IOP Conference Series:
Earth and
Environmental Science

PAPER • **OPEN ACCESS**

Earthworm invasion in Chayu River valley of Tibet under climate change

To cite this article: Mingyue Jin *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1087** 012039

Earthworm invasion in Chayu River valley of Tibet under climate change

Mingyue Jin[1], Lei Hou[1,3,5], Yihua Ren[2,3,4] and Yaozhi Zhou[2]

[1] Department of Resources & Environment, Tibet Agriculture & Animal Husbandry University, Nyingchi 860000, China;
[2] Institute of Plateau Ecology, Tibet Agriculture & Animal Husbandry University, Nyingchi 860000, China;
[3] Tibet Key Laboratory of Forest Ecology in Plateau Area, Ministry of Education, Nyingchi 860000, China;
[4] Nyingchi Ecological Monitoring Station, Tibet Ecological Environment Remote Sensing Monitoring Center, Nyingchi 860000, China.

[5] Corresponding author's e-mail: 465133704@qq.com

Abstract. Climate change affects biological invasion. To understand the invasion pattern of alien species of earthworm in Gongrigabu river watershed of Chayu river in Tibet under climate change, the participate rural appraise (PRA) was applied to investigate and analyze the peasant's perception of the appearance time and harm of alien species of earthworm in 13 villages. The results showed that the local climate was warming and drying, and climate warming was the main reason for the invasion of alien species of earthworms. Since the appearance of alien species of earthworm at an altitude of 1528 m in 2008, they had invaded the upstream area at a climbing speed of 71.43 m·a-1 and had been outbreaking in areas below 2028 m. For the climate change adaptation measures, the local peasants should change the crop layout.

1. Introduction

Earthworms belong to the Oligochaeta and are found in most ecosystems. They are the most abundant invertebrate soil animals in terrestrial ecosystems [1] and are known as "ecosystem engineers" because of their important role in material cycling and energy transfer in soil processes [2-3]. In addition, earthworms can create and sustain habitats for other soil organisms through physical and chemical modifications to the environment [2,4]. Earthworms are generally considered to have positive effects on agricultural production, improving soil structure [5], fertility [6-7], and contaminated soil [8-10]. However, once a certain limit is exceeded, earthworms can disrupt the soil ecosystem balance and cause soil loosening [11-12], which harms agricultural production. Farmers are directly engaged in labor production activities that are closely related to the natural environment and are therefore sensitive to changes in the natural environment and their impacts. During a survey on climate change perception and adaptation in the Chayu River basin in Tibet, based on farmers' own practical experience in agricultural labor production, farmers in certain villages believed that earthworm species that had not previously appeared had negative impacts on their village paddy fields, such as breaking field ridges and causing crops to fall over.

Biological invasion is one of the major environmental problems that threaten global ecological security. Along with economic globalization and climate change, China is also suffering from serious biological invasions, and more than 500 invasive species have been identified [13]. Biological invasions and climate change are two important factors affecting biodiversity and ecosystem function, and previous studies have suggested that each has an independent impact on biodiversity, but many existing studies have suggested that climate change affects the rate and extent of biological invasions and that rising temperatures, changing precipitation patterns, and the continued occurrence of extreme weather events may also affect the prevalence and distribution of invasive organisms [14].

