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CLIMATE CHANGE AND COMMUNICABLE DISEASES

Schistosomiasis and climate change

Giulio A De Leo and colleagues consider the effect of changing climates and human activity on schistosomiasis transmission and potential solutions to contain its spread

Giulio A De Leo,¹ Anna-Sofie Stensgaard,^{2,3} Susanne H Sokolow,^{1,4} Eliézer K N'Goran,^{5,6} Andrew J Chamberlin,¹ Guo-jing Yang,^{7,8,9} Jürg Utzinger^{7,8}

¹ Hopkins Marine Station, Woods Institute for the Environment, Stanford Program for Disease Ecology, Health and the Environment, Stanford University, Pacific Grove, CA, USA

² Department of Veterinary and Animal Sciences, Faculty of Health and Medical Sciences, University of Copenhagen, Copenhagen, Denmark

³ Center for Macroecology, Evolution and Climate, GLOBE Institute, University of Copenhagen, Copenhagen, Denmark

⁴ Marine Science Institute, University of California, Santa Barbara, CA, USA

⁵ Unité de Formation et de Recherche Biosciences, Université Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire

⁶ Centre Suisse de Recherches Scientifiques en Côte d'Ivoire, Abidjan, Côte d'Ivoire

⁷ Swiss Tropical and Public Health Institute, Basel, Switzerland

⁸ University of Basel, Basel, Switzerland

⁹ Hainan Medical University, Haikou, Hainan Province, China

Correspondence to: G A De Leo
deleo@stanford.edu

Cite this as: *BMJ* 2020;371:m4324

<http://dx.doi.org/10.1136/bmj.m4324>

Published: 16 November 2020

In 2014, a group of German and French tourists with no history of travel to tropical or subtropical countries were diagnosed with urogenital schistosomiasis, a debilitating parasitic disease that affects more than 200 million people in South America, Asia, and particularly sub-Saharan Africa. The European Centre for Disease Prevention and Control eventually tracked 120 cases of *Schistosoma* infection that were acquired in summer 2013 (and seven more, between 2015 and 2016) by people swimming in the Cavu River in Corsica. This French Mediterranean island is a popular summer destination for tourists from all over Europe. Until then, Corsica had been considered outside the geographic range of schistosomiasis transmission because of the near freezing temperatures of inland waters in the winter.

Genetic analyses showed that the parasites isolated in Corsica originated in the lower basin of the Senegal River, where schistosomiasis is hyperendemic. Its temporary establishment on Corsica was thought to have been caused by human movement and subsequent contamination of the river by parasite eggs that established locally in susceptible intermediate host snails and circulated for several seasons.¹ Interruption of disease transmission during Corsica's cold winters probably contributed to the natural gradual death of the parasite, and no cases of human schistosomiasis have been reported in the island since 2017. However, a small and short outbreak in this new territory raises concerns about the potential expansion of the range of schistosomiasis as the world becomes warmer.

Schistosomiasis is a tropical and subtropical disease (fig 1) caused by infection with parasitic blood flukes of the genus *Schistosoma* (fig 2), which use freshwater snails as necessary intermediate hosts. The schistosomiasis pathology results mainly from inflammatory processes caused by parasites' eggs in the human body, which may lead to several conditions such as abdominal pain, diarrhea, chronic anemia, cognitive impairment in children, growth stunting, infertility, a higher risk of contracting HIV in women, and death from liver failure or bladder cancer in cases of intense and chronic infection. These effects, combined with poverty and a lack of access to clean water, improved sanitation and hygiene make schistosomiasis one of the world's most important, but also most neglected, human diseases. The intermediate host snails of schistosome parasites are poikilotherm—that is, their body temperature changes depending on the environment. As a result, reproduction, survival, and dispersal are strongly influenced by ambient temperature, as is parasite development inside the snail. Therefore, rising water temperatures and altered precipitation associated with climate change could considerably alter the distribution and abundance of the intermediate host snail and its schistosome parasites, resulting in a shift in disease dynamics and transmission to people. Assessing the impact of global warming and its compounded effect with change in land use are important challenges that will face global health soon.

