ENVIRONMENTAL MICROBES AND HEALTH

UO-CHC 441H/431H: Microbes + Social Equity

Lecture 10

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Learning objectives

- Environmental microbial exposure
  - *What does good mean?*
- Some ways environmental microbial exposure can benefit health
- Discussion: access to natural environments

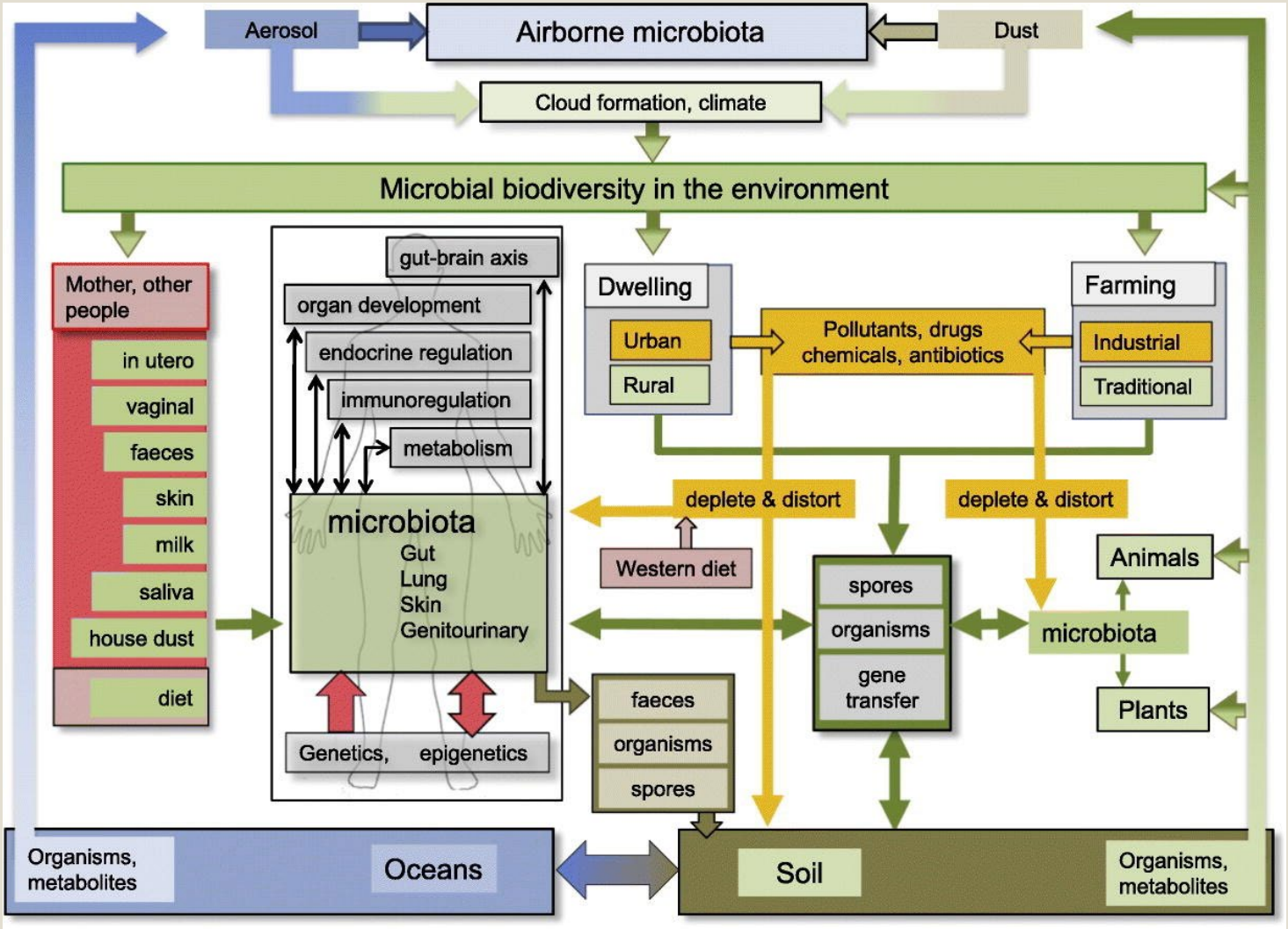
ENVIRONMENTAL MICROBIAL EXPOSURE

How do we define good or bad?

- Depends on
  - *Which microbial community exposed to*
  - *Route of exposure (inhalation, skin, ingestion)*
  - *Other factors that affect interaction*
    - Ex. particle in air which cause damage to mucosal membranes
  - *When in your life?*

- Generally, we think we want microbial exposure that:
  - *Increases our total microbial diversity*
    - And by extension, the function of that community
  - *Reduces pathogens, especially human-specific infectious organisms (ex. viruses)*

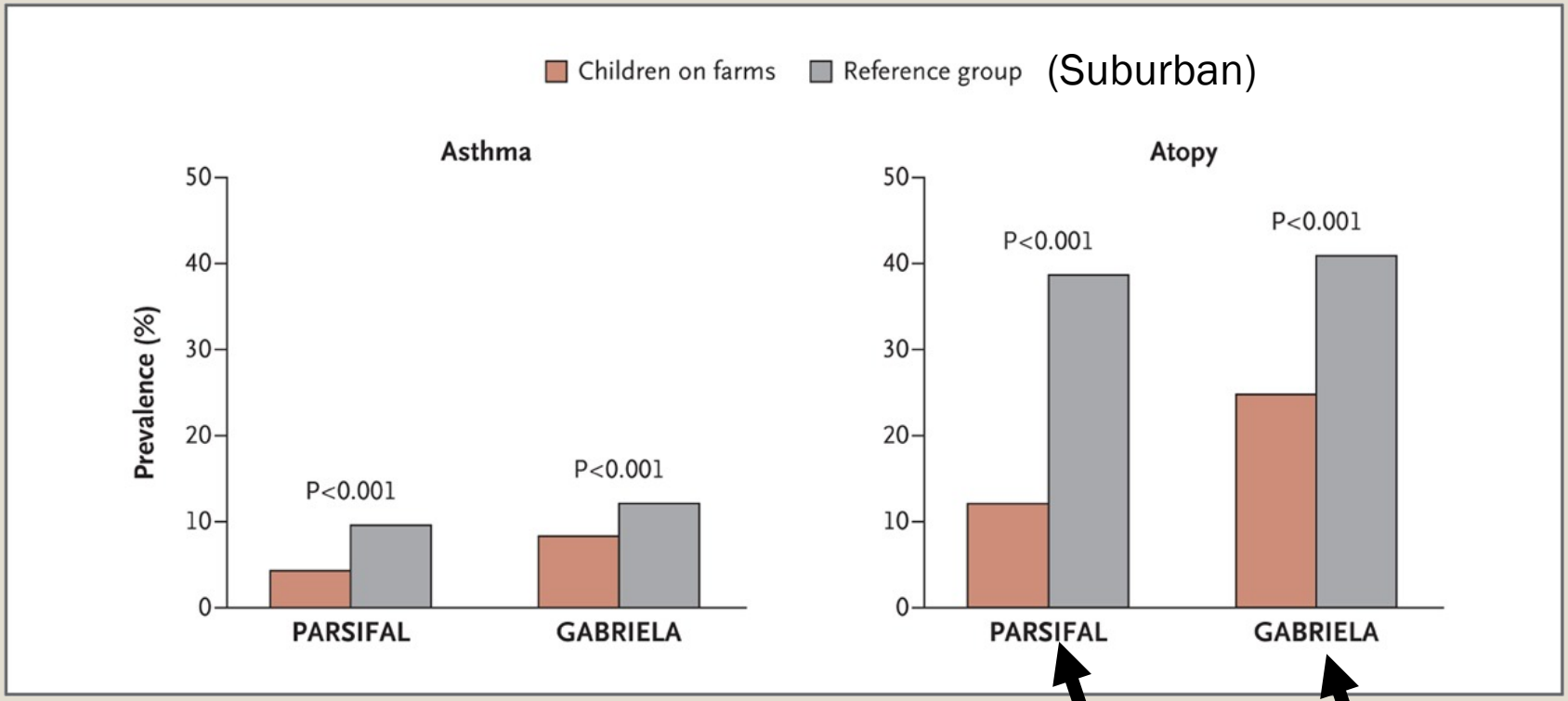
Interacting with the environment transfers microbes