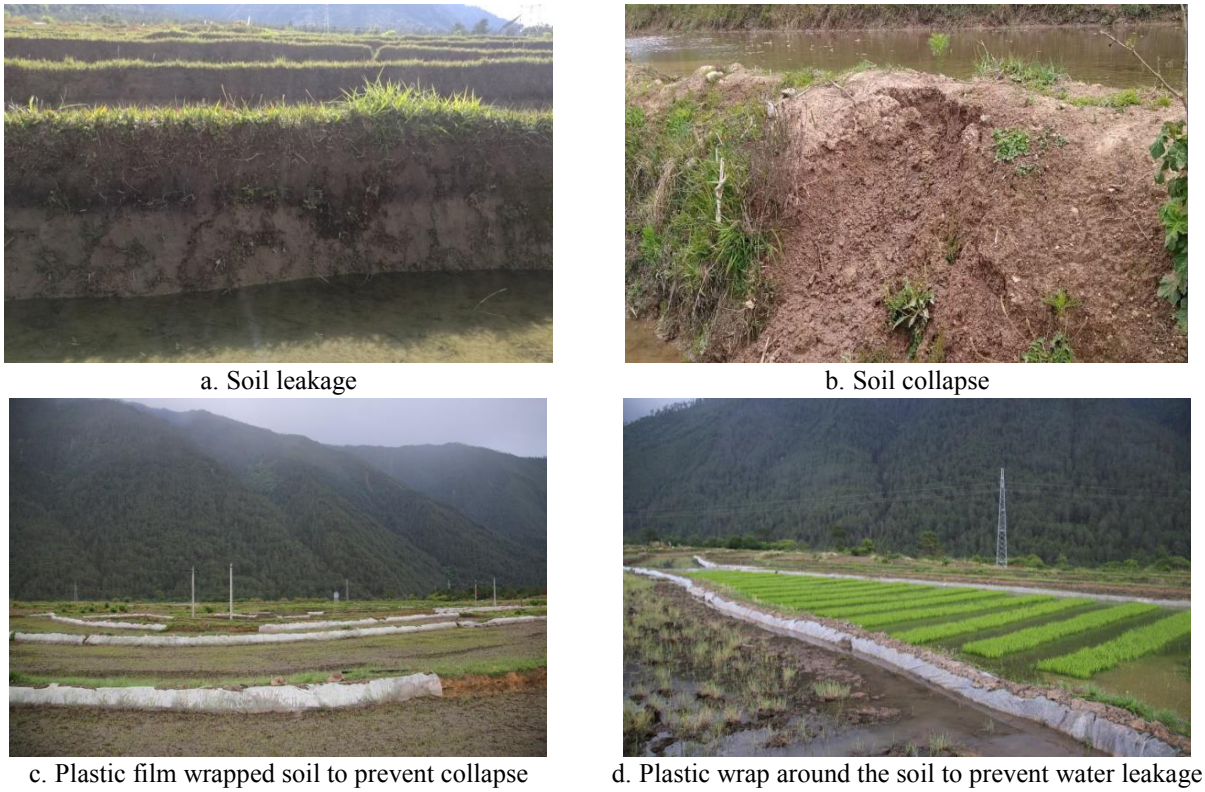
At present, climate change has become an important issue of concern in various countries and regions, with far-reaching effects on the structure, function, and processes of various ecosystems, which are relevant to all aspects of human society [15]. Climate change has also impacted agricultural production, mainly due to the increase in temperature and changes in precipitation patterns [16-19], and the corresponding changes in biogeography [20-22]. The high average altitude of the Tibetan Plateau, with its unique geographic location and topography, has a significant impact on the climate of China, Asia, and the world [23-24]. Not only that, but the Tibetan Plateau is also an amplifier and driver of global climate change [25] and is sensitive and ahead of its time in climate change and its response [26-27]. Therefore, the Tibetan Plateau faces a more serious threat of climate change, especially the agricultural population that depends on natural resources such as agriculture, herding, and gathering, which not only increases the risk of livelihood after the impact of climate change but also may become poor as a result [28]. According to the study, under the fact of global warming [29], the Qinghai-Tibet Plateau is also accelerating [30], which also affects meteorological elements such as precipitation and humidity in different parts of the plateau [31]. The invasion of earthworm exotics to paddy fields can then be considered a threat under the influence of climate change. Climate not only determines the biological processes of earthworms themselves but also acts by changing their habitat and food supply, which in turn changes the species and distribution range of earthworms [32]. In the high-altitude region of the southeastern Tibetan Plateau, changing climatic conditions may be promoting earthworm invasion [33].

In this paper, we constructed a simple model of earthworm exotic species invasion based on the emergence time and location of the earthworm exotic species, Amynthas hupeiensis, in the Gongrigabu watershed of the Chayu River, to provide a theoretical basis for understanding the response of earthworms to climate change, preventing and controlling earthworm hazards, and enhancing farmers' adaptation to climate change.

2. Materials and methods

2.1. Study site

The study area is located in the watershed of the tributary of the Chayu River basin in Tibet, including Upper Chayu town and Lower Chayu town, which belong to Chayu County, Linzhi City, Tibet. The Chayu River is large in eastern Tibet, with double-branch rivers, the eastern branch of the Gongrigabu, and the western branch of the Sangqu, which converge into the Chayu River and flow southward out of the national border to join the Brahmaputra River (i.e., the Yarlung Tsangpo River). The Gongrigabu originates from the end of the modern glacier in Gongrigabu, and is about 170 km long, with a drop of 5140 m and an average elevation of 3980 m. The overall flow is northwest-southeast, with a watershed area of 4900 km2 [34]. Influenced by warm and humid air currents of the Indian Ocean, precipitation is relatively abundant, with annual precipitation reaching 800 mm, wet and rainy from March to September and low rainfall from October to February of the following year [35]. The average annual temperature is 12.1°C, the average wind speed is 2.1 m/s, and the frost-free period is 215 days [36]. The main ethnic groups are Tibetans, as well as Han, Naxi, Luoba, etc., living on the flatter mountainous areas on both sides of the river, with a population of about 10,600. They are engaged in agricultural, herding, and gathering production activities. Crops such as paddy and barley are grown. Rich in plant and animal resources.



a. Soil leakage b. Soil collapse

c. Plastic film wrapped soil to prevent collapse d. Plastic wrap around the soil to prevent water leakage

Figure 1. The harm and prevention of earthworm in paddy field.

The emergence and outbreak of exotic species of earthworms had damaged the soil structure of paddy fields, mainly through its activities to break through or break down the field ridge, resulting in water and fertilizer leakage or loss (Figure 1 a, b). To prevent field soil damage, soil and water fertility loss, and earthworm migration, farmers in the study area mostly adopted plastic film to wrap the field soil (Figure 1 c, d).

2.2. Research methods

The study hypothesized that earthworm exotics would invade the Gongrigabu river watershed of the Chayu River from the downstream to the upstream direction. To test this hypothesis, farmers' perceptions of the emergence time and damage of earthworm exotics were surveyed in villages along the Gongrigabu river from downstream to upstream.

