Climate Change, the Anthropocene and Human Health: Implications for Epidemiology in the 21st Century

Robert Cruickshank Lecture
World Congress of Epidemiology
Global Epidemiology in a Changing Environment: The Circumpolar Perspective

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“Epidemiology and Community Health in Warm Climate Countries”

Editors: Robert Cruickshank, KL Standard, HBL Russell

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Main Themes

Epidemiology: continuing to evolve, as social values and public health issues change
  - Mechanistic vs. Systems-based concepts
  - Individuals vs. Populations: ‘human ecology’
  - Paradigm shifts

The Anthropocene and Climate Change
  - Risks to Human Population Health – e.g. the Arctic

Concepts and Methods: scope, resources

Role and Relevance in 21st Century
  - Inputs to precautionary ‘public health’ action
  - Impact monitoring; updated projections
The Anthropocene: The (red) Sliver of Time within the Most Recent Half-percent of Earth’s Existence

Homo genus splits from australopithecine genus

Hominins split from chimpanzee lineage

Great apes evolve

Geological Epochs

Miocene

Pliocene

Holocene (11,000 yrs)

Anthropocene (200 yrs ?)
The ‘Safe Operating Space for Humanity’

Planetary boundaries: unsafe if breached

- Biodiversity loss
- Chemical Pollution (not yet quantified)
- Climate change
- Ocean acidification
- Atmospheric aerosol loading
- Nitrogen cycle
- Global freshwater use
- Change in land use
- Biogeochemical flow boundary
- Stratospheric ozone depletion
- Phosphate cycle

Green = estimated ‘safe operating space’

Rockstrom et al. Nature 2009
The Lancet, August 8th: Planetary health - Call for special-issue
... Innovative research and review papers:

• Global environmental change, ecosystem impairment, and consequences for health of human societies and civilizations

• Effects of adaptation strategies; achieving resilient societies

• Near-term health co-benefits from local actions to avert climate/envtl change

Goal: Interdisciplinary assessment /understanding of complex inter-linkages between environmental sustainability and population health ...

... seeking a sustainable, health-supporting, future within "the finite, but uncertain, limits of exploitation of planetary resources and ecosystems’ capacity to absorb the current world economy’s wastes".

http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(14)61289-7/fulltext
# Chronology of Prevailing/New Paradigms* in Epidemiological Thinking

<table>
<thead>
<tr>
<th>Pre-18C</th>
<th>Divine wrath</th>
<th>POPULATION-LEVEL ECOLOGICAL MODEL</th>
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<tbody>
<tr>
<td>... 18C, 19C</td>
<td>Miasmas: foul vapours (versus contagion)</td>
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<table>
<thead>
<tr>
<th>Late 19C-20C</th>
<th>Germ theory ...</th>
<th>INDIVIDUAL-FOCUSED; BIOMEDICAL MODEL</th>
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<tbody>
<tr>
<td>to mid-20C</td>
<td><em>Specific</em> causes: Germs, workplace toxins, vit. deficiencies, cigarettes</td>
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<tr>
<td>1960s</td>
<td>Multi-causality (eg cardiovascular dis, cancers, resp. allergy): <strong>Risk Factors</strong></td>
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<tr>
<td>1990s</td>
<td>Life-course, evolution-of-pathology, perspective</td>
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<tr>
<td>1990s</td>
<td>Molecular (incl. genetic) epidemiology: ‘discrete’ gene effects??</td>
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<tr>
<th>1990s</th>
<th>Social determinants of disease</th>
<th>POPULATION-LEVEL ECOLOGICAL MODEL</th>
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<tr>
<td>2000s</td>
<td>Systemic Environmental Changes: <strong>systems-based influences</strong> on health</td>
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* See T Kuhn, 1962
R = reinforcing (positive feedback) cycle
Default effect of each link is shown:
+ = increase
− = decrease

This Influence Diagram then used for

Five possible future cycling scenarios are explored, each plateauing by late 2030s – by when the proportions range from 1% to 35%.

