Origin and Biogeography of Human Infectious Disease

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Outline

- Evolution of virulence (Ewald 1983)
- Origin of human infectious diseases (Wolfe et al 2007).
- Biogeography of human infectious diseases (Cashdan 2014).

Diseases differ in virulence

- Some diseases kill you quickly.
- Others hardly make you sick.

Why the difference?

Advantages of virulence

- Virulence results when pathogens reproduce rapidly.
- And selection favors pathogen genotypes that do this, because they have lots of descendants.
- Selection within the host favors virulence.

Disadvantages of virulence

- If the population of pathogens reproduces too rapidly, it will kill the host before the infection can spread.
- Selection between hosts opposes virulence.

The virulence of a pathogen depends on the balance of these opposing forces (Ewald 1983).

Serial passage experiments

- Infect a mouse with some disease.
- After it gets sick, draw blood from that mouse and inject it into another.
- Repeat ad infinitum.

Consistently causes rapid evolution of virulence, because it removes opposing selection.

Perhaps the best example of group selection.

Person-to-person transmission: the common cold

- To infect other people, you have to be well enough to walk around, sneeze, and touch doorknobs.
- If you are incapacitated, you stay home and don't transmit the disease.
- Diseases spread by person-to-person contact tend not to be virulent.

Transmission by insect vectors: malaria

- To infect other people, a mosquito bites you and then bites someone else.
- You can infect other people even if you are too sick to walk.
- Insect-borne diseases tend to be virulent.

Transmission by water: cholera

- Cholera causes severe diarrhea, which gets into the water supply when people wash your soiled sheets.
- You can infect other people even if you are too sick to walk.
- Water-borne diseases tend to be virulent.

Mortality by Transmission

	Transmission	
Mortality	Without vector	With vector
$> 1\%$	5	10
$< 1\%$	40	8

Numbers of diseases

Vector-borne diseases tend to be more virulent (Ewald 1983).

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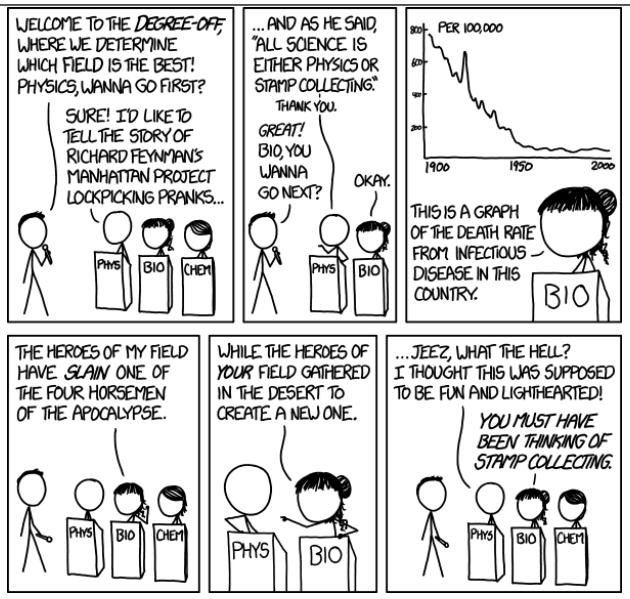

Temperate diseases

Disease	Trans.	Dur.	Fatal.	Imm.	Origin
Diptheria	human	1 wk	35–90%	yes	D.A.
Hep. B	human	months	5–10%	yes	apes
Flu. A	human	1 wk	varies	varies	wild birds
Measles	human	weeks	10-25%	yes	cattle
Mumps	human	weeks	1–2%	yes	pigs?
Pertussis	human	weeks	high	yes	mammal
Plague	fleas	1 wk	25–90%	yes	rodents
Smallpox	human	weeks	20–50%	yes	camels?
Syphilis	human	years	50%	no	?
Tetanus	wounds	2 wks	50%	no	?
Typhoid	human	weeks	10–20%	yes	?
Typhus	louse	2 wks	10–40%	yes	rodents?

Generalizations about temperate diseases

- transmitted mostly from human to human
- brief infection
- substantial mortality
- long-lasting immunity
- many from domestic animals

Tropical diseases

Disease	Trans.	Dur.	Fatal.	Imm.	Origin
AIDS	human	years	100%	no	chimp
Chagas	kiss.bug	years	30%	no	animals
Cholera	human	1 wk	50%	partial	aquat.anim.
Dengue	mosq.	1–2 wk	15%	yes	OW primates
Sl.sick.	tsetse	months	100%	no	ruminants
Falcip.mal.	mosq.	years	5–25%	no	birds
Leishman.	sand fly	years	85%	no	rodents
Vivax mal.	mosq.	years	low	no	macaques
Yel.fever	mosq.	1–2 wk	50%	yes	primates

Generalizations about tropical diseases

- transmitted mostly from vector to human
- duration often long
- immunity uncommon
- many acquired from wild animals

Temperate versus tropical diseases

Compared to tropical one, temperate diseases

- usually brief
- more often have human-to-human transmission
- more often confer immunity
- less often have animal reservoirs

Many temperate diseases require large populations

If illness is brief, quickly transmitted, and confers immunity, the disease cannot persist in a small population.