2.2.1. Climate data sources. Temperature, precipitation, and relative humidity data from the Chinese meteorological data network (http://data.cma.cn/) of the Chayu station since 1969 were used to characterize the climate change conditions in the Gongrigabu watershed of the Chayu river.

2.2.2. Survey Metho;dology. To grasp the emergence time of the earthworm exotic species Amynthas hupeiensis and its harmful status to paddy fields, a special survey was conducted in May 2018 in each village of Upper and Lower Chayu towns in the Gongrigabu watershed, and 13 villages with the emergence of the earthworm exotic species were identified (Table 1, Figure 1). A participatory rural appraisal (PRA) method was adopted, including questionnaires, observation methods, and mini-symposiums. Farmers who owned paddy fields were selected for interviews. The interviewed farmers were mainly Chinese Tibetan and Mishmi people, and all of them had been engaged in agricultural activities for more than 10 years, and their knowledge about the emergence time of earthworm exotics and their hazards was representative. The farmers were generally less educated, speaking Tibetan and Chinese. To complete the questionnaire effectively, the trained Tibetan and Mishmi student

investigators filled out the questionnaire. The questions included age, years of farming, the year in which earthworms were found in the village's paddy fields, and the year in which ridges in the paddy fields leaked or collapsed. For integration into the local society, the selected investigators were all born in Chayu County. The investigators did not have an ownership or interest relationship with the respondents, which can ensure the objectivity of the survey information.

Table 1. The location of the study area.

Village	Altitude (m)	Latitude and longitude	Position order
Rongyu	2028	96°42'1.33"E; 28°51'3.17"N	1
Songlin	1904	96°44'8.63"E; 28°45'39.89"N	2
Gonggu	1889	96°44'59.32"E; 28°45'48.85"N	3
Guba	1850	96°50'45.38"E; 28°40'25.82"N	4
Geyong	2077	96°51'15.98"E; 28°40'1.16"N	5
Zhaba	1783	96°54'51.66"E; 28°36'16.06"N	6
Zigeng	1732	96°56'8.92"E; 28°34'34.07"N	7
Talin	1715	96°59'23.24"E; 28°32'32.46"N	8
Xiani	1686	96°59'31.31"E; 28°31'36.01"N	9
Xin	1774	96°59'28.82"E; 28°30'57.74"N	10
Baantong	1708	96°59'59.10"E; 28°30'52.56"N	11
Gamei	1623	97°0'17.03"E; 28°30'8.57"N	12
Shaqiong	1528	97°0'45.43"E; 28°29'5.57"N	13

Note: 1-13 indicates the upstream and downstream distribution of villages along the Gongrigabu watershed of the Chayu River, with smaller numbers indicating more upstream and larger numbers indicating more downstream.