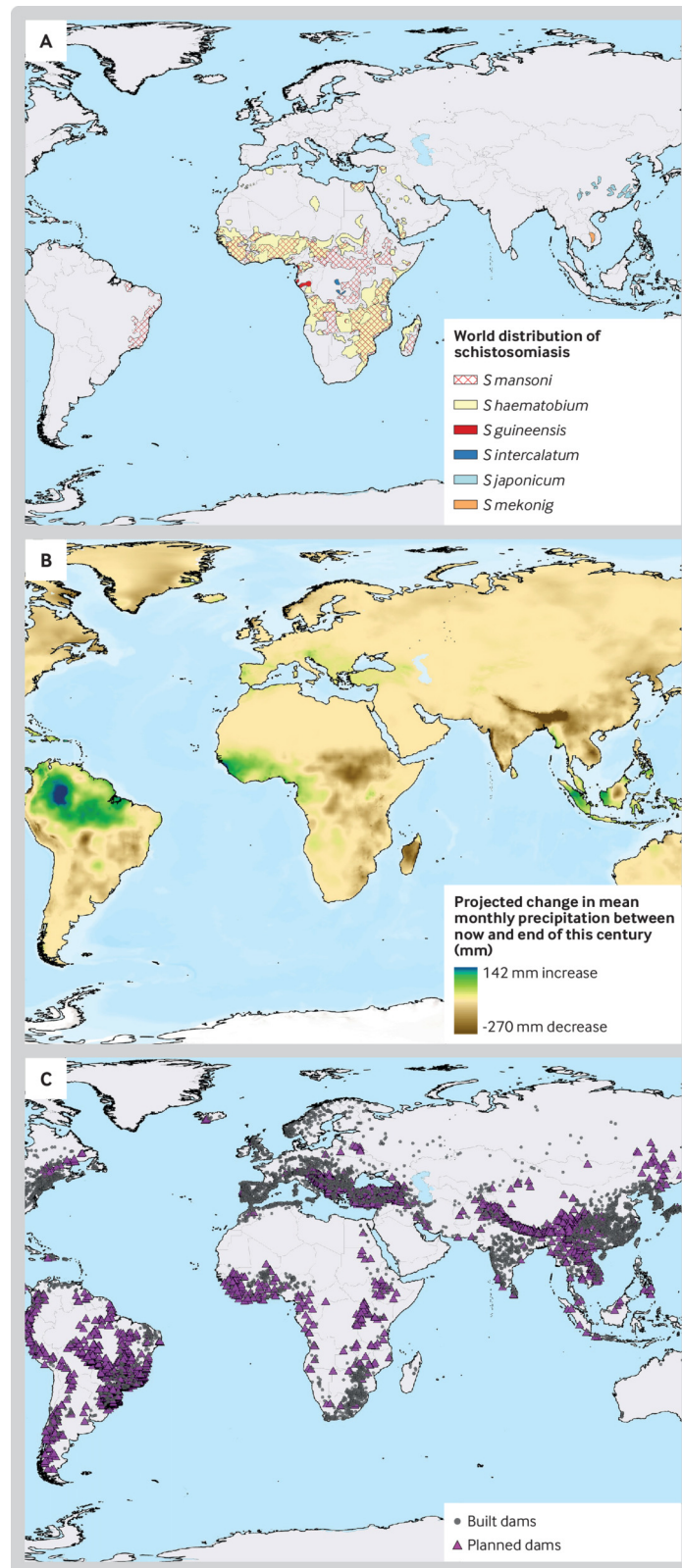


Fig 1 | a) World distribution of schistosomiasis (data from <http://www.thiswormyworld.org>); b) Projected precipitation changes to the end of the 21st century, under the high greenhouse gas emission scenario CMIP6 model BCC-CSM2-MR, ssp 585, from <https://www.worldclim.org> ("business as usual"); c) Built and planned dams, 2020-2028 (<http://globaldamwatch.org/fhred/>)

