Impacts of Deforestation on Vector-borne Disease Incidence

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Impacts of Deforestation on Vector-borne Disease Incidence

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Abstract

Forest clearance alters ecosystem dynamics and leads to new breeding habitats for disease vectors, such as mosquitoes, fleas and ticks, by reshaping existing ecosystem boundaries. Such boundaries are often sites of contact between humans and forest pathogens. There is a well-documented, positive association between the increased deforestation of an area and the emergence of zoonotic, vector-borne diseases. Populations living within or near these fragmented forests are at a much higher risk of infection due to increased contact with vectors at forest edges and the reduced biodiversity of the area. This paper explores studies that have demonstrated that human-vector contact in newly created forest edges has led to increased risk of malaria in Peru, American Cutaneous Leishmaniasis (ACL) in Costa Rica and hantavirus in Panama. It is important to identify at-risk populations and develop strategies to minimize their exposure in order to prevent wider spread of these diseases and help implement targeted control strategies.

Introduction

Developing countries continue to clear forests for agriculture to meet the demands of their growing populations. Populations living within or near these fragmented forests are at a much higher risk of contracting zoonotic infectious diseases because of increased contact with vectors at forest edges and the reduced biodiversity of the area.[1,2] These diseases represent a significant threat to humans living in affected areas. In the interest of public health, it is important to identify the land alterations that are putting these people at risk in order to better mitigate their effects and ultimately reduce the disease burden. In this paper, I address the association between the conversion of forested areas to agricultural land and the emergence of zoonotic, vector-borne diseases. To illustrate the effects of forest clearance on the incidence and prevalence of infectious diseases, I will discuss the examples of malaria in Peru, American Cutaneous Leishmaniasis (ACL) in Costa Rica and hantavirus in Panama. I will then focus on what can be done in the future to prevent wider spread of these diseases and implement targeted control strategies. These countries and diseases were chosen because of the availability of existing case studies from each, which examine the relationship between deforestation and disease incidence, that will be used here to examine this important and often overlooked issue.

Deforestation, an ongoing problem in the developing world, creates ideal conditions for vectors to breed and spread infectious diseases.[1] The Food and Agriculture Organization of the United Nations (FAO) published a report stating that between 1990 and 2010, Latin America lost 88 million hectares to deforestation and that the leading cause of this deforestation was the conversion of forests to farmland and pasture.[3] Often, developing countries, such as those in Latin America, are the ones that carry the heaviest burden of infectious diseases and lack the resources to cope adequately with the problems they present. It is difficult to determine how the conversion of land will affect the rate of infectious disease spread in a particular area, mainly because of the variable vulnerability of exposed populations and the complicated relationships between disease transmission, habitat modification and ecosystem function.[4] By gaining more insight into how deforestation and other land-use changes are putting vulnerable populations at risk for infection, we can better tailor intervention strategies to suit particular regions.[5]

> **Deforestation, an ongoing problem in the developing world, creates ideal conditions for vectors to breed and spread infectious diseases**

While the increase in infectious disease is not the only threat posed by deforestation, it has arguably the most direct, measurable impact on health.[2] Infectious disease emergence in areas affected by deforestation acts as an important diagnostic measure of the health of these human populations. Malaria, ACL and hantavirus illustrate the complex relationship between deforestation and infectious disease and can all behave as the "canary in the coal mine" for population health, as illustrated below. This paper aims to identify the impact of deforestation on infectious diseases and health through the creation of new vector habitats, loss of biodiversity and increased contact between humans and disease reservoirs and vectors.