Flandroy et al. 2018

Rural upbringing associated with reduced asthma and atopy compared with suburban

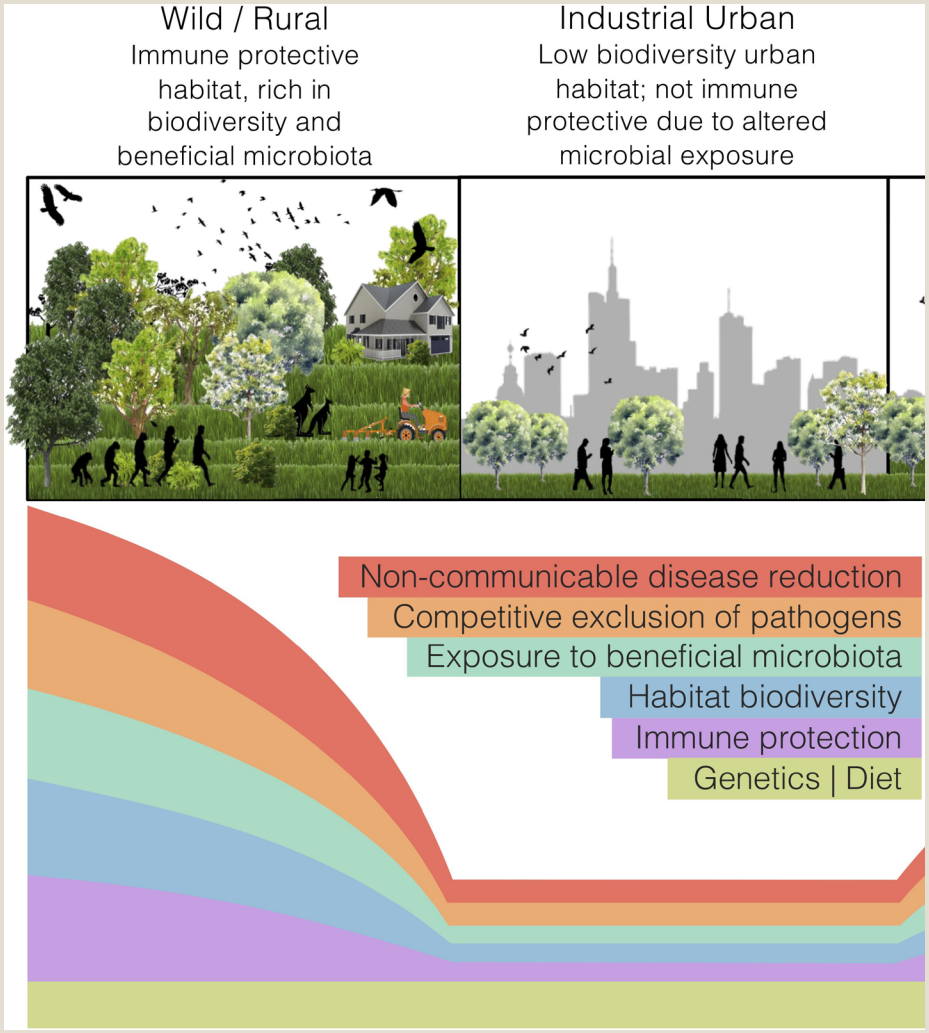
Studied 16,500 children in Germany



Ege et al. 2011

Names of the cohorts

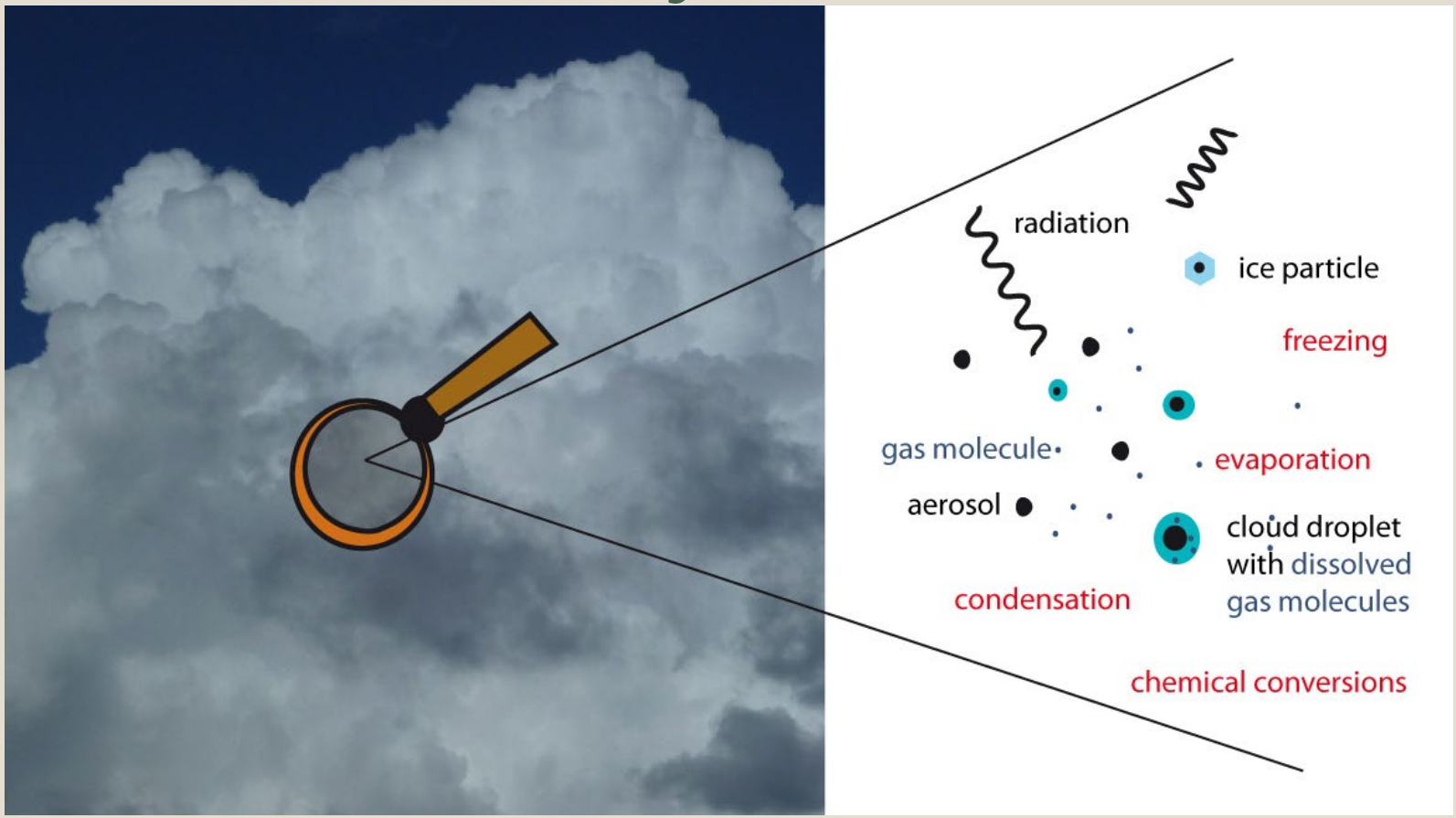
Microbiome Rewilding Hypothesis



Mills et al. 2019

MICROBES IN THE SKY WITH DIAMONDS

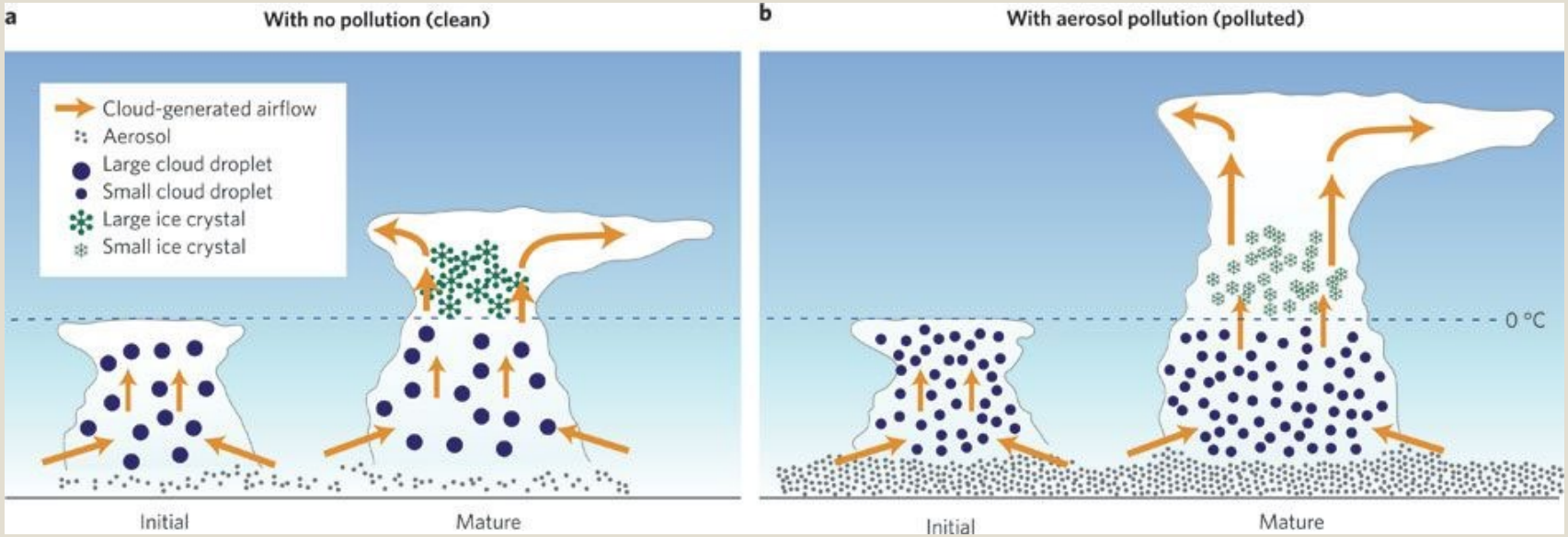
Clouds are ecosystems with a lot of chemistry



Leipziger Institut für Meteorologie - Universität Leipzig

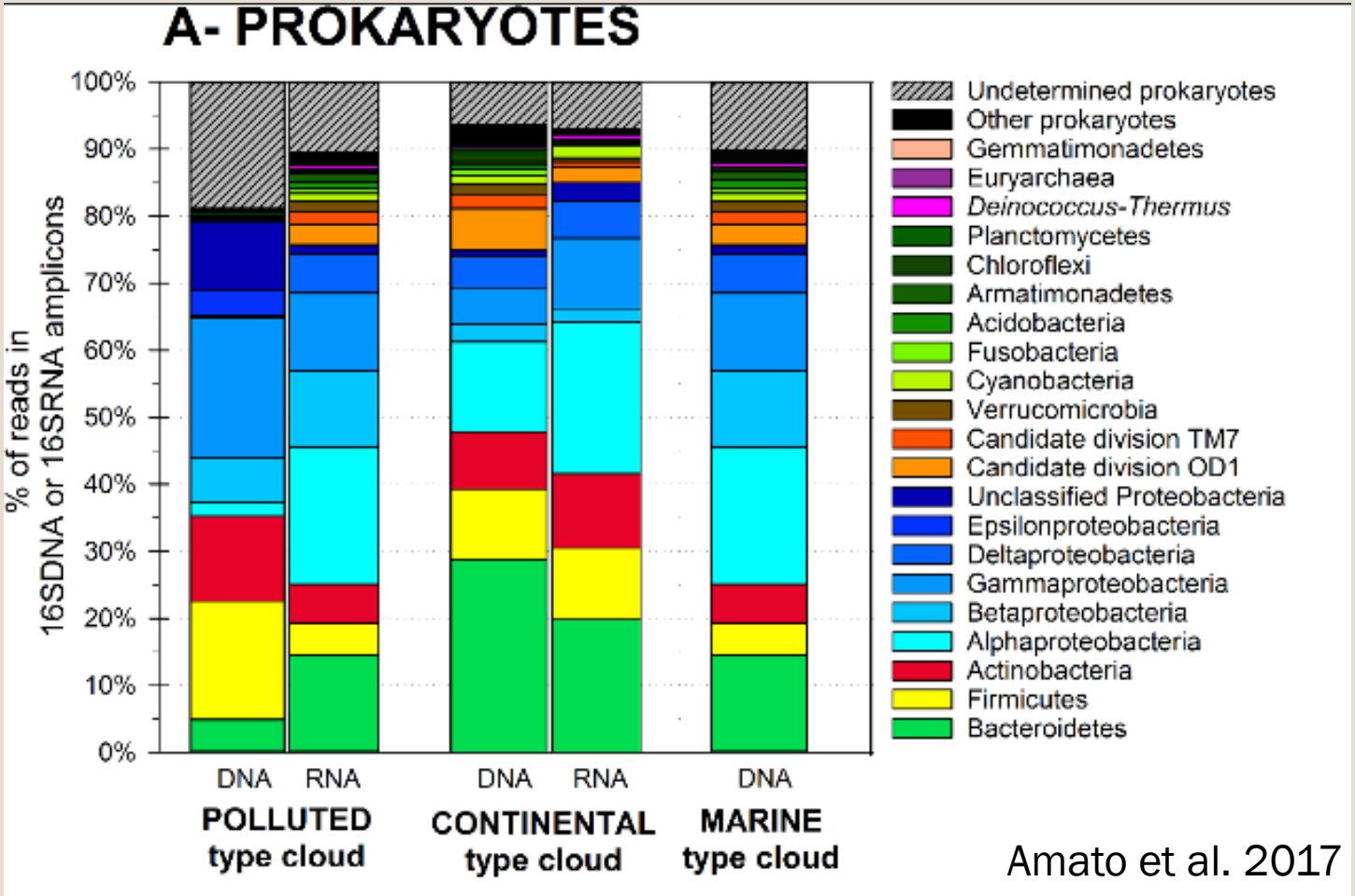
Particles in clouds allow water to form droplets around them