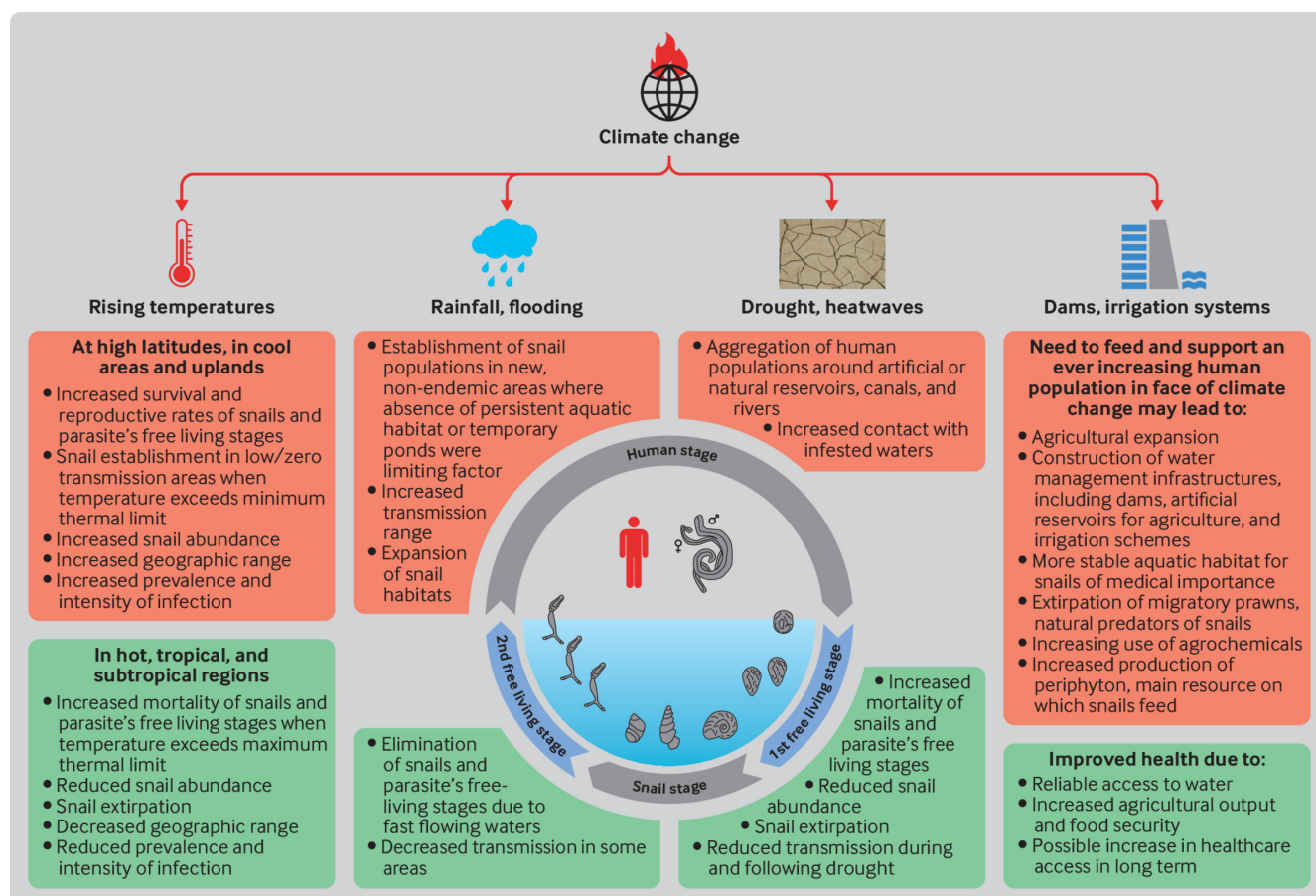


Fig 2 | Schistosomiasis life cycle (central panel) and pathways by which climate change, land use change, agricultural expansion, and development of water management infrastructure may affect disease transmission and human health. The red panels indicate an expected increase in transmission risk for schistosomiasis. The green panels indicate an expected decrease in transmission risk

Predicting the effect of global climate change on schistosomiasis is a complex task,^{2,3} because how the disease responds to climate varies with the specific ecology of many different snails and parasite species (table 1) as well as the geographic context that may respond differently to rising temperatures and changes in precipitation (fig

1). We discuss potential effects of climate change on schistosomiasis, its interactions with other determinants of disease transmission, and considerations for schistosomiasis control and elimination in a changing world.

Table 1 | Geographic distribution of schistosomiasis and associated parasite and snail species

Disease	Parasite species	Snail species	Geographic distribution
Urogenital schistosomiasis	<i>Schistosoma haematobium</i>	<i>Bulinus</i> spp	Africa, Middle East, Corsica (France)
	<i>S. mansoni</i>	<i>Biomphalaria</i> spp	Africa, Middle East, Caribbean, and Brazil, Suriname, and Venezuela
Intestinal schistosomiasis	<i>S. mekongi</i>	<i>Neotricula aperta</i>	Several districts of Cambodia and Laos
	<i>S. guineensis</i> ; <i>S. intercalatum</i>	<i>Bulinus</i> spp	Rainforest areas of Central Africa
	<i>S. japonicum</i>	<i>Oncomelania hupensis</i>	China, Indonesia, Philippines

Africa

The past decade has seen increasing attention paid to the effects of climate change on schistosomiasis in Africa, where an estimated 90% of all human cases are concentrated. Whereas some studies predict that schistosomiasis infection risk may increase by up to 20% in eastern Africa,³ others present a more complex pathogenic landscape, with decreases as well as increases in schistosomiasis transmission risk.^{2,4} For example, a continental scale study predicted

a 14% reduction in the total geographic area suitable for *Schistosoma mansoni* transmission in sub-Saharan Africa in 2061-2080 (fig 3a) as temperatures exceed the maximum thermal tolerance for the main intermediate host snail, *Biomphalaria pfeifferi*.⁵ However, the same study also showed that other known intermediate host snail species tolerate increasing temperatures better, highlighting the importance of specific snail-parasite ecologies when developing prediction models.⁵