Malaria

Malaria is an often-fatal disease found primarily in tropical areas of the world. It is caused by Plasmodium protozoans and spread by anopheline mosquitoes. Malaria represents a significant disease burden on developing countries, annually infecting an estimated 300-500 million people worldwide and killing approximately 1.5-2.7 million.[6] Sixty-five out of every 1,000 people in the world are at risk of contracting malaria, the majority of whom are concentrated in developing countries.[7]

Malaria has been historically prevalent in the northeastern region of Peru, but incidence rates were dramatically reduced in the late 1960s due to mosquito eradication programs. In the 1990s, corresponding to a jump in population growth that led to land clearing for subsistence-scale agriculture, malaria prevalence increased from 641 cases in 1992 to more than 120,000 cases in 1997.[8] The epidemiology of malaria in the Peruvian Amazon is being altered because of changes in the abundance of the Anopheles mosquito vectors.[9] The anopheline mosquitoes breed in standing water, where eggs and larvae can hatch and grow undisturbed. Deforestation and land alteration facilitate environmental and climatic conditions that impact the ecology of mosquito habitats and create new places for water to accumulate. Mosquitoes then have a much wider variety of areas in which to breed, creating a larger vector population to spread the Plasmodium parasite.[9]

Anopheles darlingi, the most common malaria vector in eastern Peru, is most often found in areas with shade and submersed vegetation.[11,12] Changes in the forest cover, hydrology and vegetation of areas that have been cleared of their natural forests have increased the number of such ideal breeding sites for A. darlingi.[9] The human activities, such as farming, in these cleared areas tend to create artificial bodies of water on the ground or in objects that can collect water, which have also contributed to the increase in available mosquito breeding sites, consequently increasing the distribution of A. darlingi.[9,13]

The Northern Amazonian region of Peru has been particularly affected by deforestation due to its rapid population growth and urban expansion. This deforestation is thought to have led to increased rates of malaria. To test this hypothesis, researchers at the University of Pennsylvania conducted a study in the northern part of the Peruvian Amazon to determine the location of A. darlingi breeding sites and whether this correlated with deforestation. A. darlingi larvae were most often found in modified landscapes with little to no forest vegetation remaining, such as shrub, village or farm sites; they were least frequently found in forested areas. Larvae were found in irrigation canals, pastures, rice fields and flooded cane fields.[9] These data indicate that A. darlingi tend to flourish in conditions created by the typical human settlement patterns of non-nomadic farmers in Peru's Amazon basin. These non-nomadic populations often settle in an area and subsequently clear all of the surrounding forest around the village for farming. When this land becomes infertile from overuse, it is then abandoned and the farmers clear the adjoining forested lands to begin the process anew.[14] It has been shown that there are 278 times more A. darlingi bites in these deforested areas than in predominantly forested areas.[8] Eighty-three percent of the breeding sites identified as containing A. darlingi larvae were within 500 meters of human settlements,[8] which is likely due in part to the availability of humans for adult mosquitoes to feed on and the human alteration of the surrounding landscape. These land alteration practices create favorable conditions for A. darlingi larval breeding and lead to an increased incidence of malaria in these populations that are now in higher contact with the vector mosquitoes in fragmented habitats.

However, increased malaria incidence due to deforestation is not limited to just the Amazon basin. Malaria has spread to new areas across the globe, such as Sri Lanka and Madagascar. Furthermore, even in countries where it was already endemic, such as Uganda and Burundi,[15,18] malaria incidence has increased significantly in recent years. The higher level of contact between humans and malaria vectors increased the size and spread of the vector population.[13]

As the rate of deforestation throughout the world is expected to continue to rise in the foreseeable future, its effects on vector-borne infectious diseases are also projected to increase,[19] and both the scope and spread of malaria will continue to grow if nothing is done.