Systems Dynamic Modelling of Future Cycling Injuries

Cyclists as Proportion of People Using All Transport Modes

Modelled Future Serious Injury and Death Rate per 1000 Cyclists
Natural Variation in Climate (Nth Hemisphere): Last 12,000 Years - & Next 100

Variations in NH Temp, °C (rel. to Holocene average)

-4 -3 -2 -1 0 1 2 4 6 8 10 12 14 16 18 20 22

Millennia BCE (1000s of yrs)

11 10 9 8 7 6 5 4 3 2 1 0

Centuries CE (100s of yrs)

2 4 6 8 10 12 14 16 18 20 22

Holocene

- Holocene Climatic Optimum, I & II
- Roman Warm Period
- Mediaeval Warm Period, Europe
- Faster warming since 1975

Post-glacial warming after Younger Dryas cooling, 12.8-11.6K yrs BP

Sahara dries

Drought, cooling in East Mediterranean region

Acute cooling: 536 CE Event

Acute cooling: Tambora eruption 1815

Little Ice Age: Europe & China

Modelled range of projected global temperature-rise to 2100 = + 2-4°C

McMichael, PNAS 2012
Much of the Arctic has warmed by 2-3°C since the 1980s – up to 3 times faster than the global surface average.
Projected Change in Global Average Surface Temperature for Different ‘Representative’ Emission-Concentration Pathways

Intergovernmental Panel on Climate Change (IPCC). Fifth Assessment Report, WkGp1, 2013
Projected Warming (RCP 4.5) by 2070

Near-Surface Global-Average Air Temperature = + 1.76°C

Antarctic coastal fringe cools – stronger southern ‘westerlies’ bring colder deep-water to surface; stratospheric ozone depletion reduces local ‘greenhouse’ effect
Climate Change: Health Impact Pathways

**Climate Change**

- Influences on natural biophysical systems
  - Glaciers, rivers
  - Ocean temp & pH
  - Sea-level rise
  - Nitrogen & phosphorus cycles
  - Soils, forests, coasts
  - Biodiversity

**Indirect and diffuse impacts**: mediated by changes to env'tl and social systems

- Property loss: job loss; displacement; resource conflicts

**Influences on social, and economic conditions**

**Influences on biological and ecological processes**

- Ecological changes: food yields, water quality, mosquito populations, etc.

**Direct impacts** via extreme weather events, heat-waves, worsened air pollution

**Health Impacts**

- Injury/death; mental stress
- Heat stress, deaths
- Infectious diseases - vector-borne and other
- Under-nutrition
- Mental stress/disorders
- Trauma/deaths

McMichael AJ, 2013
Climate Change and Health Consequences in the Arctic

Thaw > Weaker foundations: buildings, roads
- Physical safety (including thinner ice cover)

Bacterial contamination of coastal shellfish: gastroenteritis

Geographic/seasonal shifts/declines in Inuit traditional food species:
- Reliance on imported processed foods \(\rightarrow\) obesity, CVD, diabetes, etc.

Invasive species: increased commercial and tourist shipping:
- Coastal & marine ecosystem vitality, productivity: food sources, protein

Reindeer herders (e.g. the Saami of northern Scandinavia)
- Reindeers’ food/nutrition – lichens, etc.
- Risks to herds crossing ‘iced’ lakes

Impairment of community morale:
- Mental health problems, and poverty-related health disorders
**Attributable Risk:** Climate change as a contributory input to a specified health outcome

“...about **one quarter** of global glacier mass loss during **1851 to 2010** is **attributable** to anthropogenic causes. That human-contribution fraction recently accelerated to **almost two thirds between 1991 and 2010.**”


How feasible for complex CC-Human Health causal webs?

| CC > Δ temp & soil moisture > crop yield/quality > [trade adjustments] > food price/access > family diet > energy & nutrient intake > child nutrition > risk of stunting > risk of death |

**Systems modelling**, incl. coupling with relevant sub-models

**Criteria** to assess the probability of, and to accept, the estimated attribution?
Extreme Heat (and Smoke) in Western Russia, Summer 2010: human (and crop) impacts

Approx. 8°C above seasonal normal

60 days:
~56,000 extra deaths in Moscow & Western Russia
... and later in Egypt?

Scenario-based Modelling: Estimate the future health risks, for successive time periods within a given climate-change scenario

Construct a Health Impact Model using published epidemiological (or other empirical) findings – typically includes linkages with pre-existing covariate sub-models

Test the coupled model by back-casting – compare ‘predictions’ with actual prior observed data

Link this Health Model to the specified climate scenario

Multiple runs, varying the starting conditions

Acknowledge sources of uncertainties: causal process, key parameter values, uncertain future contexts
Modelled percent changes in heat-related, cold-related and net temperature-related deaths, using IPCC/A2 emissions scenario: 2020s, 2050s and 2080s (relative to 1980s)

Based on: Li et al. Projections of seasonal patterns in temp-related deaths for Manhattan, NY. Nat Clim Change 2013
2030-2040: + 1.5°C
Period of ‘Committed climate change’
Increased impacts – esp. Heat; Under-nutrition; Food- and water-borne infections