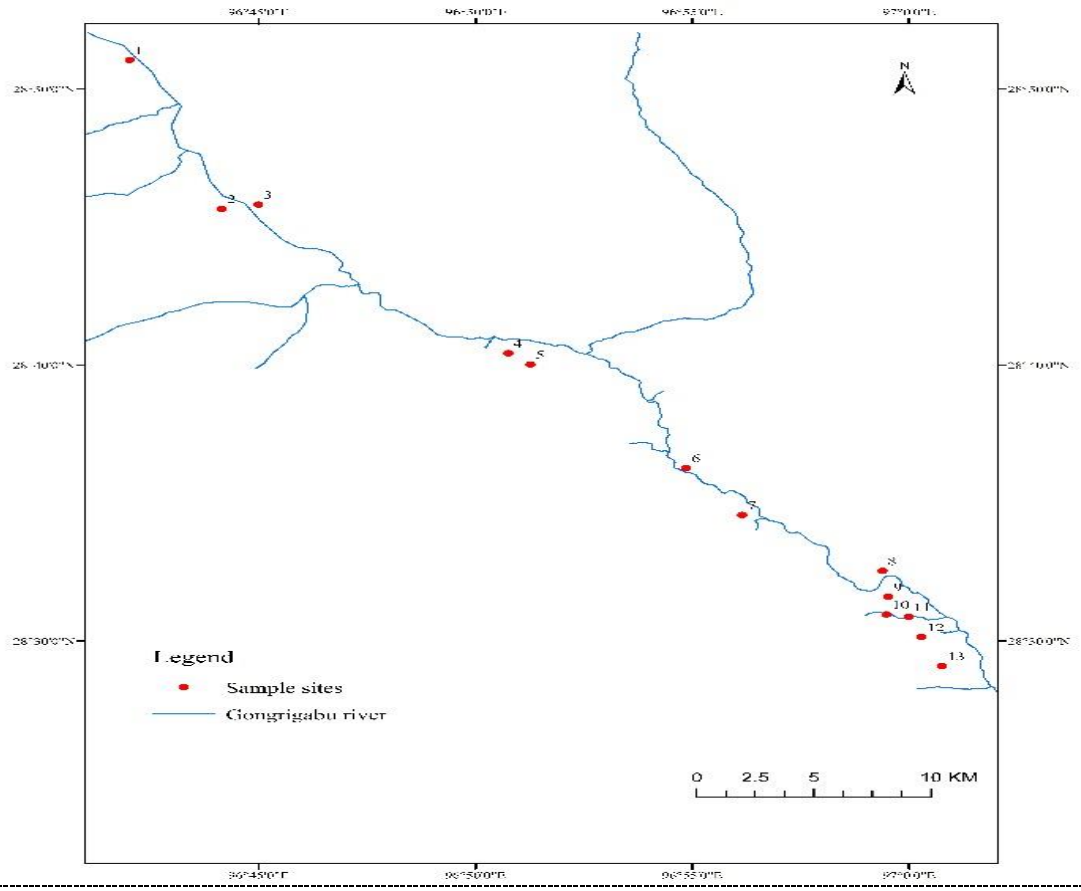


Figure 2. Location map of sample points.

Note: 1-13 indicates the upstream and downstream distribution of villages along the Gongrigabu watershed of the Chayu River, with smaller numbers indicating more upstream and larger numbers indicating more downstream.

3. Results

3.1. Climate change in the Gongrigabu watershed of the Chayu River

The trend of climate change in the Gongrigabu watershed of the Chayu River was analyzed in terms of three meteorological elements: temperature, relative humidity, and precipitation. In the past 40 years, although the temperature decreased slightly from 1969 to 1984, it had been on an upward trend after 1984. Relative humidity, in contrast to temperature, showed an increasing trend from 1969 to 1984 and had been decreasing after 1984. Precipitation had not changed much, but there was an overall decreasing trend (Figure 3). The climate as a whole tended to be warm and dry.

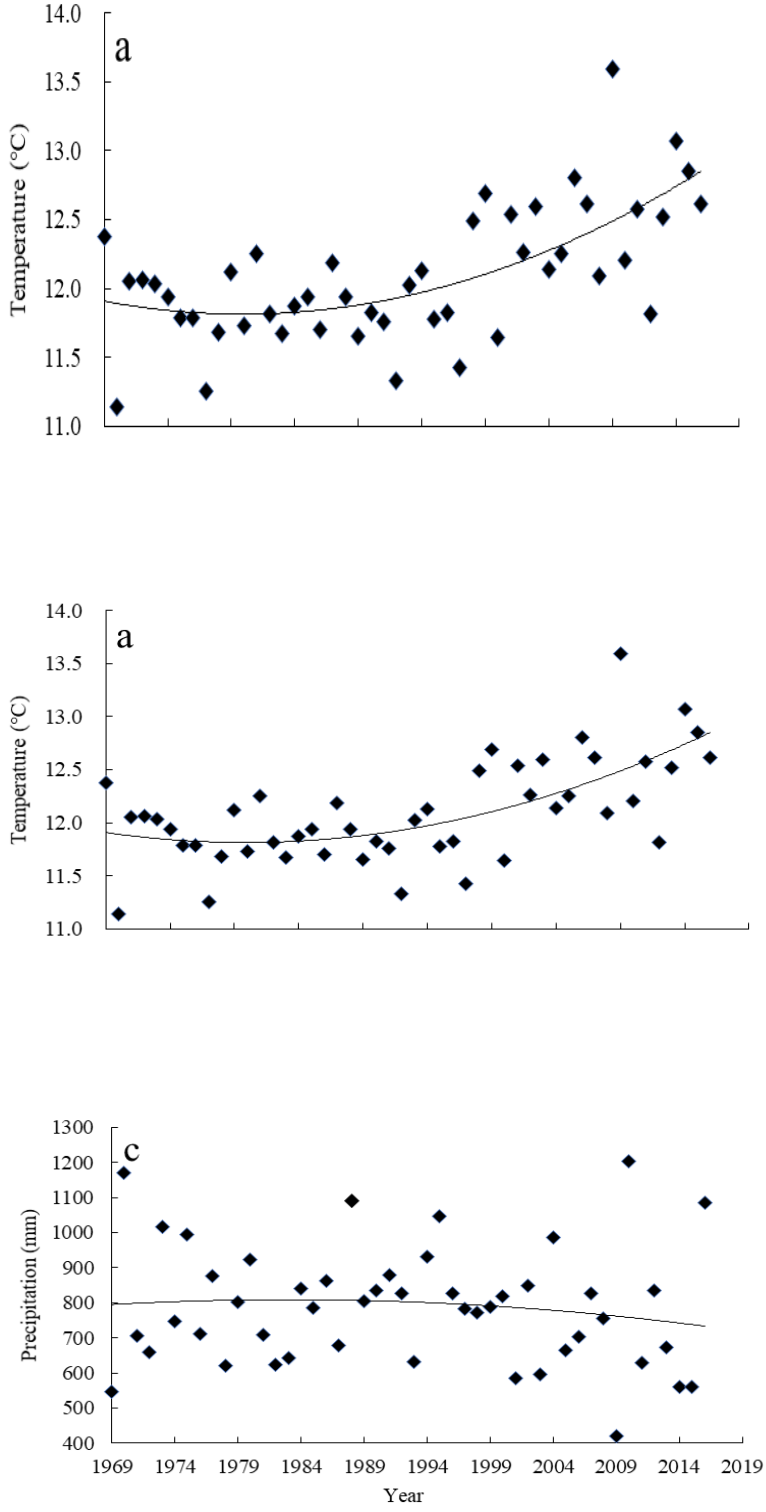


Figure 3. Trend line of average temperature, relative humidity, and precipitation in recent 40 years in Chayu river valley.

