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Original Article

Applied research progress of the ecological niche in vector-borne disease

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Abstract: In recent years, zoonotic infectious diseases, such as Middle East Respiratory Syndrome (MERS), Ebola, highly pathogenic avian influenza, bovine spongiform encephalopathy (BSE), Severe Acute Respiratory Syndromes (SARS), West Nile fever et al. become an increasing threat to human beings through a variety of transmission routes. It has been currently reported that at least more than 200 kinds of animal infectious diseases and parasitic diseases can be transmitted to humans, which are known as zoonotic infectious diseases. Ecological niche study was conducted to determine the effect of different environmental risk factors on the transmission of vector borne infectious diseases.The literature search was made of articles published up until July 2015 in PubMed. Inclusion criteria contained ecological studies for vector-borne and zoonotic diseases that used ecological niche models. Abstracts and full texts were read and evaluated by two independent readers.We investigate the evidence of 37 studies from a total of 187 selected in PubMed. Initially, 187 abstracts were found in the PubMed, among which 154 full-text articles were retrieved. After screening abstracts and titles, 83 citations were rejected because they were not for vector-borne and zoonotic diseases. 71 abstracts fulfilled the predefined criteria and were included as full texts. Finally, 37 of these fulfilled the inclusion criteria, while the other 34 were excluded because they did not use the ecological niche model. Results derived from ecological studies provide a better understanding of the inner relationship among the pathogen, host, external environment and the influence of different environmental factors on the transmission of infectious diseases. More studies of high quality are needed to investigate ecological factors for vector-borne and zoonotic diseases.

Keywords: Ecological niche, vector-borne, zoonotic disease

Introduction

Recently, MERS, Ebola, high pathogenic avian influenza, BSE, SARS, West Nile fever and other zoonotic infectious diseases frequently attack humans via various transmission routes. So far it has been known that at least 200 animals infectious diseases and parasitic diseases can be transmitted to humans. Spreading and prevalence of these diseases are subject to the influence of environmental factors. Especially, in the context of the global warming, the alternation of the disease vectors, the host range and habitat, resulted in the change of prevalence and trends of some infectious diseases, and drove pathogens spreading to new areas. Therefore, we sought to explore the relationship between the occurrence and development of the diseases and the local natural environment, along with the changes of diseases and human activities by means of the ecological niche. This review has been developed to gain the research progress of the ecological niche in vector-borne diseases.

Materials and methods

We searched PubMed using combination terms, including ecological niche and infectious disease, with the last update in July 2015. Inclusion criteria contained ecological studies for vector-borne and zoonotic diseases using ecological niche model. The studies without full text were excluded while studies without primary data, commentaries, or letters to the editor were also ruled out. There was no limitation of the publication date for the search. We included paper only written in English.

Abstracts and full texts were evaluated by two independent readers based on the criteria

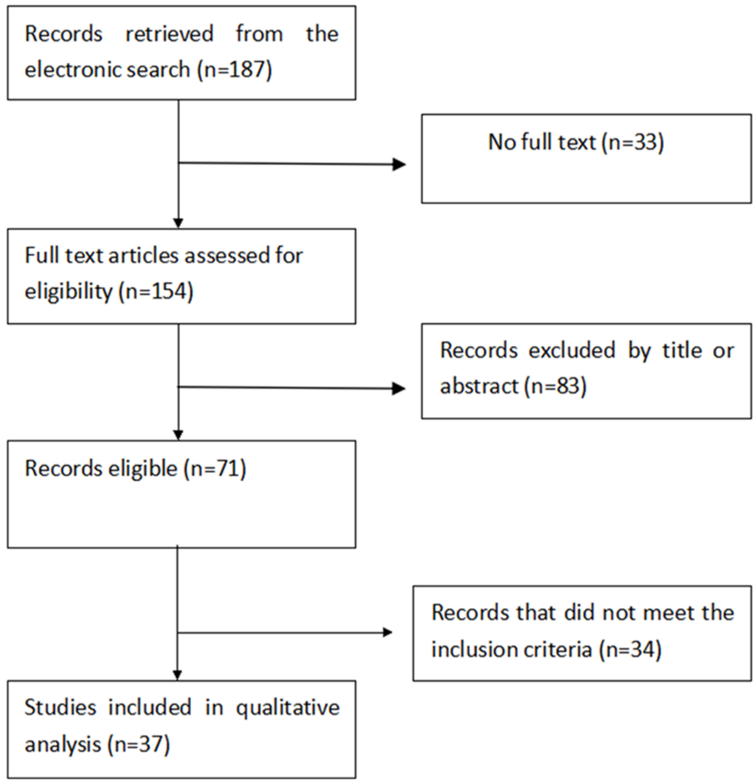

Figure 1. Flow diagram of study selection process.

described above. Consensus was obtained by discussion in case of opposing decisions.