- The composition of aerosols (particles dispersed in air) alters how clouds form and grow



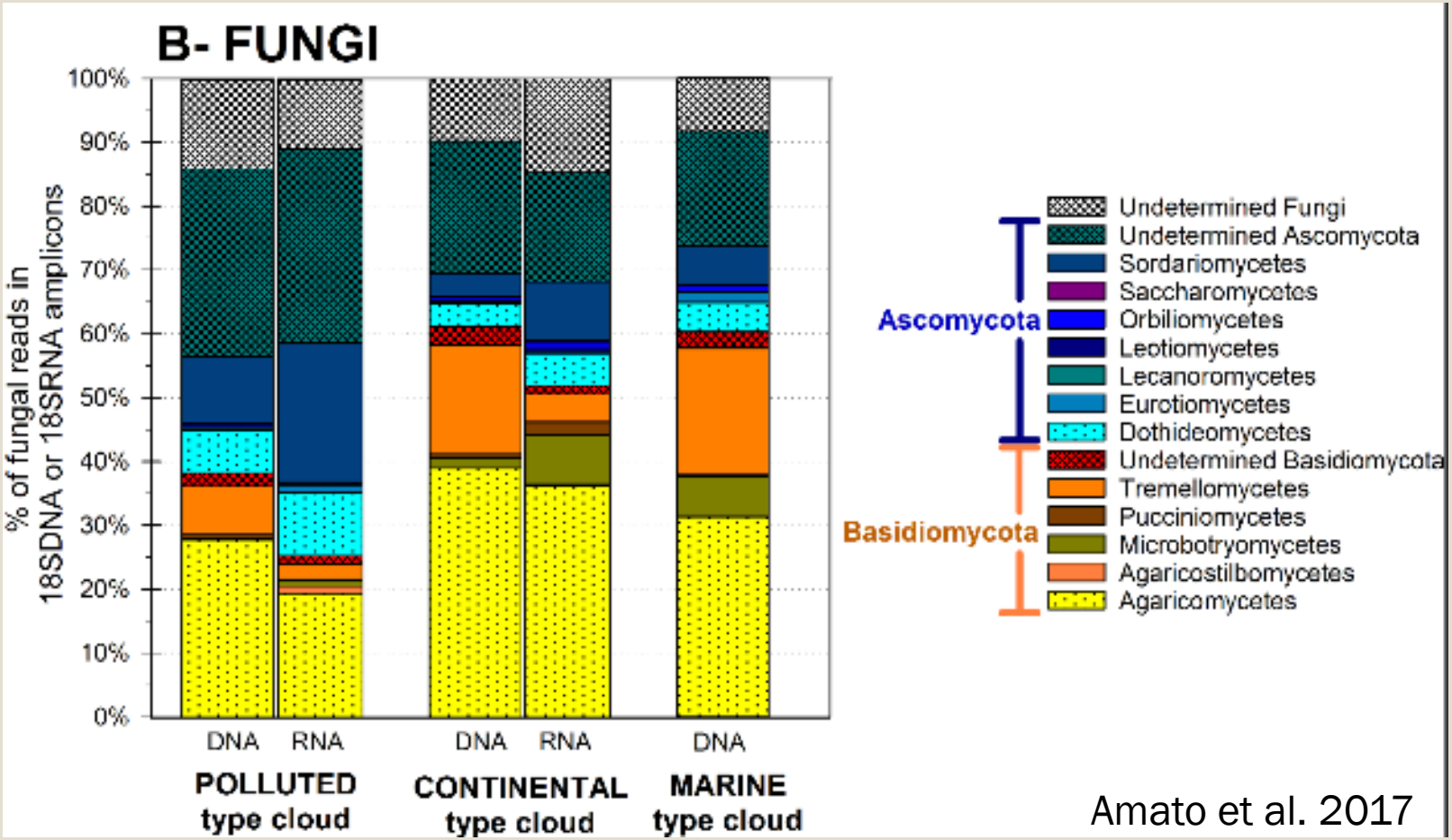
Lee, 2011

Clouds carry active bacteria



Amato et al. 2017

Clouds carry active fungi



Amato et al. 2017

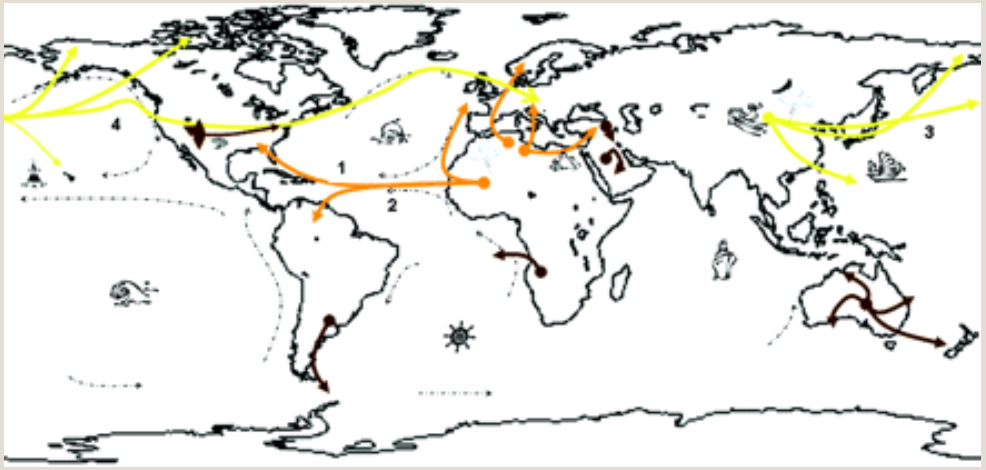
WHAT YOUR AIR QUALITY HAS TO DO WITH MICROBES

Mechanisms

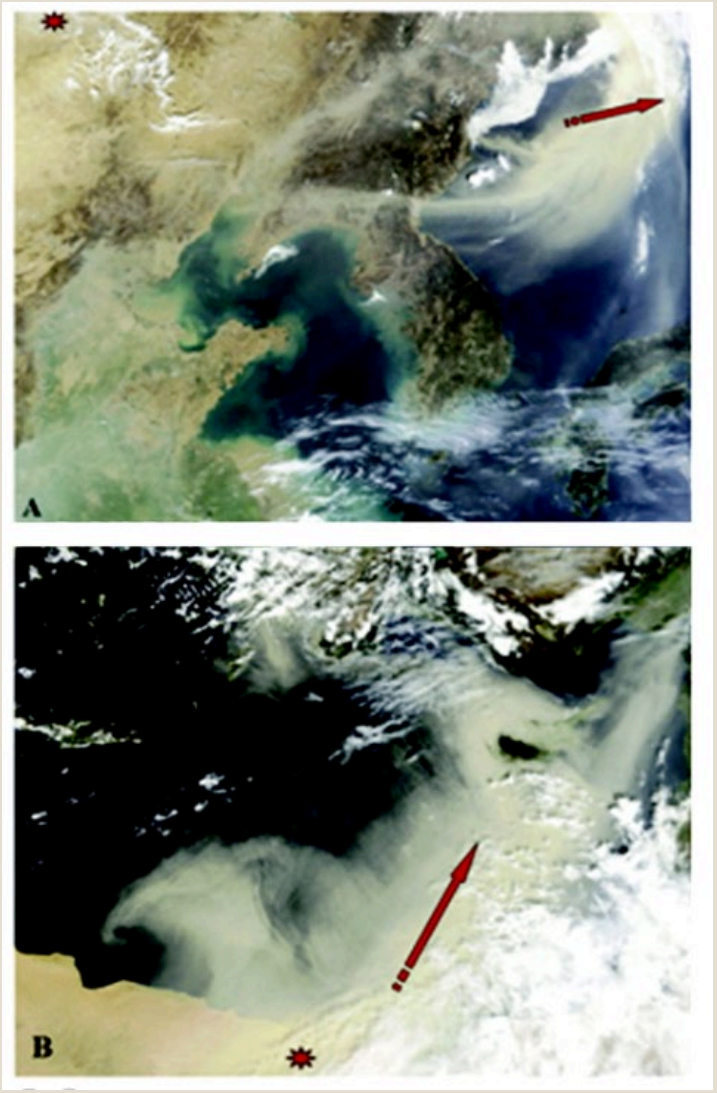
- High humidity promotes microbial growth
- Transmission of aerosolized microbes from one place to another
- Dust/wind lowers humidity
  - *Dried out mucus membranes or skin is more susceptible to pathogen invasion*
- Dust/wind/particles irritates lungs
  - *Inflammation*
  - *Particles accumulate*

CLOUDS AND EPIDEMICS

Dust storms move **billions of tons** of dust globally every year



Griffin, 2007



Dust storms also carry microbes globally – ex. fungi found in dust capable of infecting humans (Griffin, 2007)