3.2. Invasion rate of earthworm exotics

The main perceived year of occurrence of the earthworm exotic species in the village was used as the perceived attitude of farmers in each village. Some villages were farther away from the river valley and higher in elevation and deviated from the trend line, but the earthworm exotic species showed an overall trend of spreading from downstream to upstream (Figure 4). Through the survey, earthworm exotics appeared from Shaqiong village to Rongyu village. Except for Rongyu village, which did not show any damage by earthworm to the paddy field, all the following villages' fields had damaged to be considered earthworm outbreaks. The villages below Shaqiong Village had not been surveyed, but because they were located at lower elevations downstream, it was inferred that earthworm exotics have already appeared and caused damage. No earthworm exotic species were found above Rongyu village. Earthworm exotics appeared in Shaqiong village as early as 2008 and as late as 2015 in Rongyu village, climbing 500 m in 7 years, with an invasion rate of 71.43 m·a-1 at altitude.

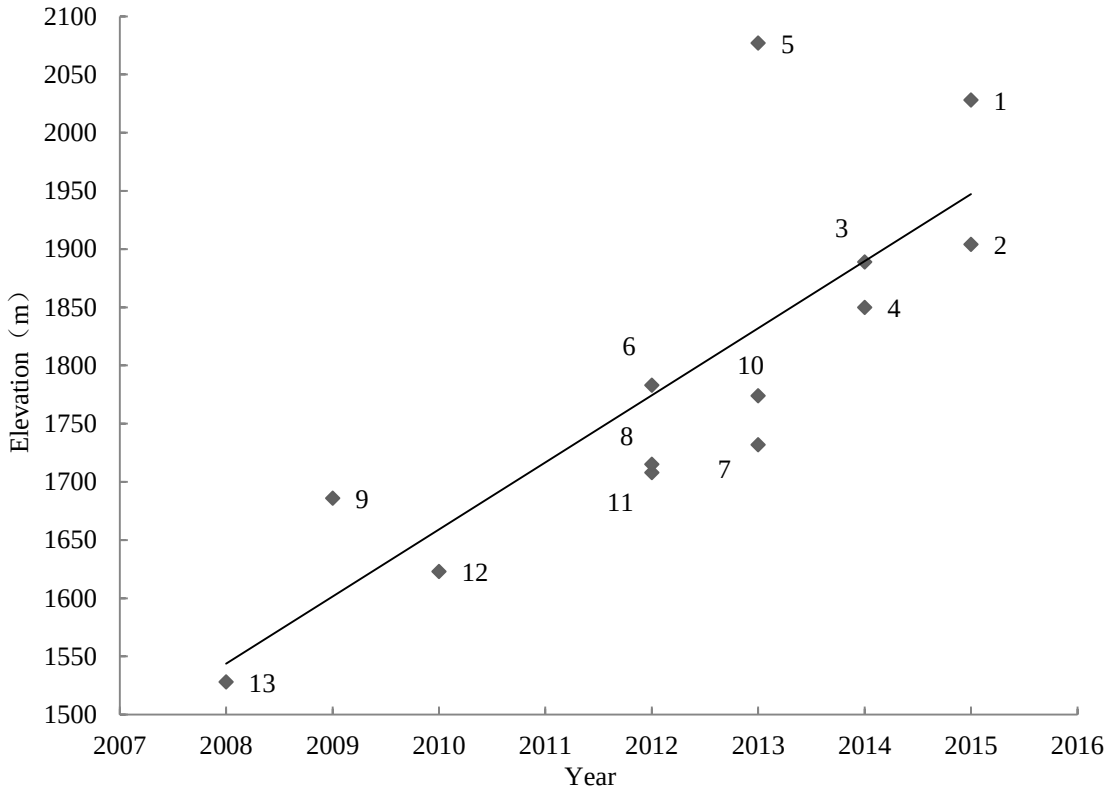


Figure 4. The invasion rate of alien species of earthworm at altitude.

4. Discussions

Global climate change is causing extensive and profound influence on human society. The Chayu River Basin in southeastern Tibet is experiencing significant climate change and its impacts, and biological invasion is one of the impacts brought about by climate change. The main processes and causes of biological invasions can be attributed to two aspects: first, the spread and proliferation of species brought about by the development of economic globalization and population movements, mainly due to human activities, intentional or unintentional[37], which can be referred to as anthropogenic introduction; and second, the ecological changes resulting from the ecological environment, i.e., natural invasion. For example, the invasion of Ageratina adenorphora has caused

serious ecological disasters and economic losses in China [38], and in Tibet, the species has also invaded Zhangmu and Jilong ports in the southern foothills of the Himalayas through economic and population activities [39], which can be considered as an anthropogenic introduction. Although this study is located in the Chayu River basin near the border of China, no border crossing has been opened, and the chance of species invasion brought about by human activities is minor, but considering that earthworm species are not as prone to carry in as plant species or other economic animals, this paper focuses on the possible effects of climate change on the spread of earthworms.