For each included study, the readers filled in a data collection sheet, with the information about diseases, study place, objectives, methods, and results to assess the level of quality of the studies, including risk factors and areas potential for spreading diseases.

Results

Initially, 187 abstracts were found in the PubMed. 154 full-text articles were retrieved. After screening abstracts and titles, 83 citations were rejected because they were not for vector-borne and zoonotic diseases. 71 abstracts fulfilled the predefined criteria and were collected as full texts. Finally, 37 of these fulfilled the inclusion criteria, while the other 34 were excluded because they were not involved with the ecological niche model (**Figure 1**).

Study characteristics

These 37 articles employed the ecological niche model to investigate the environmental ecology, weather factor, social environment, to illustrate the relation between pathogen/host and external environment, as well as to study the time and space distribution patterns of distinct infectious diseases and the impact of diverse environmental factors on the transmission of infectious diseases. The spread of pathogens and the possibility of epidemic could be predicted on the basis of transmission rules.

The studies of these 37 papers were located in Africa [16], American [11], and other regions, including South East Asia, Western Europe, etc. [10]. The vector borne diseases in the research included highly pathogenic avian influenza, leishmaniasis, brucellosis, malaria, dengue fever, leptospirosis body disease, monkeypox, hemorrhagic fever with renal syndrome, Buruli ulcer, West Nile fever, Lyme disease, filariasis, cone worm disease, Rift Valley fever, Nipah disease, Toxoplasma and Trichinella spiralis infection diseases. There are 15 articles focusing the study of the host's adaptive environment, which are mainly related to the density of the biotic population, land cover, etc.. While another 17 papers mainly studied ecological changes caused by meteorological factors, which are mainly related to the temperature and precipitation. 5 papers emphasized the investigation on social environment factors, while 2 articles were written on both the adaption of host to the environment and social factors (**Table 1**).

The adaption of host to environmental ecology

Vegetation zones vary widely on the earth, which are associated with relevant climate zones. There are also specific biotic populations that adapt to the vegetation zones. If the population gets denser, the number of pathogen will increase; or the natural enemies are artificially reduced, the possibility of infectious

Table 1. Characteristics of included studies

Research focus	Environmental impact factors	Vectors involved	Diseases involved
Host adaptation to environmental ecology	Normalized differential vegetation index (NDVI)	Domestic animal	High pathogenic avian influenza H5N1, H7N9
		Bat	Rabies
	Land cover	Sand fly	Sand fly fever, leishmaniasis
		Tsetse fly	Trypanosomiasis disease
	Terrain	Flying fox	Nipah virus disease
		Fruit bat	Buruli ulcer
	Altitude	Hemiptera insect	Brucellosis
		Egypt Culex and Aedes	Rift Valley Fever
		Ticks	Lyme disease
Climate ecology	Temperature	Sand fly	Leishmaniasis
		Domestic animal	A/H1N1 influenza
		Bank vole	Hemorrhagic fever with renal syndrome
		Ticks	Lyme disease
	Precipitation	Angiostrongylus cantonensis	Diseases of Angiostrongylus cantonensis
		White-footed mice	Leptospirosis
	Wind speed	Sand fly	Leishmania infantum
		Blood sucking insects	Lymphatic filariasis
		Monkey	African monkeypox
Social ecology	Larger population density and mobility	Fruit bat	Nipah virus disease
		Mosquitos	Malari, West Nile fever
	The expansion of agricultural and animal husbandry zones	Tsetse fly	Trypanosomiasis disease
	The rise of irrigated farmland and rural population	Toxoplasma and trichinosis	Toxoplasma and trichinosis
	Housing materials and the way of drinking water		Chagas' disease

diseases outbreak will be reinforced. Therefore, vector-borne diseases correlate with the ecological environment that biotic populations inhabit. For instance, the plague niche might be driven by the ecological requirements of fleas [1].