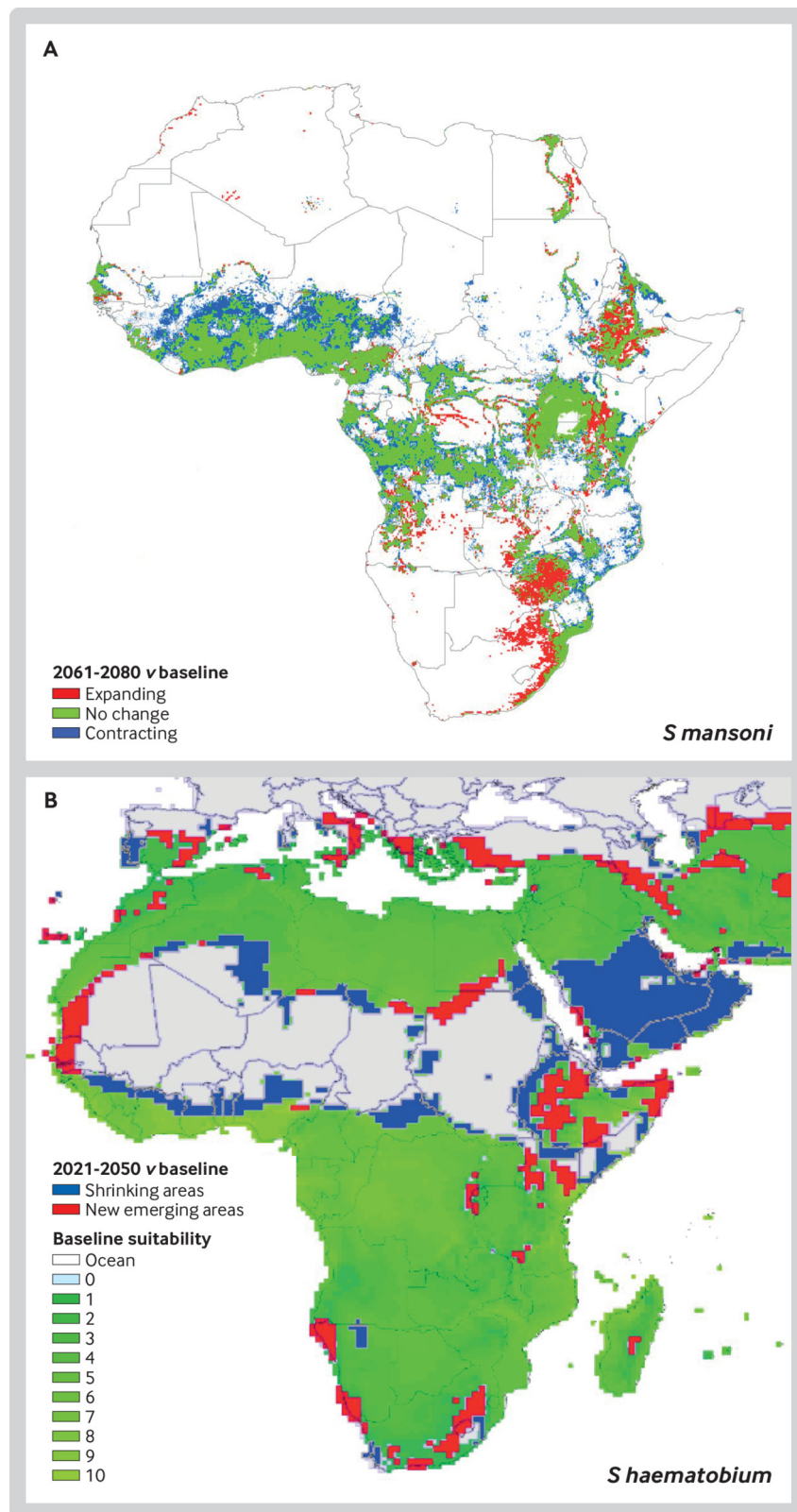


Fig. 3 | Top panel: Predicted changes in the risk area for intestinal schistosomiasis transmission in 2061-2080 compared with present baseline in Africa. Blue color indicates predicted shrinking areas as the temperature becomes unsuitable for the intermediate host *Biomphalaria pfeifferi* (adapted from Stensgaard et al).⁵ Bottom: Predicted changes in risk area for urogenital schistosomiasis in 2021-2050 compared with present baseline in Africa and Middle East. Suitability ranges from zero (not suitable conditions) to 10 (most suitable). Blue color indicates shrinking areas for schistosomiasis as the temperature becomes unsuitable for the parasite to persist (modified from Yang and Bergquist).⁶