Climate change can affect the ability of invasive species to survive in new areas and alter their competitive relationships with native species. For agroecosystems, climate change weakens their defenses against invasive species, thus substantially increasing the likelihood of invasion by exotic species. Native species have been adapted to their original environment for a long time and have difficulty adapting to the new environment created by climate change in a short-term period; invasive species are generally able to adapt to the new environment more rapidly. The present study suggests that the functional richness of the earthworm community may decrease due to climate change [40] and the increase in temperature is harmful to the earthworm population [41].

Temperature is a major factor limiting the survival and reproduction of many organisms. Along with global warming, alpine forest and tree lines are extending to higher elevations [42], and as a result, some insects have shortened developmental cycles, accelerated reproduction, and are spreading to higher elevations and latitudes [43]. In terms of temperature, the Chayu River basin is experiencing a warming process, which is the same warming trend as that of the Tibetan Plateau [30,44] and southeastern Tibet [45], as evidenced by the temperature analysis of Chayu County by Li Dihua et al [36]. Continued climate warming may increase the adaptability of exotic species and expand their suitable range for survival. With regional warming, exotic species originating from warmer regions may form larger and more widely distributed dominant populations. Influenced by warm and humid air currents from the Indian Ocean, most of the Chayu River basin is a warmer region with increasing temperature suitability, which is increasingly suitable for the survival, reproduction, and spread of earthworm exotics. Some existing studies also support the possibility that warming is causing the expansion of some large pest species, including earthworms, into alpine regions [46-47]. Meanwhile, artificial warming experiments have shown that earthworms are sensitive to warming and that their species richness, density, and biomass decrease with increasing temperature [48-49]. This suggests that most earthworm species are unsuitable for warming, but this also provides opportunities for exotic species that are suitable for warming. The fluctuating resource hypothesis suggests that increased precipitation is conducive to biological invasion by increasing water availability [50]. Invasive species are likely to profit from increased water availability if they have high water requirements relative to native species. Characteristics of high water demand include short lifespan, rapid growth, and frequent aggregation, which are typical of opportunistic species [51] and are common in invasive organisms. Earthworms are a group of soil animals with high water demand [52] and are more abundant in the wet season when precipitation and humidity are ample [53-55]. The Chayu River basin is located in southeastern Tibet and is one of the areas with the highest humidity and rainfall in the entire Tibetan Plateau system. According to the meteorological data, the precipitation and relative humidity in this region show a decreasing trend, which is consistent with the study of Li Dihua [36], but contrary to the overall wetting trend of the Tibetan Plateau [53-58], and also contrary to the study of Chen Baoxiong et al [45] in southeastern Tibet. However, a survey on climate change perception and adaptation in the Chayu River basin in recent years revealed that farmers' perceptions of humidity and precipitation in 2015 and 2018 were significantly different, with those who perceived "dryness" varying from none to many, and those who perceived a decrease in precipitation increasing significantly. This indirectly confirms the trend of precipitation and humidity, indicating a drying of the climate, with a greater change after 2015. The drying of the climate in the basin, especially the larger changes in humidity, may be influenced by the increase in temperature. In the case of climate change, although the decrease in humidity and the weak trend of decrease in precipitation are unfavorable to the survival and

reproduction of earthworms, the increase in temperature is large and favors the spread of earthworms. This suggests that temperature becomes the main factor affecting the invasion of earthworm exotics.

To prevent the invasion of earthworm exotics on paddy fields and reduce the loss of agricultural production, farmers in the region have taken two main measures: first, wrapping the field ridge with plastic film to prevent the spread of earthworm exotics and maintain soil fertility; second, applying pesticides for earthworm control to kill earthworms. The former measure can play a role in a short period, but the plastic film breaks down quickly in the natural environment and produces solid waste after use without treatment to pollute the soil; the latter measure can kill some earthworm exotics, but it also kills other earthworm native species and causes pollution to the soil environment. At present, it seems that the measures taken by farmers are short-term and unhelpful maladaptive strategies. According to the actual local situation, the crop layout can be changed appropriately, i.e., switching to other food crops or shifting from food crops to cash crops, such as planting fruits and herbs, to mitigate and adapt to the effects of climate change.

5. Conclusions

The climate of the Chayu River basin in southeastern Tibet is developing towards warm and dry. Rising temperatures have become the main meteorological factor for the invasion of earthworm exotics. The likelihood of human-caused earthworm invasion is extremely low. All earthworm exotics below 2028m (Rongyu) have broken out and are harmful to paddy fields. Earthworm exotics have invaded upstream areas at a climbing rate of 71.43 m·a-1 since 2008 when they were found at an altitude of 1528m (Shaqiong). To cope with the invasion of earthworm exotics, a long-term capable response might be to change the crop layout.

Acknowledgments

All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by the Key Laboratory of Forest Ecology in Tibet of the Ministry of Education, grant number XZA-JYBSYS-2020-07.