American Cutaneous Leishmaniasis

According to the World Health Organization (WHO), "Neglected tropical diseases affect more than 1 billion people, primarily poor populations living in tropical and subtropical climates. These populations are frequently geographically clustered and individuals are often afflicted with more than one parasite or infection. More than 70% of countries and territories that report the presence of neglected tropical diseases are low-income or lower middle-income economies."[20]

American Cutaneous Leishmaniasis (ACL) is classified as a neglected tropical disease by the WHO and represents one of the foremost emerging and re-emerging vector-borne diseases in the Americas.[21] The disease, caused by species of the Leishmania parasite, is transmitted by sand flies that have previously fed on an infected animal reservoir, usually a rodent.[22] Once infected, a patient will develop one or multiple lesions or ulcers on the skin that can take over a year to heal. Secondary bacterial infections occur in nearly one-fifth of patients and may lead to serious pain and disability.[23,24] About 10% of patients who are treated for ACL experience relapses of the disease that can be even more severe than the initial infection.[25] According to the WHO, there are an estimated 1.5 million new cases each year and an estimated 12 million people infected worldwide,[16] placing a significant and increasing burden on all populations in endemic areas.

> There has been a documented association between deforestation in tropical and subtropical regions and the re-emergence of leishmaniasis

As with the case of malaria, there has been a documented association between deforestation in tropical and subtropical regions and the re-emergence of leishmaniasis.[26] It has been found that ACL infection rates are highest in populations that live close to forest edges and/or work in the forests to harvest natural resources.[27,28] Leishmaniasis, especially ACL, is becoming more of a burden in areas of Central and South America as widespread urbanization and changing agricultural practices increase the rates of deforestation.[29] During the 1960s and 1970s, Costa Rica had the fastest rate of land-use alteration and population growth in the Americas and thus provides an important case study on the effects of deforestation.[30] The prevalence of ACL infection in rural Costa Rica has been linked directly to contact with forests near agricultural land.[22]

Deforestation in Costa Rica is especially associated with rapid human population growth and the expansion of large-scale commercial agriculture. Such expansion often leads to the singular cultivation of a number of commercial crops in which ACL reservoirs tend to be concentrated.[31,32] These population and agricultural shifts bring imbalances in land ownership, raise the numbers of displaced and landless farmers and increase pressure to clear land for the harvesting of natural resources and local subsistence farming.[30,33] The resulting land-use change and deforestation lead to a higher level of contact between socially marginalized populations and ACL vectors and sylvatic reservoirs.[28]

In addition, human populations that live within or near fragmented forests mixed with crops are at a much higher risk of ACL infection due to the reduced overall biodiversity of the local environment.[34] It has been well-documented in environmental studies that in fragmented, isolated and disturbed landscapes, habitat destruction and related biodiversity loss lead to the loss of keystone species and eventually result in niche changes that significantly reduce landscape biodiversity in a positive feedback loop.[34] These keystone species, such as large mammals and predators, play a critical role in the structure of an ecosystem. Since the main reservoirs of the Leishmania species that transmit ACL are small mammals, such as rodents and sloths, deforestation and the resulting loss of biodiversity have a significant impact on the incidence of the disease.[27] Forest fragmentation significantly alters the inter-species relationships within the ecosystem and leads to a decrease in mammal biodiversity. First, large predators disappear resulting in rodent population increases.[35] While only a relatively small number of mammals exposed to sand fly vectors are actually infected with Leishmania and act as reservoirs, deforestation increases their populations and changes disease transmission dynamics by increasing human contact with the sand fly vectors, increasing the spread of ACL in nearby populations.[35]

The number of annual cases of ACL in Costa Rica increased from 690 in 2002 to 1,870 in 2007, in association with population growth and a changing landscape in highly endemic regions.[36] Marginalized populations, such as Nicaraguan refugees, living in areas affected by deforestation and land-use changes have suffered epidemics that affected more than 200 people.[36] Brazil has suffered similar effects from deforestation. Between 1998 and 2002, ACL incidence in Brazil increased from 21,800 cases to 40,000 cases.[29] As can be seen in both rural Costa Rican populations and Brazilian populations, deforestation and the ensuing effects on the landscape and ecosystem are putting human populations at an increased risk for ACL. There are now more reservoir animals, and the forest edges of their habitats are becoming more fragmented. Not only are the reservoir species now more likely to leave the forest occasionally, but the humans who have cleared the land for farming are also now living much closer to the forest edges. Altogether, humans and ACL reservoirs are coming in contact with each other much more frequently now than before and therefore disease transmission has increased.