A similar modeling approach was used to map the predicted change in risk of *S. haematobium* for 2021-2050.⁶ The model highlighted potential emerging, as well as contracting, areas in Africa, the Middle East, and southern parts of Europe (fig 3b). A different approach based on data from laboratory and field experiments was used to develop a simulation model to predict the effect of rising temperatures on *S. haematobium* and its intermediate host snail *Bulinus globosus*.⁷ This model predicted that snail abundance and production of cercariae—the free living stage of the parasite shed by infected snails—may decrease by up to 14% and 8%, respectively, for each 1°C rise in ambient temperature. These results agree with the findings of other studies that suitable places for *S. haematobium* in Africa near the equator will decrease under future climatic conditions.²

Yet concern is growing that urogenital schistosomiasis may further expand into areas with colder climates, such as South Africa and the Ethiopian highlands, where the presence of the suitable snail species, lack of access to clean water, and limited or no active surveillance may put an immunologically naive population at risk of infection. Given that many sub-Saharan African countries have limited capacity to adapt to the negative effects of climate change, increased investment in schistosomiasis surveillance and control is a public health priority.

Asia

S. japonicum occurs in China, the Philippines, and the Indonesian island of Celebes. Unlike the schistosome parasites in the African continent, *S. japonicum* is transmitted through a unique amphibian

snail intermediate host, *Oncomelania hupensis*. Adult parasites can inhabit more than 40 vertebrate definitive hosts, including cattle, goats, water buffalo, and many rodent species; this many reservoir hosts makes control and elimination of schistosomiasis difficult.

Historical data suggest that average monthly temperatures below 0°C have prevented northward spread of *O. hupensis*, but climate change is already altering the geographic distribution of schistosomiasis. A study in China found that the 0-1°C isothermal zone moved from latitude 33°15' N to 33°41' N between the 1960s and 1990s, corresponding to a 48 km northward shift in just 30 years.⁸ This shift increased the potential schistosomiasis transmission area by over 40 000 km² with an additional 20.7 million people at risk of infection.

A new transmission risk index has been proposed based on growing degree days for parasites and the snail intermediate host,⁹ which suggests that *S. japonicum* transmission areas may increase by 662 373 km² by 2030 and by 783 883 km² by 2050 (fig 4). Recent analyses, based on projections from five global circulation models and representative concentration pathway 4.5 scenario in the fifth assessment report of the Intergovernmental Panel on Climate Change, confirmed future northern expansion of schistosomiasis in China by 2100.⁶ At the same time, these analyses also suggested that the mountainous regions of Sichuan province, where schistosomiasis is currently prevalent, would become unsuitable for snail breeding, thus reducing transmission. However, the areas of the Yangtze River from Sichuan to Hunan and Hubei provinces, a stretch of river affected by the Three Gorges Dam, will still be favorable for snail survival.⁶