Reference

[1] Katheem K S, Ibrahim M H, Quaik S, et al 2016 Prospects of Organic Waste Management and the Significance of Earthworms Important Digestive Enzymes of Earthworm *Switzerland: Springer International Publishing* 10-122

[2] Blouin M, Hodson M E, Delgado E A, et al 2013 A review of earthworm impact on soil function and ecosystem services European *Journal of Soil Science* **64** 161-182

[3] Jang J, Xiong X, Liu C, et al 2022 Invasive earthworms alter forest soil microbiomes and nitrogen cycling *Soil Biology and Biochemistry* 108724

[4] Bernard L, Chapuis-Lardy L, Razafimbelo T, et al 2012 Endogeic earthworms shape bacterial functional communities and affect organic matter mineralization in a tropical soil *Isme Journal* **6** 213–222

[5] Huang F Z 1979 The influence of earthworm on the formation of soil structure *Acta Pedologica Sinica* 211-217

[6] Yang Y K, Lin B X, Li C X, et al 2018 Effects of vermicompost compound substrate on growth and photosynthetic characteristics of tomato seedlings Jiangsu *Agricultural Sciences* **46** 137-139

[7] Wu C T, Zhu Z J, Liu C, et al 2018 Study on the effect of earthworm manure as a rapid fertilizer improver for poor soil Modern *Agricultural Science and Technology* 191-195

[8] Cheng J, Wong M H 2002 Effects of earthworms on Zn fractionation in soils *Biology & Fertility of Soils* **36** 72-78

[9] Song F M 2013 Progress on environmental pollution control and resource application using

earthworms Guangdong Agricultural *Sciences* **40** 164-168
[10] Liu Z Z, Huang S F, Tang H 2018 Effects of earthworm activity on phytoremediation of Hg contaminated soil Environmental *pollution and prevention* **40** 866-869 + 874
[11] Liang Z J, Chen X, Ma J J, et al 2014 The occurrence and control of earthworm in facility agriculture in Korla Region Xinjiang *Agricultural Sciences* **51** 257-263
[12] Wang Z Y, Ayman A, Zhang X M, et al 2018 Earthworm population outbreak and effect of soil compaction on earthworm behavior Resource *Development & Market* **34** 1271-1275
[13] Wang F H 2012 Biological invasions: a guide to invasive alien plants in China Science Press
[14] Wu M L 2012 Global climate change and biological invasion *Bulletin of biology* **47** 4-6
[15] Li G D, Zhang J H, Chen C, et al 2013 Research progress on carbon storage and flux in the different terrestrial ecosystems in China under global climate change *Journal of ecological environment* **22** 873-878
[16] Zhang Q, Yang X W, Huang C Y 1995 Impact of climatic variation in maize productive capacity in the loess plateau area in recent 30 years *Agrometeorology in China* 19-23
[17] Ge Y N, Liu L, Xv X L, et al 2015 Temporal and spatial variations of Chinese maize production potential on the background of climate change during *Journal of natural resources* **30** 784-795
[18] Wang X Y, Yang X G, Song S, Xie W J 2015 Comparison of potential yield and resource utilization efficiency of main food crops in three provinces of Northeast China under climate change *Journal of Applied Ecology* **26** 3091-3102
[19] Zhang X F, Wang H Z, Liu L, et al 2014 Spatial-temporal characteristics of soybean production potential change under the background of climate change over the past 50 years in China Progress in Geographical *Science* **33** 1414-1423
[20] Fu Y Q, Chou J M, Dong W J 2014 Impacts of Climate Change on Crop Sown Area in China *Progress in Geographical Science* **10** 110-117
[21] Yv D 2012 Biogeographic analysis, morphological differentiation, and response to climate change of Phoxinus tench lineage *Graduate School of Chinese Academy of Sciences*
[22] Su Z H, Pan B R, Zhuo L, et al 2018 Impact of future climate change on the distribution pattern of Tamarix taklamakanensis and its conservation revelation *Arid Zone Research* **35** 150-155
[23] Ye D Z 1979 Meteorology of the Qinghai-Tibet Plateau *Science Press* 1-278
[24] Duan A M, Wu G X 2005 Role of the Tibetan Plateau thermal forcing in the summer climate patterns over subtropical *Asia Climate Dynamics* **24** 793-807
[25] Pan BT, Li J J 1996 Qinghai-Tibetan Plateau: a driver and amplifier of the global climatic change-Ⅲ. the effects of the uplift of Qinghai-Tibetan Plateau on climatic changes *Journal of Lanzhou University* 108-115
[26] Wu X D, Lin Z Y 1981 Some characteristics of the climatic changes during the historical time of Qinghai-Xizang plateau *Acta Meteorologica Sinica* 90-97
[27] Yao T D, Xie Z C, Wu X L, Thompson L G 1991 Climatic change since little ice age recorded by Dunde ice cap *Science China Chemistry* **34** 760-767
[28] Zhao X Y 2014 Review on farmer's climate change perception and adaptation Acta *Meteorologica Sinica* **25** 2440-2448
[29] IPCC 2013 the physical science basis Cambridge: Cambridge Press
[30] Wu G X 2016 Characteristics of climate change over the Tibetan Plateau under the global warming during 1979-2014 *Research progress of climate change* **12** 374-381
[31] Yang C Y, Shen W S, Lin N F 2014 Climate change and its regional differences over the Tibet Plateau *Geography of arid area* **37** 290-298
[32] Phillips H R P, Guerra C A, Bartz M L C, et al 2019 Global distribution of earthworm diversity *Science* **366 (6464)** 480-485
[33] Singh J, Schädler M, Demetrio W, et al 2019 Climate change effects on earthworms-a review *Soil organisms* **91(3)** 114
[34] Sun D X, Zhong D L, Ji J Q, Tu J Y 2015 Inversion model of drainage basins' tectonic-thermal