Studies via the ecological niche on characteristics of ecological environment in different areas where highly pathogenic avian influenza (HPAI) H5N1 and H7N9 occurred demonstrated that less cases of H5N1 in Nigeria were reported under the circumstances of low normalized differential vegetation index (NDVI) and small seasonal change, while cases presented an acute increase as NDVI rose with dramatic seasonal change [2, 3]. NDVI also unraveled the Mideast of China as high-risk zone for HPAI H7N9. This index has a considerable effect on the distribution of two types of bats (Tadarida brasiliensis and Lasiurus cinereus) in the United States, which carry rabies virus [4].

Michelle et al. established the ecological niche of two genuses of sand flies in Afghanistan, Armenia, Egypt, Iran and other 24 Middle East countries, and they found the land cover was the most pronounced factor that affected Pappataci fever and leishmaniasis, and directly determined the distribution and density of the sand flies [5]. The tsetse flies, whose living environment was in relation to the temperature and precipitation, exhibited a higher population density in Brazil, Zambia and Zambezi River basin, indicating a high risk of trypanosomiasis in those areas [6, 7].

In Thailand, the flying foxes carrying Nipah virus mainly locate in central plains region, such as Buddhist temples or areas close to water and vegetation, and pig farms in Bangkok became the high-risk zones [8]. Evidence also revealed Bangladesh as the favorable area for Nipah virus spreading, on the grounds that flying foxes prefer the habitats near the areas with low annual precipitation and high population density [9].

The distribution of Mycobacterium ulcerans in Cameroon showed an obvious seasonal variation and had an intense relationship with land cover and ecological environment of terrain. The prevalence of the disease also related to the abundance of Hemiptera [10, 11]. The ecological environment in Middle East of Inner Mongolia and Northeast China may facilitate the occurrence of brucellosis epidemic in humans [12].

The central and northwest of Tanzania, West Lake Victoria, Lake Victoria, northern Malawi, Kenya rift area exert as potential suitable habitats for West Africa Egypt Culex and Aedes, which have the possibility of the potential outbreak of Rift Valley fever [13]. Higher population density of ticks concentrated in Vancouver coastal, Colombia's southwest coast and valleys below 51 degrees north latitude, along with high risk of Lyme disease infection [14].

Meteorological ecology

The changes of temperature, air humidity, airflow, air pressure and solar radiation determine the lifetime and spreading of pathogenic microorganisms relying on air transmission and thereby affect the occurrence of the diseases. In addition, climatic and geographical factors directly impact the growth of vector insects. The occurrence of the diseases has obvious seasonal, the trends of which are consistent with the period of insect activities.

First, temperature and precipitation play an essential role in the incidence of many vector-borne infectious diseases, such as cutaneous leishmaniasis [15, 16], malaria [17], H1N1 flu [18], leptospirosis [19], hemorrhagic fever with renal syndrome [20], monkeypox [21, 22], Buruli ulcer [23], West Nile fever [24].

The active periods of sand flies in Iran Qom Province sand flies are May and August, which mostly depend on the monthly mean temperature. Therefore, high potential risk of leishmaniasis transmission may exist in lowlands of this province. The bridge area of the basin in India is associated with high risk of malaria, owing to precipitation and temperature. Factors of precipitation, wind speed that are related to H1N1 flu epidemic in Vellore area showed negative correlation with factors of temperature, humidity.

The local temperature exhibited more relevance with leptospirosis in Mexico than precipitation did. 55.7% areas in Mexico possess the right environmental conditions for the pathogen and are primed higher risk of infection. The spread of monkeypox in Africa is related to mean precipitation and low altitudes and high-risk areas are mainly in the central and western regions, especially in the south of the Sahara, Sahel. The activities of bank voles in Western European are significantly influenced by the local climate, including temperature, precipitation, etc.. Inhabitants in agricultural area, ranging over pastures, forests and semi deep forest, face severer dangers of hemorrhagic fever with renal syndrome by being infected with Puumala virus that bank voles carry. The long-term rainfall indicates the possibility of prompt outbreak of Buruli ulcer in French Guiana.