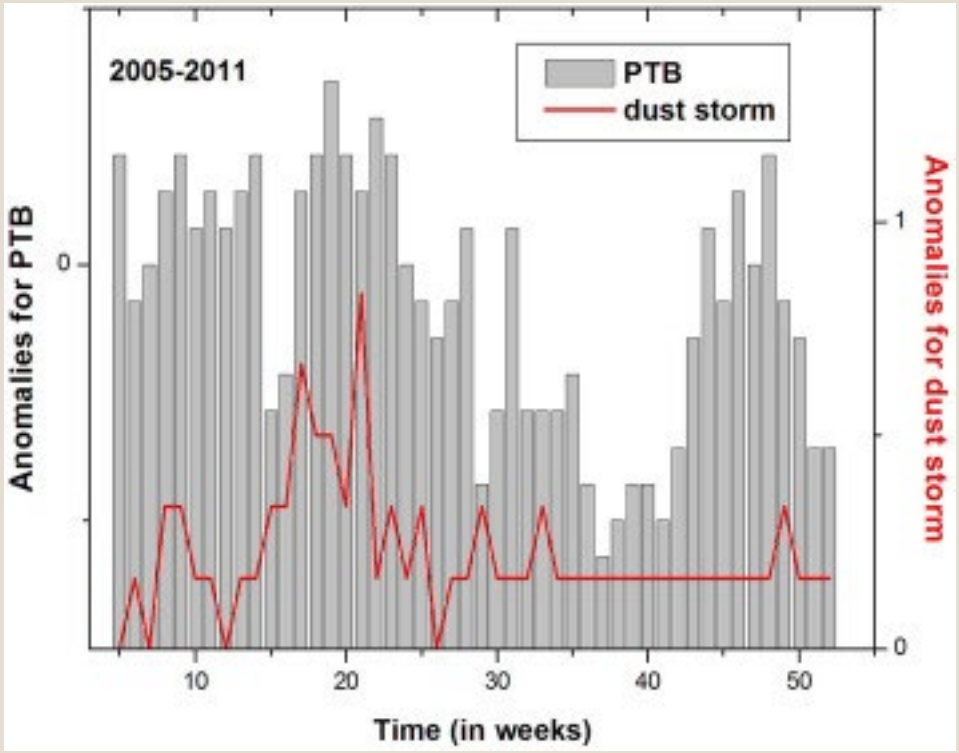
TABLE 3.

Fungi capable of affecting humans[a]

Organism	Location(s) (reference[s])[b]	Dust source region(s)	Miscellaneous information[c]	Disease(s)[d]
Acremonium	USVI, Turkey (82, 83)	Sahara/Sahel, Middle East	Common in soil, on plants, and indoors	Mycetoma (colonization of tissue/bone), onychomycosis (colonization of nail), mycotic keratitis, a number of different allergen-related disease types in the immunocompromised
Alternaria	Mali, Africa, mid-Atlantic, Barbados, Taiwan, Saudi Arabia, Israel, Turkey (82, 83, 92, 117, 126, 190, 207, 256)	Sahara/Sahel, Gobi/Takla Makan, Middle East	Common in soil, on plants, and indoors	Cutaneous phaeohyphomycosis (colonization of skin), potent allergen (common cause of extrinsic asthma)-related disease, deep tissue infections in the immunocompromised
Alternaria infectoria	Turkey (82)	Sahara	Common environmental isolate	Phaeohyphomycosis
Arthrinium	Barbados (190)	Sahara/Sahel	Common environmental isolate	Allergen-related disease
Aspergillus	Mali, Africa, USVI, Barbados, Taiwan, Saudi Arabia, Israel (79, 83, 92, 117, 126, 207)	Sahara/Sahel, Gobi/Takla Makan, Saudi Arabia	Common in soil, organic detritus, and indoors	Aspergillosis (pulmonary [allergic and colonizing], disseminated, central nervous system, cutaneous, nasal-orbital, and iatrogenic), a number of different allergen-related disease types in the immunocompromised
Aspergillus clavatus	Barbados (190)	Sahara/Sahel	Common environmental isolate	Invasive aspergillosis
Aspergillus flavus	Barbados, Israel (190, 207)	Sahara/Sahel	Common environmental isolate	Invasive aspergillosis
Aspergillus fumigatus	Barbados, Israel (190, 207)	Sahara/Sahel	Common environmental isolate	Invasive aspergillosis
Aspergillus niger	Mali, Africa, Barbados, Israel (117, 190, 207)	Sahara/Sahel	Common environmental isolate	Invasive aspergillosis
Aspergillus terreus	Barbados (190)	Sahara/Sahel	Common environmental isolate	Invasive aspergillosis
Aspergillus ustus	Israel (207)	Saharan	Common environmental isolate	Rare, invasive aspergillosis
Aspergillus versicolor	Mali, Africa, Israel (117, 207)	Sahara/Sahel	Common environmental isolate	Invasive aspergillosis
Aureobasidium	Mid-Atlantic, USVI (79, 83)	Sahara/Sahel	Distributed in temperate areas; common on plant tissue and indoors	Cutaneous phaeohyphomycosis, invasive disease in the immunocompromised
Bipolaris	USVI (79)	Sahara/Sahel	Common plant and indoor isolate	Pansinusitis, meningoencephalitis, chronic pulmonary disease
Cladosporium	Mali, Africa, mid-Atlantic, USVI, Barbados, Taiwan, Saudi Arabia, Turkey (78, 79, 82, 83, 92, 117, 126, 256)	Sahara/Sahel, Gobi/Takla Makan, Middle East	Most commonly isolated fungus in outdoor studies	Cutaneous phaeohyphomycosis, chromoblastomycosis (subcutaneous skin infections), mycotic keratitis, potent allergen-related disease
Cladosporium cladosporioides	Mali, Africa, USVI, Israel (78, 117, 207)	Sahara/Sahel	Common environmental isolate	Cutaneous phaeohyphomycosis, chromoblastomycosis
Cladosporium sphaerospermum	Israel (207)	Sahara	Common environmental isolate	Cutaneous phaeohyphomycosis, chromoblastomycosis
Chrysosporium	USVI (79)	Sahara/Sahel	Common environmental isolate	Opportunistic, infecting brain, nasal and skin tissue
Curvularia	Taiwan, Barbados (92)	Gobi/Takla Makan	Common environmental isolate	Allergen-related disease, opportunistic, pneumonia, disseminated
Emericella nidulans	Mid-Atlantic (83)	Sahara/Sahel	Common in tropical and subtropical environments	Allergic alveolitis
Fusarium	Taiwan, Turkey (82, 92, 256)	Gobi/Takla Makan, Middle East	Common soil and indoor isolate	Invasive cutaneous (erythematous lesions and nodules), systemic granulomatous disease, allergen-related disease
Microsporum	USVI, Turkey (79, 82)	Sahara/Sahel, Middle East	Some species are geographically restricted	Dermatophytosis (i.e., ringworm)
Mortierella	Saudi Arabia (126)	Saudi Arabia	Common environmental isolate	Rare, cutaneous
Mucor	Saudi Arabia (126)	Saudi Arabia	Common environmental isolate	Rare, opportunistic, pulmonary, disseminating, cutaneous
Neotestudina rosatii	Mid-Atlantic (83)	Sahara/Sahel	Common environmental isolate; Africa, Australia, India	Mycetoma
Nigrospora	USVI, Taiwan (79, 92, 256)	Sahara/Sahel, Gobi/Takla Makan	Common in soil, organic detritus, and indoors	Allergen-related disease
Paecilomyces	USVI (79)	Sahara/Sahel	Common in soil, organic detritus, and indoors	Mycotic keratitis paecilomycosis, pneumonia, allergen-related disease
Pithomyces	Taiwan (92, 256)	Gobi/Takla Makan	Typically found on dead plant detritus	Allergen-related disease
Phoma	Mid-Atlantic (83)	Sahara/Sahel	Common plant pathogens	Allergen-related disease
Pythium	Saudi Arabia (126)	Saudi Arabia	Common plant pathogen	Pythiosis
Penicillium	Mid-Atlantic, USVI, Barbados, Taiwan, Saudi Arabia, Turkey (79, 82, 83, 92, 126, 190, 256)	Sahara/Sahel, Gobi/Takla Makan, Middle East	Very common in temperate regions, common in soil and indoors	Bronchopulmonary penicilliosis, potent allergen-related disease (hypersensitivity and allergic alveolitis)
Penicillium brevicompactum	Turkey (82)	Sahara	Common environmental isolate	Rare, necrotic lung ball
Penicillium chrysogenum	Israel (207)	Sahara	Common environmental isolate	Rare, endocarditis, necrotizing pneumonia
Penicillium spinulosum	Israel (207)	Sahara	Common environmental isolate	Allergen-related disease
Phoma cava	Israel (207)	Sahara	Common environmental isolate	Subcutaneous phaeohyphomycosis
Rhizomucor	USVI (79)	Sahara/Sahel	Common environmental isolate	Rare opportunistic, pulmonary, disseminating, cutaneous zygomycosis
Stachybotrys	Mid-Atlantic (83)	Sahara/Sahel	Commonly found in soil and decaying plants	Rare, toxin producer, pulmonary
Stemphylium	Taiwan (256)	Gobi/Takla Makan	Common plant pathogens	Phaeohyphomycosis
Torula	Taiwan (92, 256)	Gobi/Takla Makan	Common environmental isolate	Allergen-related disease
Trichophyton	Mid-Atlantic, USVI, Turkey (79, 82, 83)	Sahara/Sahel, Middle East	Commonly found in soils and indoors	Dermatophytosis, allergen-related disease
Ulocladium	Taiwan, Saudi Arabia (92, 126)	Gobi/Takla Makan, Saudi Arabia	Found in soil, on plants, and in high-moisture environments	Phaeohyphomycosis
Ulocladium botrytis	Mid-Atlantic (83)	Sahara/Sahel	Found in soil, on plants, and in high-moisture environments	Allergic alveolitis