Pretty soon, everyone is either dead or immune, and the disease goes extinct.

In a large, dense population—several hundred thousand people—such diseases survive by moving to new areas, and returning in a few years.

These diseases could not have existed before the Neolithic.

Pre-Neolithic diseases

Must survive in small population.

Don't kill your host quickly.

Don't make hosts immune.

Rely on wild-animal reservoir.

These are properties of modern tropical diseases.

The other effect of agriculture

Agriculture also put humans in close contact with large herds of domestic animals.

Most temperate diseases came from domestic animals; most tropical ones from wild animals.

New World versus Old World

Nearly all major human diseases originated in the Old World.

Two reasons:

1. Most domestic animal species originated in the temperate Old World.
2. Our closest primate relatives live in the tropical Old World.

Old World diseases reflect both of these sources.

Amerindians had no immunity to such diseases and suffered catastrophic mortality after European contact.

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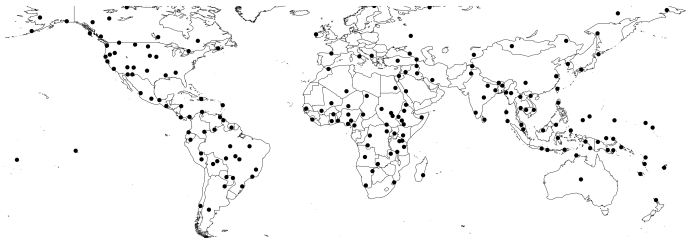
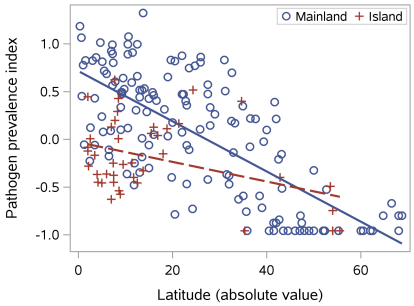
Standard Cross-cultural sample



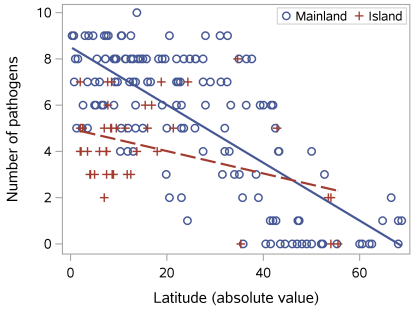
186 societies. Study of Elizabeth Cashdan (2014).



Pathogen prevalence by latitude

Pathogen prevalence lower in North.

Effect smaller on islands.

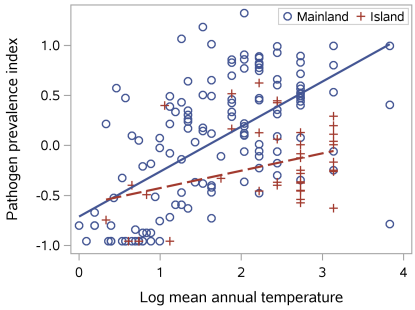


Pathogen number by latitude

Similar pattern for number of pathogen species.

As modern humans moved into Eurasia, pathogen pressure must have decreased.

But what causes this latitudinal effect? Temperature? Rainfall?

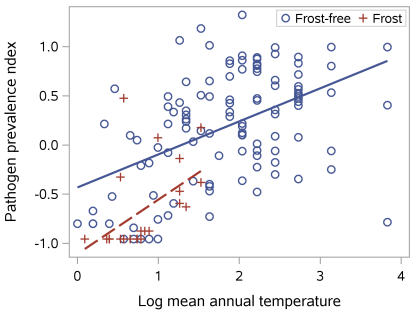


Pathogen prevalence by temperature

Temperature has a strong effect, especially on the mainland.

Pattern seen in 7 of 10 groups of pathogens.

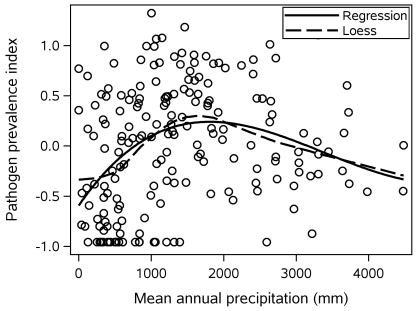
But temperature is correlated with aridity, so it's not yet clear what's going on.