Secondly, due to climate change, the habitats of the vectors will also be changed. It has been anticipated that, from the year 2040 to 2060, the potential habitat of Ixodes ricinus in Europe may expand 3.8%. The habitats will be extended to high altitude and latitude areas (e.g. Scandinavia, the Baltic Sea, Belarus, etc.), while in other areas (such as the Alps, Pyrenees, mainland Italy, Poland northwest) the scope will relatively reduce [25]. The potential proper habitats of Angiostrongylus cantonensis, originated from southeastern Asia, locate in tropical and subtropical regions. However, as the climate changes, the habitats are deviating from the equator at a speed of 68-152 km/10 years. Highly suitable habitat (> 50%) may shrink 13.11-16.11% till around 2070 [26]. Lyme disease in Quebec Canada correlates with the large amount of white-footed mice, which incline to live in mild and short winter. With the global climate change, the range will further expand northward [27]. Climate change also increase the risk of infection of leishmaniasis in the United States, with the high-risk area extending to the north [28]. Study on infantile leishmaniasis in Columbia predicted that the parasite species and abundance were subject to the impact of climate; thereby incidence of human cases would reduce [29]. The transmission of lymphatic filariasis in Africa is expected to extend from west to east in the future (2050), and spread from West Africa to the Middle East and the island of Madagascar [30].

Social ecology

As the population increases, agricultural and pastoral areas have been expanded, and directly encroached the traditional habitat of the pathogen. Due to the contact, animals and plants become the new hosts of the pathogen, which then infect humans. Earlier studies showed that over the past 20 years, a sharp reduction of Southeast Asian forests on account of deforestation and drought gave rise to a change of the habitat of fruit bats, from the forest to the orchard. As the natural host, and fruit bats carry the Nipah virus to pigs, and then humans and domestic animals are infected [31].

The expansion of areas for agriculture and animal husbandry reduce the size of the environment suitable for tsetse fly, in a long period of time, however, trypanosomiasis remains a public health threat in Zambia area [6]. As the activity of Trypanosoma cruzi parasite has been increasing in urban areas, especially along the Pacific coast, there is a great diversity of species concentrated in the Neotropic, so that 88% of the areas of Mexico are facing up with the possibility of Chagas disease infection [32]. The housing materials and the way of drinking water in Bolivia have close relation to the Chagas disease, and the local embryo walls as well as drinking directly from rivers or wells boost the risk of Chagas disease infection [33].

As one of the domestic animals, pig is the main host of Trichinella spiralis and Toxoplasma gondii. At present the Midwest and Southern US are intensive areas for Toxoplasma and Trichinella spiralis infection, therefore close monitoring for two parasites in these regions should be conducted [34]. The increase of the occurrence of West Nile fever in North American plains follows the rise of irrigated farmland and rural population [35]. Population density and population mobility pose a severe risk of malaria in Africa [17, 36]. The distribution of malaria in Cameroon is influenced by the human activities, indicating that both human and vector share the same adapt ecological conditions [37].

Conclusions

Early studies concerning ecology mainly focused on animal and plant, which were widely used in the spatial distribution patterns of species, the influence of global change on species distribution or diversity, and early warning for exotic species invasion. Further understanding of the diseases gradually facilitates the application of ecological niche models in infectious diseases research. Imperative measures were taken to destroy the fertility of microbial pathogens, insect vectors and parasites, based on the results of the distribution of medical vectors and the spread of the diseases. Nonetheless, as an emerging field, the application of ecological niche models in infectious diseases remains to be further investigated with substantial problems to be solved.

Firstly, in the GIS geographical distribution map, the importance of fine mapping should not to be ignored, and especially in developing countries, the accuracy of the ecological niche may arise the question due to the inaccurate map and geographical information. Second, the storage of archive data on primary disease, the collection and accumulation of raw data will affect the accuracy of the results. Eventually, in the study of the disease ecology, it remains to be determined whether the option of potential medical vectors distribution conforms to the existing ecological niche model and difficulties still exist in the choice of disease ecology-related variables, though the accuracy of ecological niche model has been proved in a multitude of experiments.

However, with the improvement of ecological niche theory and the modeling method of disease ecology, the discovery and explanation of the occurrence and development of infectious diseases become more reasonable, which offers support for the predict of the spread of pathogens and the possibility of epidemic.

Disclosure of conflict of interest

None.

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