Dust storms and pulmonary tuberculosis

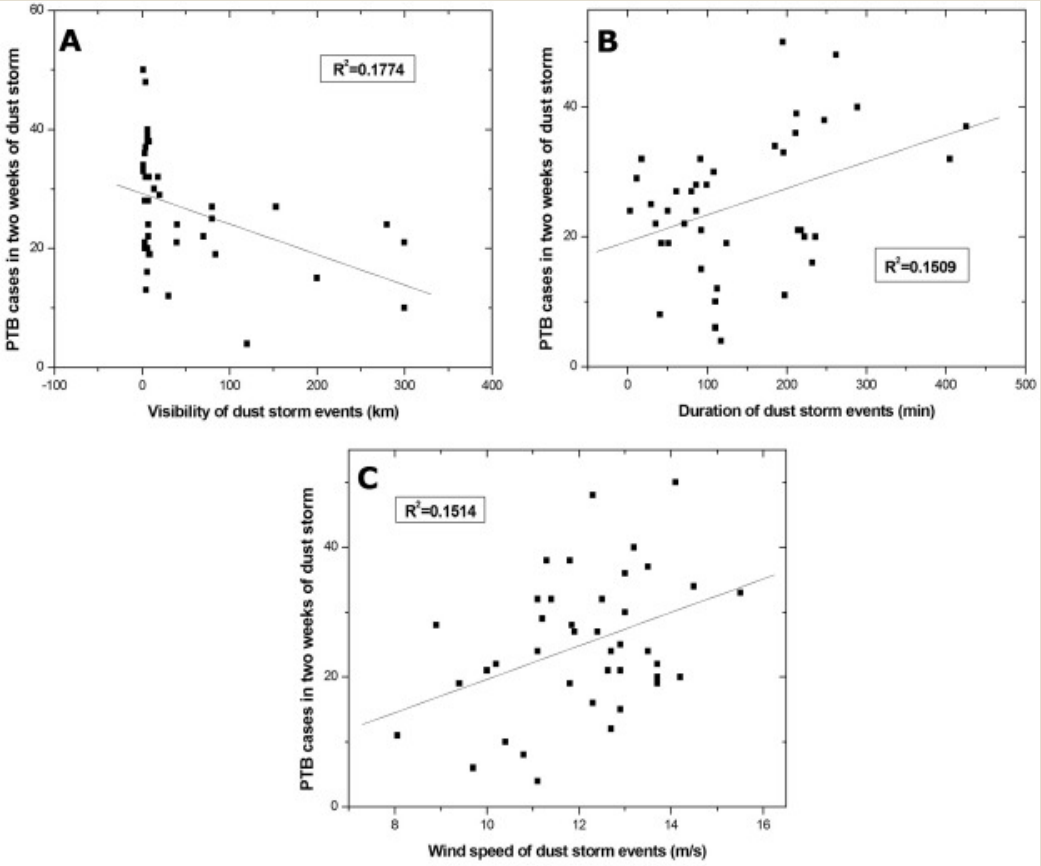
- Noticed that tuberculosis outbreaks/clinical visits coincided with dust storms
- *Mycobacterium tuberculosis* transmitted person to person, especially during coughing
- Dust storms and particulate matter in air caused worse symptoms, spread more TB



Wang et al. 2016

Dust storms and pulmonary tuberculosis

- (A) Smaller dust particles cause more cases
- (B) Longer storms cause more cases
- (c) Higher winds during the storm caused more cases



Wang et al. 2016

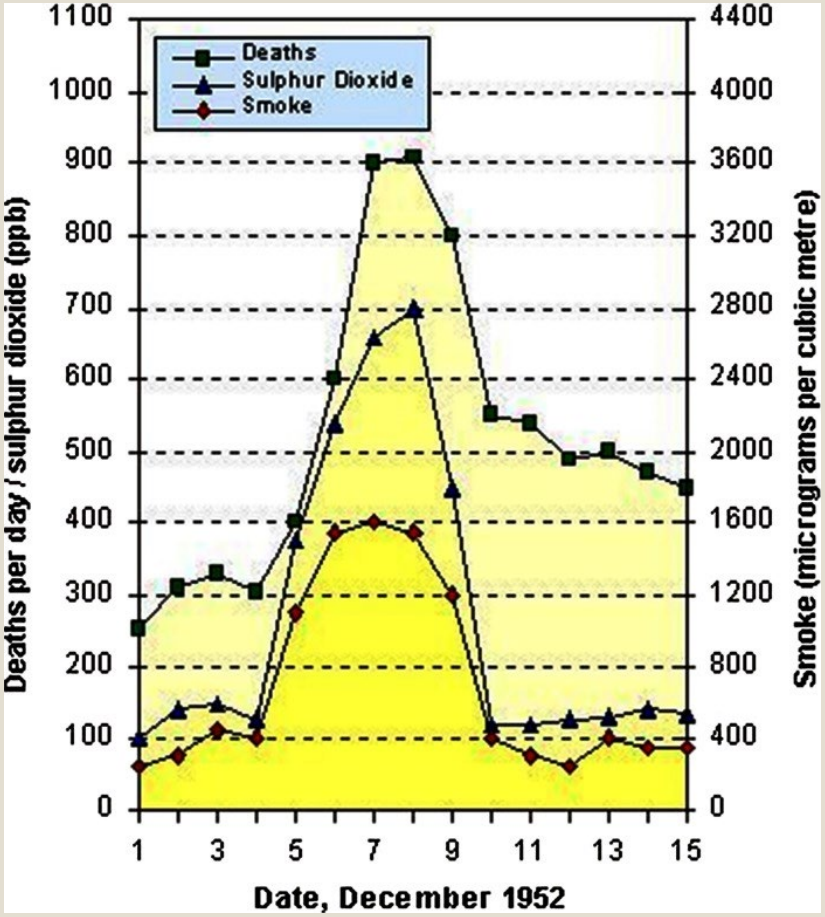
OUTDOOR AIR QUALITY AND HEALTH

What is air pollution?

- Anything harmful in air
  - *Measured as concentrations of each thing, or particle size fractions*
- Particulate matter (PM)
  - *Course, PM10 = 2.5 – 10 microns*
  - *Fine, PM2.5 = <2.5 microns*
- Black carbon
- Organic carbon
- Inorganic secondary aerosols
- Ozone (at low altitudes, can react with many other chemicals)

Effect of smog on health has been known since the Industrial Era

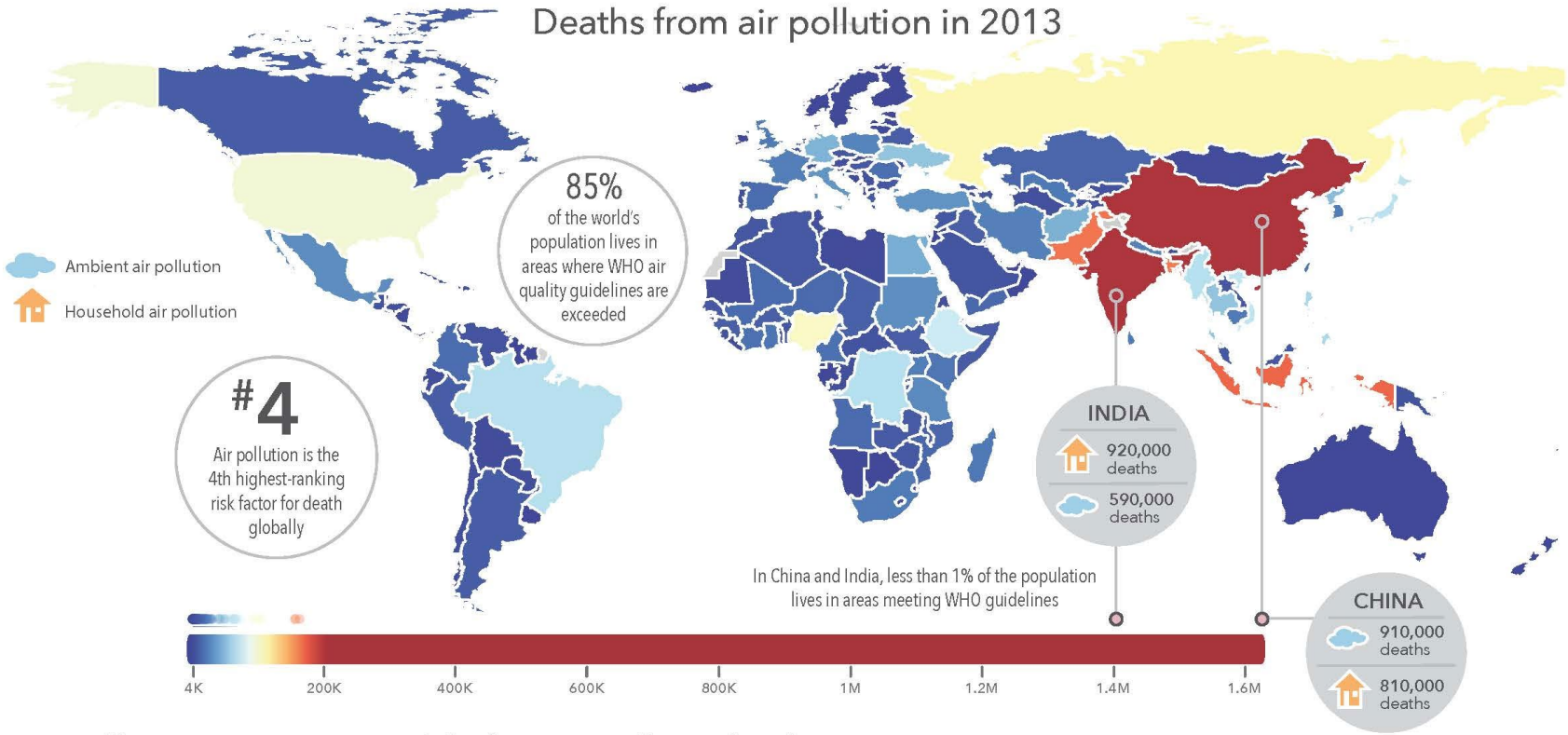
- Increase in urbanization since the 1950s has driven more research
- Kelly and Fussell, 2015
  - *For details on toxicity*
- Pagalan et al. 2019
  - *Prenatal exposure to air pollution associated with autism spectrum disorder*



Death toll and pollution concentrations during the 1952 London Smog. *Source*: Wilkins (1954)

Copied from Kelly and Fussell, 2015

Global Burden of Air Pollution



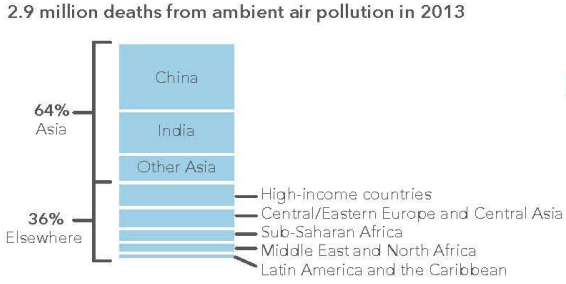
Air pollution was responsible for 5.5 million deaths in 2013

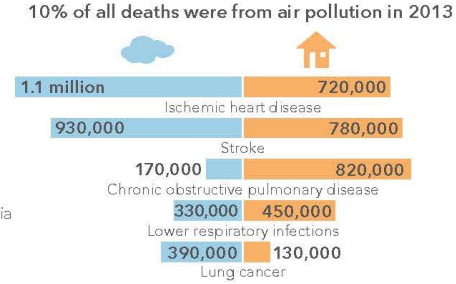
Household air pollution
Caused by burning solid fuels for heating and cooking, including:

- Coal
- Wood
- Dung

Ambient air pollution
Caused by emissions from things like:

- Power generation
- Transportation
- Agriculture
- Open burning
- Household air pollution



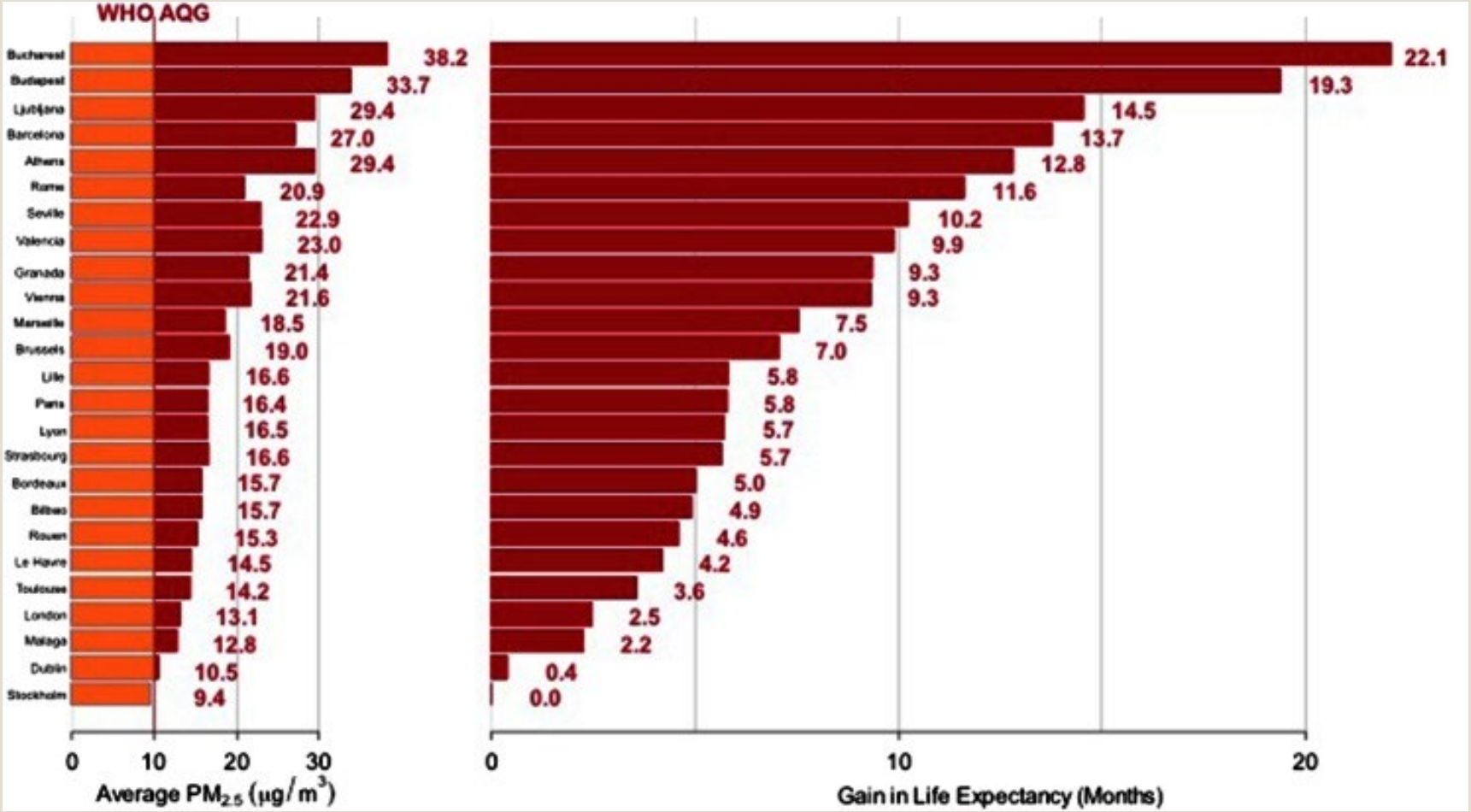


Source:

1. Forouzanfar MH, et al. Global, regional, and national comparative risk assessment of 79 behavioral, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990-2013: a systematic analysis for the Global Burden of Disease Study 2013. *The Lancet*. 2015 Dec 5;386(10010):2287-323.
2. Brauer M, et al. Ambient air pollution exposure estimation for the Global Burden of Disease 2013. *Environmental Science & Technology*. 2016 Jan 5;50(1):79-88.

IHME | UNIVERSITY of WASHINGTON

Predicted average gain in life expectancy (months) for persons 30 years of age and older in 25 Aphekom cities for a decrease in average annual level of $PM_{2.5}$ to 10 µg/m^3. *Source*: Aphekom project, InVS (Aphekom 2011)

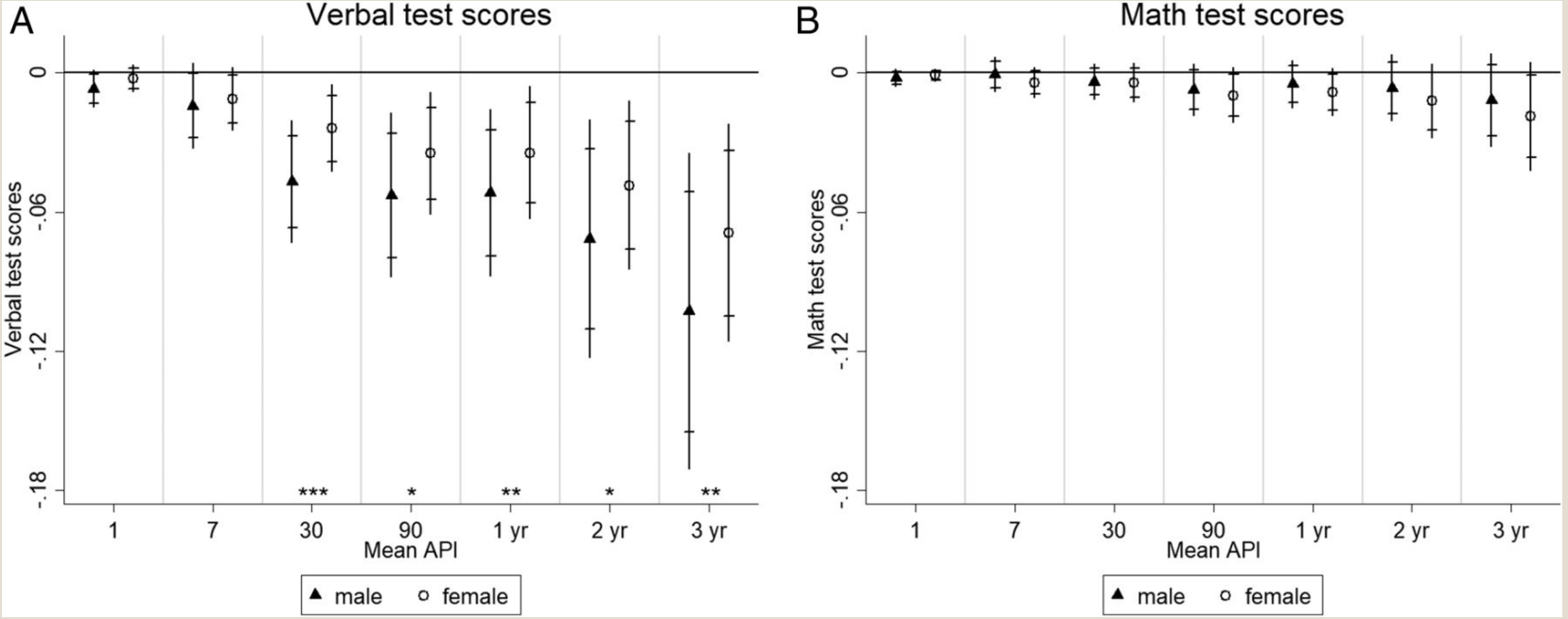


Copied from Kelly and Fussell, 2015

Smog and mental health

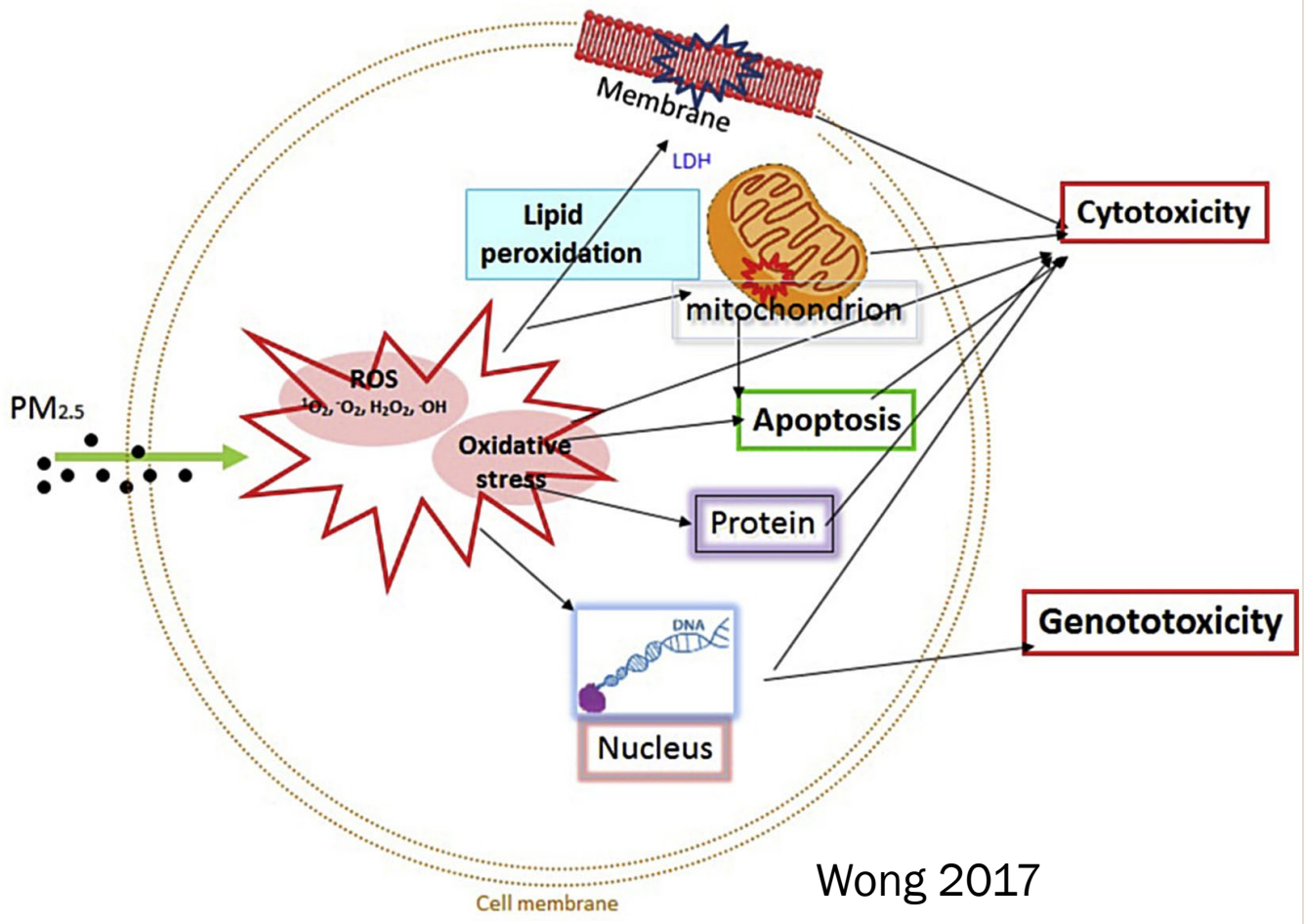
- Chen et al. 2017 measured university students for psychopathology before and after 7 days of intense smog exposure
  - "higher levels of positive symptom distress, obsessive-compulsive symptoms, interpersonal sensitivity, depression, and psychoticism"