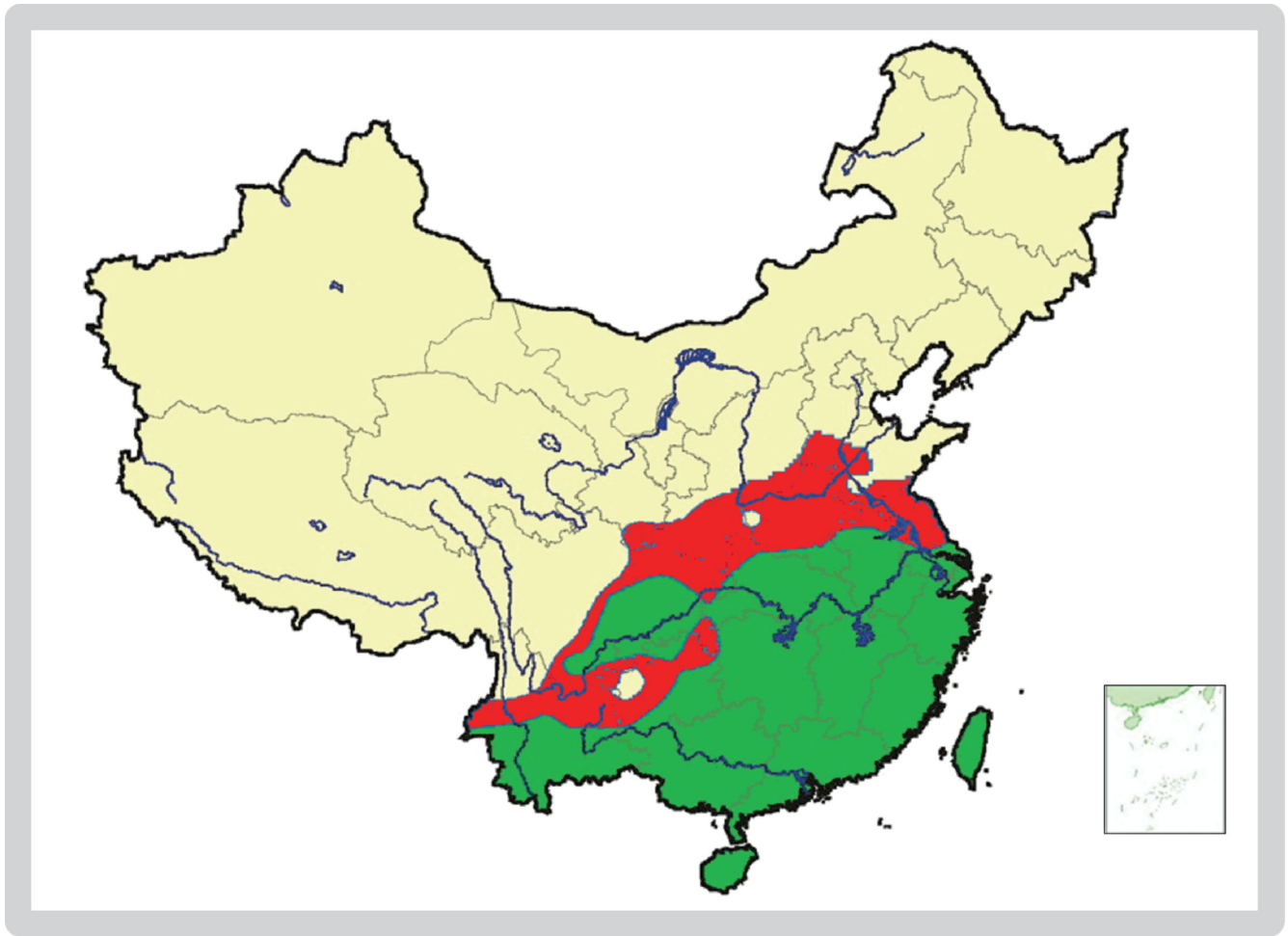


Fig 4 | Areas of potential expansion of schistosomiasis (in red) in China, where schistosomiasis is expected to emerge as a result of climate change, and areas where it is currently endemic (in green), elaborated from Zhou et al⁹

Climate change is also predicted to increase the frequency of extreme climate events, such as droughts, which might reduce the transmission season for schistosomiasis, but also floods, which can locally help the spread of *O. hupensis* snails.¹⁰ To track changes in transmission risk for schistosomiasis in China, it will be important to establish early warning systems that report changes in the distribution of the intermediate snail host and possible new cases of human infection.¹¹

The Americas

Few studies have examined the effect of climate change on schistosomiasis in the American region. Schistosomiasis is endemic to several territories, including Brazil, Dominican Republic, Guadeloupe, Saint Lucia, Suriname, and Venezuela. Most current schistosomiasis infections in the region occur in Brazil, one of the largest tropical countries, the leading dam building nation, and one of the largest agricultural producers in the region.

Climate change is predicted to be particularly severe in some parts of Brazil, including desertification and warming in the northeast of the country,¹² where schistosomiasis is endemic. Brazil's most populous areas, in the south east, are on the edge of the climate suitability range for the main intermediate host snails, so it is unclear whether more warming in this region could expand the habitat suitable for schistosomiasis transmission.¹³

Finally, schistosomiasis is traditionally considered a rural disease, but Brazil has many pockets of "urban schistosomiasis,"¹⁴ where population growth has outpaced the ability of development to supply safe water and sanitation. This situation has created a complicated situation where poverty, development, land use, and climate change act together to influence transmission.

Ecological and socioeconomic determinants

The development and management of the infrastructure for water resources, such as dams and canals for hydropower generation, agricultural irrigation, and drinking water, will be important components of society's response to fight climate change and the associated potential water scarcity. Yet, these changes in land use can also increase the risk for schistosomiasis transmission. For instance, to lessen increasingly recurrent droughts in the northern part of China, the South North Water Transfer project has diverted water from the Yangtze River, the current schistosomiasis endemic region, to northern regions, thus increasing the risk of spread of *O. hupensis* northward.⁸

Dams affect schistosomiasis transmission in many ways (fig 1). More stable water reservoirs inevitably lead to an increase in suitable snail habitat.¹⁵ These reservoirs also support growing human settlements and foster expansion of irrigated agriculture and use of fertilizers and herbicides, which have also been shown to increase

snail proliferation.¹⁶ Dams not only change the habitat for the snails, but also have been shown to block migratory predators¹⁷ that have historically kept snail populations in check. The history of the Dama dam in Senegal is a typical example. The dam was built in response to a climatic stress, a severe drought in the western Sahel region in the 1970s. In response, the countries of the region constructed a dam near the mouth of the Senegal River to stabilize flow, prevent saltwater intrusion, support agricultural development, and protect the availability of freshwater for communities. Within a few years of completion of the dam in 1986, and as a result of its construction, the landscape had changed substantially, the African river prawn—an effective predator of aquatic snails—had been wiped out, and schistosomiasis transmission had increased so that the lower basin of the Senegal river has become one of the most important regions of the world for schistosomiasis transmission.