evolution through detrital AFT ages: A case study of Chayu River in southeastern Tibet *Acta geophysica Sinica* **58** 613-627
[35] Wu P J 2006 Status and conservation of large and medium-sized mammals in the upper Zayu river basin *Journal of natural resources* 584-589
[36] Li D H 2014 Brief analysis of climate change in Chayu County in recent 32 years Tibet *Science and Technology* 44-46
[37] Guo Y, Xv L X 2004 The distributions and damages of invasive species in China *Land and natural resources* 82-83
[38] Xu H G, Ding H, Li M Y, Qiang S, Guo J Y, Han Z M, Huang Z G, Sun H Y, He S P, Wu H R, Wan F H 2006 The distribution and economic losses of alien species invasion to China *Biological Invasions* **8** 1495-1500
[39] Tu Y L, Liu L S, Liu Z Q, et al 2018 Invasion status and Countermeasures of malignant invasive plant Eupatorium adenophorum in Tibet Tibet *Science and Technology* 71-75
[40] Fourcade Y, Vercauteren M 2022 Predicted changes in the functional structure of earthworm assemblages in France driven by climate change *Diversity and Distributions* **28 (5)** 1050-1066
[41] Marcos A, Trigo D, Muñiz-González A B, et al 2021 Effects of bisphenol S on the life cycle of earthworms and its assessment in the context of climate change *Science of The Total Environment* **781** 146689
[42] Kullman L 1998 Tree-limits and montane forests in the Swedish Scandes: sensitive biomonitors of climate change and variability *Ambio* **27** 312-321
[43] Kiritani K 2011 Impacts of global warming on Nezara viridula and its native congeneric species *Journal of Asia-Pacific Entomology* **14** 221-226
[44] Li L, Chen X G, Wang Z Y, Xu W X, Tang H Y 2010 Climate change and its regional differences over the Tibetan Plateau *Research progress of climate change* **6** 181-186
[45] Chen B X, Wang J S, Ran C Q, et al 2012 Characteristics of climate change in forestry region in southeast Tibet during 1954-2009 *Research progress of climate change* **8** 43-47
[46] Bohlen P J, Scheu S, Hale C M, et al 2004 Non-Native Invasive Earthworms as Agents of Change in Northern Temperate Forests *Frontiers in Ecology and the Environment* **2** 427–435
[47] Eisenhauer N, Stefanski A, Fisichelli N A, et al 2014 Warming shifts 'worming': effects of experimental warming on invasive earthworms in northern North America *Scientific Reports* **4** 6890
[48] Zaller J G, Caldwell M M, Flint S D, et al 2009 Solar UVB and warming affect decomposition and earthworms in a fen ecosystem in Tierra del Fuego, Argentina Global Change *Biology* **15** 2493–2502
[49] Briones M J I, Ostle N J, Mcnamara N, et al 2009 Functional shifts of grassland soil communities in response to soil warming Soil *Biology and Biochemistry* **41** 315–322
[50] Davis M A, Grime J P, Thompson K 2000 Fluctuating resources in plant communities: a general theory of invisibility *Journal of Ecology* **88** 528-534
[51] Daehler C C 1998 The taxonomic distribution of invasive angiosperm plants: Ecological insights and comparison to agricultural weeds *Biological Conservation* **84** 167-180
[52] Yao B, Sun J, Jiang J B, et al 2018 The Distribution of amynthas earthworm in china and its response to hydrothermal conditions *Journal of Zoology* **53** 554-571
[53] Cao S P, Tan C, Wang H, et al 2018 Distribution of terrestrial earthworms and its influencing factors in the Nanniwan wetland Resources and environment in Arid *Areas* **32** 80-84
[54] Wang S J, Wang H, Li J H 2017 Effects of different land-use types on the spatial-temporal distribution of earthworm density and biomass *Journal of Biology* **36** 118-123
[55] Wang S J, Wang H, Li J H 2017 Spatiotemporal distribution characteristics of soil earthworm number and biomass under different forest communities *Journal of Nanjing Forestry University*（*Natural Science Edition*）**41** 37-42
[56] Gu Z, Chen S R, Zhou B 2018 Spatiotemporal variation of vegetation coverage over the Tibetan

Plateau and its responses to climatic factors *Journal of Ecology* **38** 3208-3218
[57] Zhao J F, Guo J P, Fang S P, et al 2011 Trends of Tibet's Dry-Wet Condition under Future Climate *Scenario Agrometeorology in China* **32** 61-66
[58] Chen D L, Xv B Q, Yao T D, et al 2015 Assessment of past, present and future environmental changes on the Tibetan Plateau *Science Bulletin* **60** 3025-3035+1-2