- Zhang et al. 2018 air pollution index (API) reduced verbal cognition and, to a lesser extent, math skill



Absorption of air pollution chemicals across mucous membranes impacts human cells via chemical reactions that cause oxidative damage

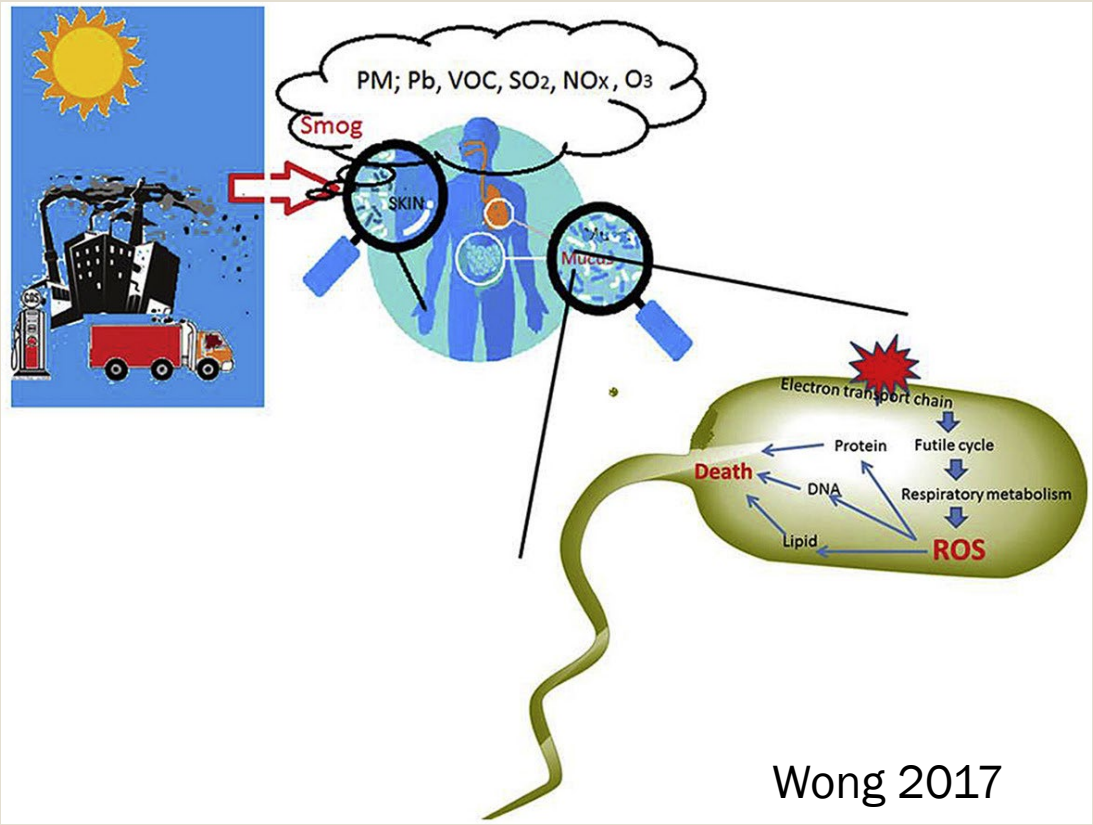
See also Kelly and Fussell, 2015



Wong 2017

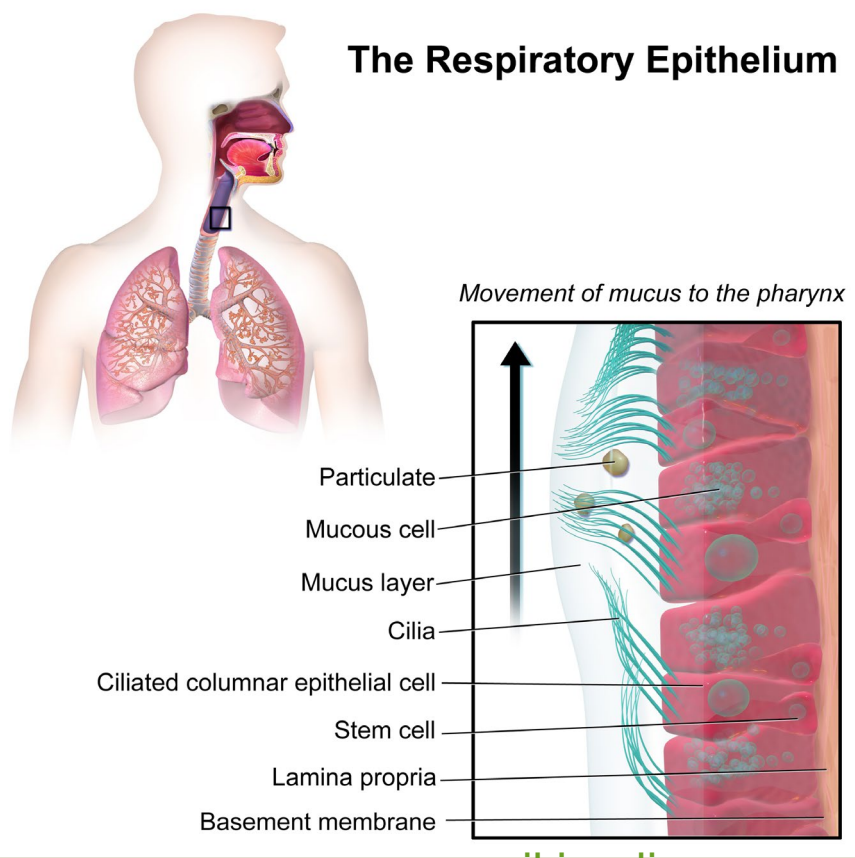
Absorption of air pollution chemicals across mucous membranes impacts host-associated microbes

Figure 3. Sunlight activates the pollutants in the air and fog, causing the formation of smog. Bacteria on the surface of our skin and mucus are the first to encounter the harmful elements in smog. These elements could uncouple the electron transport chain of the bacterium and induce ROS formation, which subsequently damage protein, DNAand lipid, leading to cell death.
ROS = reactive oxygen species;
PM = particulate matter.



In addition to ingestion, PM is cleared from lungs to back of throat where it is swallowed for digestion/destruction (smokers, Möller at al. 2004)

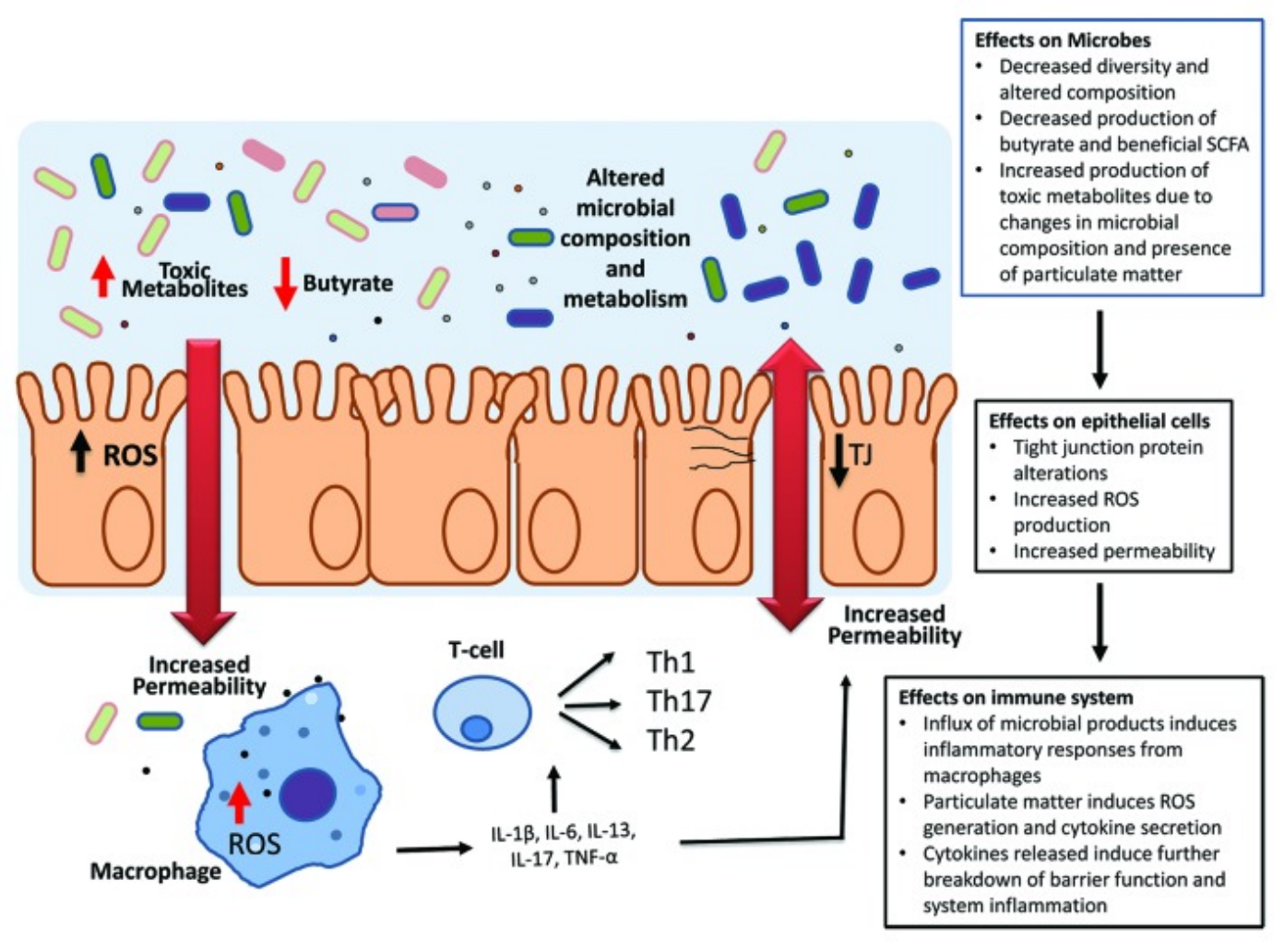
- Pseudostratified ciliated columnar epithelia cell lining
  - *Single layer that is squished (Pseudostratified)*
  - *Column shaped*
  - *Have cilia*
- Specialized goblet cells secrete mucin (mucus)
- Ciliated to move mucus/debris out of lungs and into back of throat
  - *swallow and destroy*