Recommendations

In summary, schistosomiasis transmission is expected to decrease in central areas of its current climatic location (that is, tropical Africa), because temperatures will exceed the critical thermal maximum of snails as a result of climate change. Transmission is expected to increase at the margins of the cooler range, where temperatures are currently too low for transmission. Climate change is also expected to affect risk of transmission indirectly through interactions with poverty and rural subsistence livelihoods,¹⁸ lack of sewage systems, lack of access to clean water and improved sanitation, lack of affordable healthcare, increasing human movement, dam development, and agricultural expansion.

Therefore, the effect of climate change on schistosomiasis can combine with the effects from land use changes, growing human population, and subsistence livelihoods in unexpected ways. We need new research to reduce the uncertainty associated with potential shifts in the range of schistosomiasis with climate change. While addressing key research questions on climate change and schistosomiasis, decision makers, public health agencies, non-governmental organizations, and communities have several options to prepare for expected shifts in distribution of schistosomiasis caused by the compounded effect of climate and changes in land use.

Integrated surveillance and response systems need to be established in areas where models predict a high likelihood of schistosomiasis becoming endemic. Control strategies, including medical treatment and environmental interventions,¹⁹ should be improved in endemic regions where transmission is expected to increase because of climate change, construction of new dams, or agricultural expansion.

Dams built in the historical range of distribution of migratory freshwater prawns, predating the snails involved in schistosomiasis transmission, should now be retrofitted with passages that allow prawns to move upstream and downstream. New dams should be designed with prawn ladders.¹⁷ Excessive use of fertilizers should be avoided in endemic regions, and pesticides with minimum effect on natural snail predators should be used instead.²⁰ Although these interventions will not be enough to eliminate schistosomiasis, they may help limit the negative effects of climate change on schistosomiasis transmission.

Key recommendations

- Invest in research to better understand the likely spread of schistosomiasis with climate change
- Establish integrated surveillance-response systems in areas at risk

- Increase control strategies, medical treatment, and environmental interventions in endemic regions
- Ensure dams allow prawns to move along the river
- Control fertilizer and pesticide use in endemic areas

Contributors and sources: ASS, GJG and JU have studied and reported widely on schistosomiasis and the related effects of climate change for almost two decades. GADL, SHS, AJC and EKN are involved in a Belmont collaborative project to investigate the effect of climate change on Brazil and Côte d'Ivoire. This work originated in a SESYNC working group on malaria and climate change led by Mercedes Pascual and Andres Baeza. GADL conceived the idea with JU and then thoroughly discussed it with ASS, SHS and GJY. Each coauthor contributed to a specific section of the manuscript. ASS, GJY and AJC produced the figures. All authors contributed to revise the final version of the manuscript prior to submission. GADL is the guarantor.

Competing interests: We have read and understood BMJ policy on declaration of interests and declare the following: GADL, SHS, and AJC have been partially supported by the Bill & Melinda Gates Foundation OPP1114050, and by the US National Science Foundation (ICER-2024383 and DEB-2011179). SHS and GADL were partially supported by National Science Foundation (CNH grant # 1414102). GADL thanks Rachel Lowe (London School of Hygiene and Tropical Medicine) for making this paper possible. ASS thanks the Knud Højgaard Foundation for supporting the Platform for Disease Ecology, Health and Climate (grant # 20-11-0483).

This article is part of a series commissioned by *The BMJ* for the World Innovation Summit for Health (WISH) 2020. *The BMJ* peer reviewed, edited, and made the decisions to publish. The series, including open access fees, is funded by WISH.

Provenance and peer review: Commissioned; not externally peer reviewed.