Relative CC-related Risks to health over time:
Present, 2030s, c.2090

Risk Level, and Potential for Adaptation
Risk with today's level of adaptation
Risk with future high adaptation
Additional adaptation
Unavoidable risk: not amenable to future adaptation

Adapted from: IPCC 5th Assessment Report, WkGp2, 2014, Ch.11
The Goldilocks (‘just right’) Effect, in Nature

1. Barley Yield deviation (%) Czech Republic since 1940s

2. Diarrhoeal cases per month

3. Temperature, Mosquito-and-Plasmodium Biology, and Malaria
Projected Warming and Schistosomiasis in China by 2050

Potential Spread of Snail-mediated Schistosomiasis in China, with Warming. Estimated with Biology-Driven Model, for 1.6°C Rise in Eastern China by 2050. (Based on Zhou et al, 2008)

IPCC 5th Assessment Report, March 2014, Ch.11: Smith, Woodward et al.
CLIMATE CHANGE to 2050: MODELLED CHANGES IN CEREAL GRAIN YIELDS

Poor and Drought-Prone Countries are Projected to Fare Worst

**NOT** including climate-related:
- Flood/storm/fire
- Droughts – severity
- Pests (climate-sensitive)
- Infectious diseases (ditto)

Percentage change in yields to 2050

UN Devt Prog, 2009
Adaptation and Mitigation

Research tasks abound

**Adaptation: Risk management**
- Immediate protection: Heat-wave warnings, dams/sea-walls, vaccines
- Longer-term: Urban design, green space, mosquito sterilisation … & geoengineering!

Priorities? (who’s most vulnerable? – individual-level epidemiology studies)
Estimation of reduction in burden-of-disease

**Mitigation: Risk Reduction - ongoing for global population**

Plus direct **Health Co-Benefits** to local population

- Cleaner urban air (less fossil fuel combustion)
- More walking/cycling
- Healthier climate-proof, insulated, housing design
- Clean, non-smoky, fuels in poor unventilated housing
- Diet: carbon-lite production of local fresh foods; less red (ruminant) meat (enteric methane!)
**Key Messages**

Humankind is now a *geological* force: we have moved ourselves into the Anthropocene.

**Climate change: a signal of having exceeded Earth’s limits**
Changes in climate (mean and variability) pose diverse health risks (+ a few benefits). Risks will increase.

*‘Exposure-effect’ relationship is typically *ecological* in type*

Most adverse impacts from disruptions of ecosystems/geophysical processes.

Poor and disadvantaged populations *most* vulnerable. All are at risk.

A challenging & morally compelling **research agenda for epidemiology** – working with cognate disciplines. Standard epi methods good for *some* aspects. But conceptual-methodological frame must now encompass:

1. Assessing health risks from changes to complex dynamic natural *systems*
2. Modelling the direction and magnitude of likely future changes in risk under plausible scenarios
3. Criteria of causal attribution, esp. for extended causal webs
4. Optimising management of now-unavoidable health risks; estimating the direct health co-benefits/harms as societies respond to climate change

**Epidemiology must engage with the widening, ongoing, paradigm shift** into *systems-based research*, to elucidate and (where possible) quantify key paths, processes and intervention points.

Enhanced information will stimulate/guide minimising health risks from disruptions of *human/environment ecology* – as has been successfully done by Modern Epidemiology for many specific risk-factor exposures.
Svante Pääbo: Elucidating *H. sapiens* evolution via ancient inter-breeding (gene-swapping) with now-extinct *Neanderthal* and *Denisovan* relatives – supplemented by the brain-enhancing pressures of natural climate changes.

**Now we must use that brain to counter human-driven climate change**

Austin Bradford Hill FRS, eminent English statistician, wondered “When do we have sufficient evidence to start acting to curtail tobacco?”

“Incomplete scientific knowledge does not confer upon us a freedom to ignore the knowledge that we already have, or to postpone the action that it appears to demand”
Relationship between rainfall index, late spring (April-June), and barley yields in the Czech Republic since the 1940s. Similar graph for winter wheat yields. The dashed curve is the graph of the 5-year running mean yield deviation.

Thomas Nagel, American philosopher (New York University):

Fighting Words: ...

“Our secular culture has been brow-beaten into regarding the reductive [reductionist] research program as sacrosanct, on the ground that anything else would not be science.”

And a challenge to the natural and social sciences:

“The world is an astonishing place, and the idea that we have the basic tools needed to understand it is no more credible than it was in Aristotle’s day.”
Drought Stress in ancient Near-Eastern agricultural systems (Fertile Crescent)

Carbon isotope profile of barley as index of crop water stress

Favourable conditions

Drought Stress

Adapted from Riehl et al, PNAS, 2014