Hantavirus

Hantaviruses are transmitted by a large number of rodent species in the Cricetidae family, found in Asia, Europe and the Americas. Transmission to humans occurs through direct contact with the rodent, such as through a bite or inhalation of the aerosolized virus in rodent urine, feces and saliva.[37] The strains of hantavirus present in the Americas cause hantavirus pulmonary syndrome, which can have a mortality rate as high as 38%.[38] While the disease is not very common in the United States, it is a significant burden in countries in Central and South America. Hantavirus prevalence has been increasing throughout South America, especially in Argentina, Brazil and Paraguay, where rodent host populations have flourished following deforestation.[39] The prevalence of the disease has also increased in Panama, where intermittent cases of hantavirus pulmonary syndrome occur every year. Rodent species represent the main reservoirs of hantaviruses in Panama, so researchers from the University of New Mexico conducted a study to determine the effect of deforestation on those reservoir species populations. The researchers compared communities of small mammals from habitats such as national parks, pastures, forests and forest edges, each with varying levels of land change and fragmentation.[40]

Ecological communities such as those studied in Panama are comprised of generalist and specialist species. Generalist species tend to be highly adaptable to a wide range of habitats and environments, whereas specialist species are highly adapted to thrive in a very narrowly defined environment. Not surprisingly, specialist species are more vulnerable to habitat change and destruction.[40] Analysis of the data from Panama exhibited discernible differences among the studied habitats in the composition and abundance of small mammals. Forest habitats tended to have higher species diversity and more specialist species, while pastures and forest edges tended to have more generalist species.[40] As generalist species are often the ones involved in transmitting zoonotic infectious diseases,[40] the fact that they are found in areas that humans are likely to have contact with means that these populations are at a higher risk of contracting hantavirus pulmonary syndrome. These data show that the increased species diversity among small mammals in forests is clearly linked to the decreased absolute abundance of hantavirus reservoir species in those areas.[40] These hantavirus reservoirs are found in greatest numbers in disturbed and forest-edge habitats and in agricultural land and pastures, known as the "seminatural matrix," the ecological niche in which more human activities tend to take place.[40,41] The highest proportion of the reservoir species was found in two national parks on the Azuero Peninsula, where the majority of the Panamanian cases of hantavirus pulmonary syndrome are reported.[40,42]

The prevalence of hantavirus has significantly increased in areas that have undergone deforestation and other ecological changes due to the decreased biodiversity of the regions and the increased contact between humans and the rodents that carry hantavirus.[29,43] Increases in the local distribution and abundance of generalists and hantavirus reservoir species in Panama can be attributed to the changes in local environments occurring due to deforestation in tropical areas, as has also been the case in other countries such as Venezuela and Costa Rica.[44,45] While not much is understood about the underlying mechanisms for the changes observed in rodent communities in disturbed habitats, the decrease in specialists and the increase in generalists have been shown to be the result of changing species interactions due to habitat loss.[46]

In fragmented habitats from the study conducted in Panama, many specialist species were either present at very low numbers or were absent completely.[40] Seroprevalence was measured to determine the level of the pathogen in the blood serum of populations from the studied habitats. It was found that the seroprevalence of hantavirus increases three-fold in these disturbed habitats over areas that still retain specialist species.[47] If the current rate of deforestation and loss of forest cover in tropical regions continues, many specialist species are likely to go extinct, and this will have serious implications not only for the function of important ecosystems, but also for human health.[48]

Recommendations

The increasing incidences of malaria in Peru, ACL in Costa Rica and hantavirus in Panama following deforestation all support the idea that populations near these fragmented forests and new forest edges are at a much higher risk of infection due to their increased contact with vectors, the increased vector and reservoir populations and the reduced biodiversity of these areas. These cases are just a few examples of a larger trend. The relationship between deforestation and infectious disease emergence has also been observed in Uganda, Sri Lanka, Madagascar, Rwanda and numerous other countries throughout the world,[15,16,18] and its impact will only continue to grow if it is not mitigated. Here, I provide recommendations for steps that should be taken to reduce this growing problem in Central and South America.