- Boissier J, Grech-Angelini S, Webster BL, et al. Outbreak of urogenital schistosomiasis in Corsica (France): an epidemiological case study. *Lancet Infect Dis* 2016;16:971-9. doi: 10.1016/S1473-3099(16)00175-4 pmid: 27197551
- Stensgaard A-SS, Vounatsou P, Sengupta ME, Utzinger J. Schistosomes, snails and climate change: current trends and future expectations. *Acta Trop* 2019;190:257-68. doi: 10.1016/j.actatropica.2018.09.013 pmid: 30261186
- McCreesh N, Nikulin G, Booth M. Predicting the effects of climate change on *Schistosoma mansoni* transmission in eastern Africa. *Parasit Vectors* 2015;8:4. doi: 10.1186/s13071-014-0617-0. pmid: 25558917
- Adekiya TA, Aruleba RT, Oyinyo BE, Okosun KO, Kappo AP. The effect of climate change and the snail-schistosome cycle in transmission and bio-control of schistosomiasis in sub-saharan africa. *Int J Environ Res Public Health* 2019;17:E181. doi: 10.3390/ijerph17010181. pmid: 31887979
- Stensgaard AS, Utzinger J, Vounatsou P, et al. Large-scale determinants of intestinal schistosomiasis and intermediate host snail distribution across Africa: does climate matter? *Acta Trop* 2013;128:378-90. doi: 10.1016/j.actatropica.2011.11.010. pmid: 22142789
- Yang GJ, Bergquist R. Potential impact of climate change on schistosomiasis: a global assessment attempt. *Trop Med Infect Dis* 2018;3:E117. doi: 10.3390/tropicalmed3040117. pmid: 30400337
- Kalinda C, Chimbari MJ, Grant WE, Wang HH, Odhiambo JN, Mukaratirwa S. Simulation of population dynamics of *Bulinus globosus*: Effects of environmental temperature on production of *Schistosoma haematobium* cercariae. *PLoS Negl Trop Dis* 2018;12:e0006651. doi: 10.1371/journal.pntd.0006651. pmid: 30070986
- Yang GJ, Vounatsou P, Zhou XN, Tanner M, Utzinger J. A Bayesian-based approach for spatio-temporal modeling of county level prevalence of *Schistosoma japonicum* infection in Jiangsu province, China. *Int J Parasitol* 2005;35:155-62. doi: 10.1016/j.ijpara.2004.11.002. pmid: 15710436
- Zhou X, Bergquist R, Leonardo L, Olivara R. *Schistosomiasis: the disease and its control*. 2008. https://www.researchgate.net/profile/Xiao-Nong_Zhou/publication/242285494_Schistosomiasis-The_Disease_and_its_Control/links/02e7e52f593b26b93a000000.pdf
- Zheng J, Gu XG, Xu YL, et al. Relationship between the transmission of *Schistosomiasis japonica* and the construction of the Three Gorge Reservoir. *Acta Trop* 2002;82:147-56. doi: 10.1016/S0001-706X(02)00046-3
- Yang GJ, Utzinger J, Lv S, et al. The Regional Network for Asian Schistosomiasis and Other Helminth Zoonoses (RNAS (+)). Target diseases in face of climate change. *Adv Parasitol* 2010;73:101-35. doi: 10.1016/S0065-308X(10)73005-0.
- Marengo JA, Torres RR, Alves LM. Drought in northeast Brazil—past, present, and future. *Theor Appl Climatol* 2017;129:1189-200. doi: 10.1007/s00704-016-1840-8.
- Scholte RGC, Gosoniu L, Malone JB, Chamartin F, Utzinger J, Vounatsou P. Predictive risk mapping of schistosomiasis in Brazil using Bayesian geostatistical models. *Acta Trop* 2014;132:57-63. doi: 10.1016/j.actatropica.2013.12.007. pmid: 24361640
- Firmo JOA, Lima Costa MF, Guerra HL, Rocha RS. Urban schistosomiasis: morbidity, sociodemographic characteristics and water contact patterns predictive of infection. *Int J Epidemiol* 1996;25:1292-300. doi: 10.1093/ije/25.6.1292. pmid: 9027538
- Wood CL, Sokolow SH, Jones JJ, et al. Precision mapping of snail habitat provides a powerful indicator of human schistosomiasis transmission. *Proc Natl Acad Sci U S A* 2019;116:23182-91. doi: 10.1073/pnas.1903698116. pmid: 31659025
- Rohr JR, Barrett CB, Civitello DJ, et al. Emerging human infectious diseases and the links to global food production. *Nat Sustain* 2019;2:445-56. doi: 10.1038/s41893-019-0293-3. pmid: 32219187

- 17 Sokolow SH, Jones IJ, Jocque M, et al. Nearly 400 million people are at higher risk of schistosomiasis because dams block the migration of snail-eating river prawns. *Philos Trans R Soc Lond B Biol Sci* 2017;372:20160127. doi: 10.1098/rstb.2016.0127. pmid: 28438916
- 18 Garchitorena A, Sokolow SH, Roche B, et al. Disease ecology, health and the environment: a framework to account for ecological and socio-economic drivers in the control of neglected tropical diseases. *Philos Trans R Soc Lond B Biol Sci* 2017;372:20160128. doi: 10.1098/rstb.2016.0128. pmid: 28438917
- 19 Sokolow SH, Wood CL, Jones IJ, et al. To reduce the global burden of human schistosomiasis, use 'old fashioned' snail control. *Trends Parasitol* 2018;34:23-40. doi: 10.1016/j.pt.2017.10.002. pmid: 29126819
- 20 Halstead NT, Hoover CM, Arakala A, et al. Agrochemicals increase risk of human schistosomiasis by supporting higher densities of intermediate hosts. *Nat Commun* 2018;9:837. doi: 10.1038/s41467-018-03189-w. pmid: 29483531

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