Philippines, the climate is highly influenced by the El Niño Southern Oscillation (ENSO). ENSO is a climate phenomenon with two opposite phases, El Niño and La Niña [50]. During El Niño, ocean surface warming occurs and precipitation tends to reduce over the Philippines. During La Niña, ocean surface cooling occurs and precipitation tends to increase [50]. These climate patterns coupled with the effects of bioclimatic variables, such as temperature and precipitation, may predict seasonal variations in infection levels [18,51]. This has implications for seasonally timed mass drug administration, which could positively impact ascariasis control strategies.

Implications of the bioclimatic envelope model and future directions

Neglected Tropical Diseases (NTD) require attention due to their effect, especially on those belonging to the vulnerable populations (marginalized sectors of society) worldwide. These diseases are commonly found in areas with limited access to water and where sanitary conditions are compromised (19,51–52]. Most of these diseases pose an economic burden to the people due to the chronic symptoms that will manifest if left untreated [53]. It is prevalent in the tropical and subtropical regions of the world, especially in Africa, some parts of Asia, and South America [54]. Some of the most common NTDs in the world are the infections caused by the STHs, which include *Ancylostoma duodenale*, *Ascaris lumbricoides*, *Necator americanus*, and *Trichuris trichiura* [55–56]. Data from the first national baseline survey of STH infections conducted between 2005 and 2008, data shows endemic levels of STH infections in Luzon, Visayas, and Mindanao [6]. The Department of Health has been implementing the Integrated Helminth Control Program (IHCP) to control STH infections, where susceptible individuals, including children aged 12 months to 12 years old and special population groups (pregnant women, farmers, adolescent females, and indigenous people), are treated with albendazole or mebendazole [57]. A research group from the University of the Philippines assessed the impact of IHCP 10 years after its implementation. The assessment revealed that the global and national targets on deworming coverage have yet to be achieved and that the program has failed to significantly reduce rates of moderate-high infections [8]. This study focused on the pathogenesis by *A. lumbricoides* (giant intestinal roundworm), the most prevalent STH that infects about 1 billion individuals worldwide.

A. lumbricoides is the largest nematode that inhabits the intestinal tract of humans due to the size of the female adult worms. These adult worms can be extracted via surgery or expelled voluntarily from the host [2]. Infection with *A. lumbricoides* occurs by ingesting infective eggs, from which the larvae hatch. The larvae will mature in the host's small intestine. Presence of *A. lumbricoides* in the intestine causes cough, low-grade fever, pneumonia, and 30–50% eosinophilia during its tissue phase [58]. The clinical features of its intestinal phase include intestinal or appendix obstruction, protein malnutrition in children, and abdominal pain [2,59]. It is essential to monitor the prevalence of ascariasis in the Philippines, as this will provide data relevant to evaluating the current health programs implemented by the government. Most studies on ascariasis occurrence in the Philippines limit their scope to a town, city, and regional basis. This study aimed to evaluate occurrence nationally.

Conclusions

This study extends the existing knowledge on ascariasis by providing key insights on updated *A. lumbricoides* distribution in the Philippines. The species predictive map generated after incorporating bioclimatic variables into the species occurrences can identify bioclimatic variables associated with the high prevalence of *A. lumbricoides*. Since extensive parasitological surveys can be costly and time-consuming, predictions on *A. lumbricoides* distribution produced by the study can fill the gap in areas lacking data. Consequently, a detailed understanding of the distribution of *A. lumbricoides* will assist in identifying high-risk areas in the Philippines. Through this, policymakers can estimate the number of people infected within a certain area and develop evidence-based, effective control strategies against ascariasis to prevent potential outbreaks. The results of this study can also assist in evaluating the success of past intervention strategies in the Philippines. Moreover, the model can predict variations in infection levels per region based on these bioclimatic variables. Therefore, seasonally timed mass drug administration could positively impact ascariasis control strategies in the country.

However, despite the robustness of the model, some limitations need to be considered because it is important to interpret models with caution. Firstly, due to current limitations in data availability, future researchers may look for studies containing data from other regions that were not included in the model. Second, the model will obviously change the moment the areas that are underrepresented in terms of sampling of *A. lumbricoides* are validated. Lastly, there is also an opportunity for other studies to investigate additional variables affecting ascariasis occurrences, such as land surface temperature, rainfall, distance to perennial bodies of water, and normalized difference vegetation index.

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Authors' contribution
LMRM, conceptualization, investigation, validation, supervision, writing–review and editing; PATZ, PDGD, AREO, data collection, formal analysis, resources, writing–original draft; DPPF, KSLL, data curation, methodology, visualization, writing–original draft; NHAD, conceptualization, methodology, project administration, writing–review and editing.

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Conflict of interest
No conflict of interest is declared.

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