Pathogen prevalence by temperature

Blue: where it never freezes; Red: where it does.

Freezing temperatures protect against pathogens, even controlling for annual temperature.



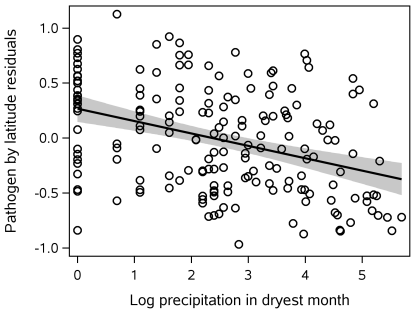
Pathogen prevalence by rainfall

Pathogens worst at intermediate rainfall.

Reflects 2 independent effects:

- Mean annual rainfall.
- Rainfall in driest part of year

These affect different sorts of pathogen.



Pathogen prevalence by arid extremes

Rain in the driest month *reduces* pathogens.

Why?

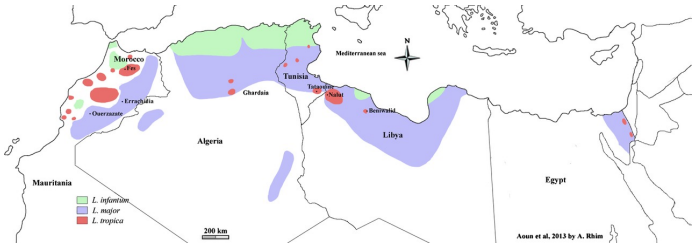
The pathogens that drive this pattern

Disease	Vector
Leishmaniasis	sand fly
Typhus	fleas and lice
Schistosomiasis	snail

All have life cycles that involve another host.

Disease spreads only where humans are in proximity to sand flies, fleas, or snails.

Leishmaniasis in N Africa



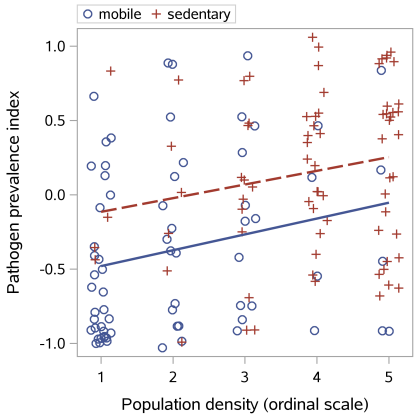
In this region, most areas are uninhabitable during drought. Humans and sand flies are concentrated near water. Facilitates transmission of leishmaniasis.

Typhus

- Transmitted by fleas and lice.
- Crowding facilitates transmission.
- Drought increases crowding.

Thompson et al (2002) studied 22 typhus outbreaks in central Mexico. Tree rings show that all 22 began in a drought.

On the other hand, mosquito-borne diseases (malaria, dengue fever, filariasise) are worse in wet climates.

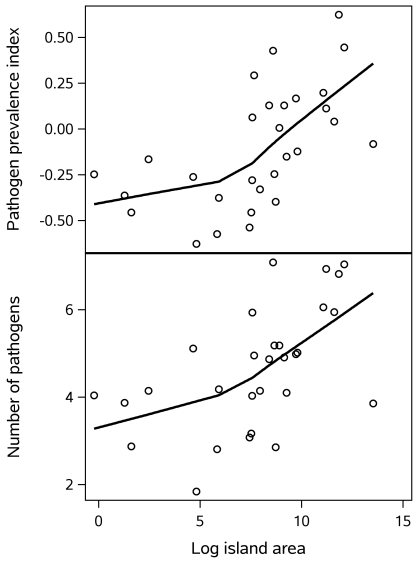


Pathogen prevalence by population density and mobility

More pathogens in dense populations.

Especially in sedentary populations.

Disease load must have increased during the Neolithic.



Large islands have more pathogens

They have more species of all types.

More arrivals, because big islands are easier to find.

Fewer extinctions, because big islands have big populations, which are less likely to go extinct.

Tahiti

In the 1840s, French troops in Tahiti had much lower mortality than those in France (Curtin 1989).

The Tahitians had enjoyed this advantage for millenia, which would have reduced selection at immune loci.

They had little resistance to western diseases, and many died.

Summary

1. Virulence evolves in response to opposing selection pressures within hosts and between them.
2. Water-borne and insect-borne diseases tend to be virulent.
3. Person-to-person transmission selects against virulence.
4. Compared to tropical diseases temperate ones are more often brief, transmitted from human to human, confer immunity, and are less likely to have animal reservoirs. They tend to require large human populations.
5. There are fewer pathogens at high latitudes and in cold climates.
6. Extreme drought promotes insect-borne diseases by crowding humans and vectors around water supplies.