Deforestation is not easily regulated due to the political and economic climates in which it usually occurs. As we will not be able to stop this process fully in the near future, it is vitally important that surveillance methods are improved and implemented in the most affected areas in order to reduce the rate of ongoing deforestation. More data on changes in vector populations, the environment, disease incidence and human migration and behavior patterns are needed to better understand the complex dynamics of this process. This information will play an essential part in early detection of disease emergence or re-emergence and in developing predictive models that can prevent future disease epidemics, especially in the most vulnerable populations.[2,10]

There was a high level of correlation between clusters of ACL incidence and clusters of social marginalization

The loss of forests and their accompanying biodiversity is a key environmental issue in tropical regions. It is the determining factor through which social marginalization increases the rates of Leishmania transmission. Socioeconomic factors play an important role in determining which marginalized populations are ultimately at highest risk. Based on ACL incidence data for all of the cantones (subdivisions of provinces) in Costa Rica between 1996 and 2000, it was discovered that the spatial distribution of ACL could not be explained by landscape alteration alone.[22] There was a high level of correlation between clusters of ACL incidence and clusters of social marginalization, a pattern demonstrated by other studies done on small spatial scales to show the tendency of other common infectious diseases to disproportionately affect populations that have been socially marginalized.[49,50] The study of ACL in Costa Rica shows that this pattern observed in the smaller-scale studies can also be true of large, geographic scales in explaining disease incidence rates through social marginalization and will be demonstrated below.

Case studies and epidemiological research into the impacts of different land-use changes and social situations are also important, as they will give us a more complete understanding of how best to approach the disease problems associated with deforestation and land alteration in various parts of the world.[51] Further research must still be done into how this information can be used to implement targeted, community level interventions in order to minimize the effects of growing agriculture and other industries in developing countries, such as Peru and Costa Rica.

While ecological mechanisms associated with infection risk and the observed disease patterns in areas affected by land-use change have been identified, new policies must still be implemented in order to work toward better control of infectious diseases, conservation of biodiversity and promotion of human well-being.[22] These

policies can work to control the extent of deforestation by limiting the allowed amount of clear cutting each year, requiring replanting to reduce the impact of tree cover loss and implementing other disease control measures in those areas most affected by the increase in susceptibility to infectious disease. It is important that new policies work to balance conservation with agriculture and economic growth, so as not to impact negatively the very populations they are trying to protect.

One possible way to mitigate the problems of deforestation and infectious disease prevalence is to target them from many angles at once: implementing policy changes, as cited above; educating communities, especially more rural and agricultural populations, about disease prevention; and promoting interdisciplinary research involving social, environmental and biological scientists on the relationship between deforestation and increasing rates of infectious disease. Colloquia, such as the Working Group on Land Use Change and Disease Emergence, help compile resources on interrelated topics and work not only to design and promote education and research, but also to effect policy changes to protect other vulnerable populations worldwide. This particular colloquium has suggested a three-fold approach to begin to address the issue of deforestation and the emergence of zoonotic, vector-borne diseases. They propose the implementation of programs to promote research that combine the natural, health and social sciences and the training of professionals to do this research. It is also important to educate local communities about the relationship between public health and environmental degradation.[52] Communication across disciplines, such as anthropology, environmental science and biology, and assessment of the current situation are essential to create policies that will promote sustainable ecosystems and health objectives specific to each country's particular situation and the needs of its population.[16,52] The neglected natures of these infectious diseases and the heavy burden they place on developing countries make this an important area of future research and development. If steps such as the ones presented above are implemented in the most impacted countries, the negative interactions between deforestation and disease incidence may diminish.

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