ca.wikipedia.org

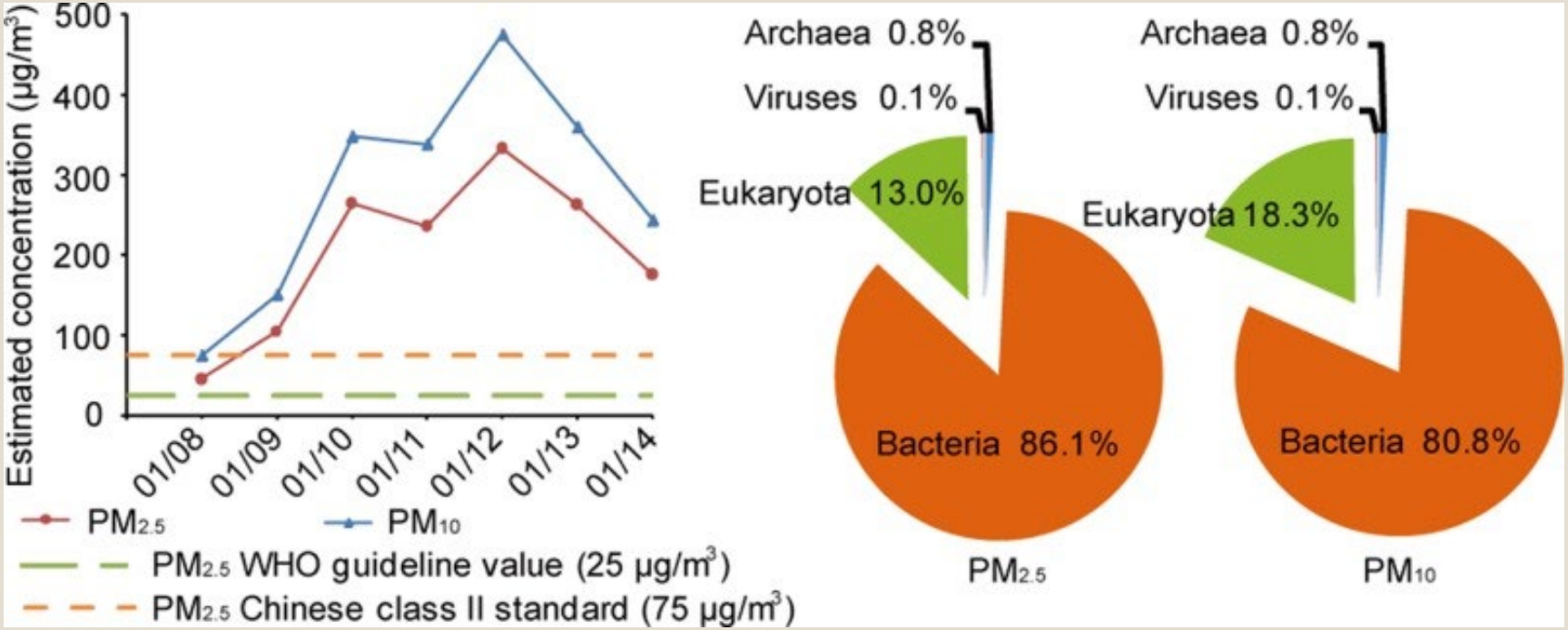
PM in smog may affect gut health and microbes

Salim et al. 2014 speculate that PM may contribute to Irritable Bowel Disease (IBD)



Microorganisms also part of air pollution

Cao et al. 2014 Beijing smog events



Air around landfills has lots of bacteria and fungi

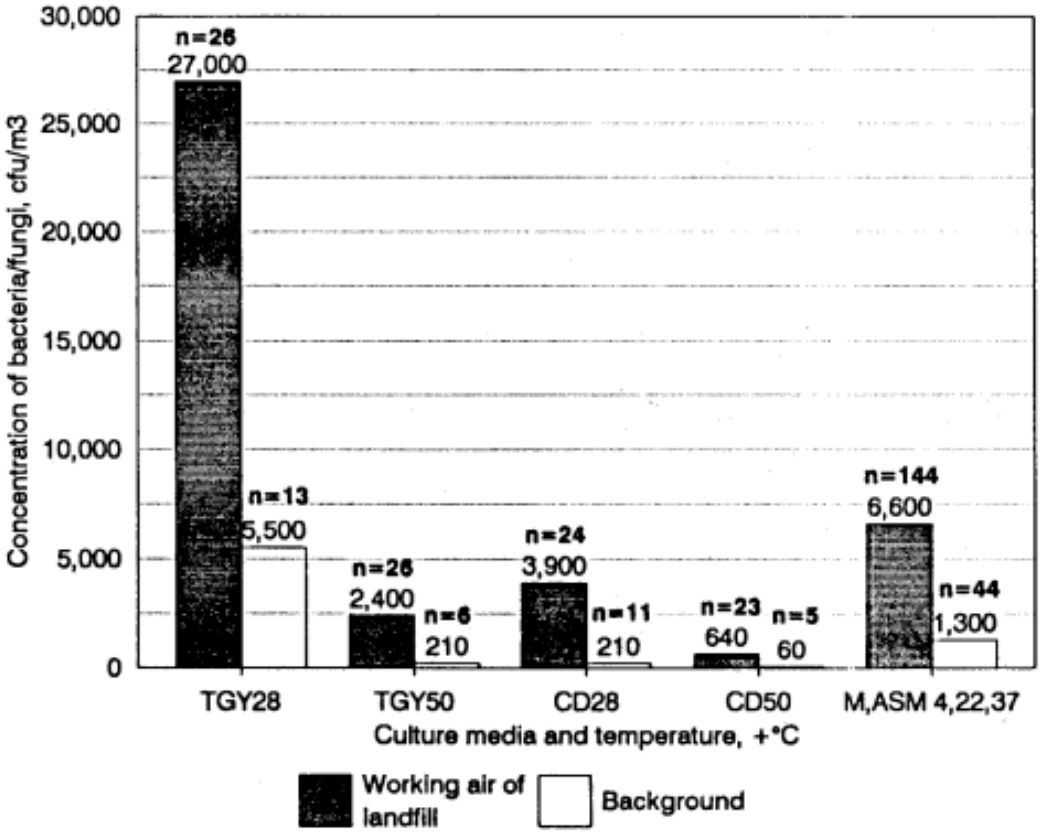


FIGURE 1. Concentrations of microbes in the working air of the landfills and in the background air.

Rahkonen et al. 1989

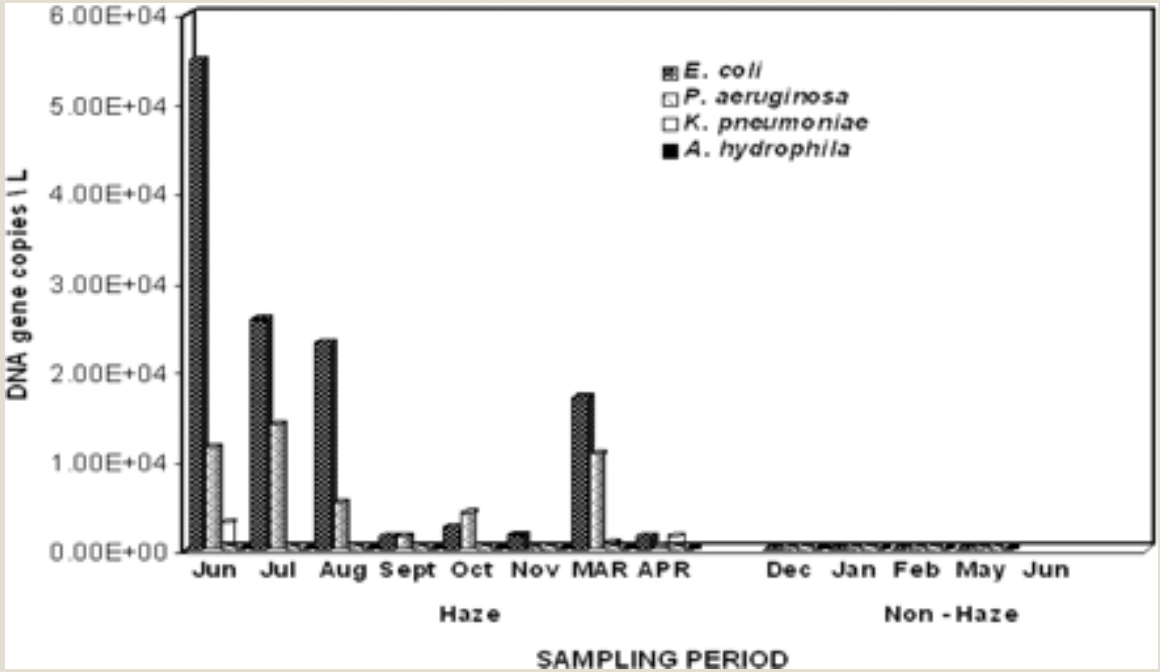
Children living in slums near landfills produced more breath methane

- Living in slum next to landfill = more likely to produce measurable breath methane
- Living in slum next to landfill = produced more methane
- Regardless of socio-economics

	Slum near the landfill	Slum away from the landfill	High socioeconomic group	*P*
Breath CH_4 producer prevalence	53.1% (59/111)[a]	31.4% (11/35)[b]	21.9% (7/32)[b]	0.001[2]
CH_4 in breath CH_4 producers ppm	24 (18.0–35.0)[a]	17.0 (10.0–31.0)[b]	17 (11.0–19.0)[b]	0.007[1]

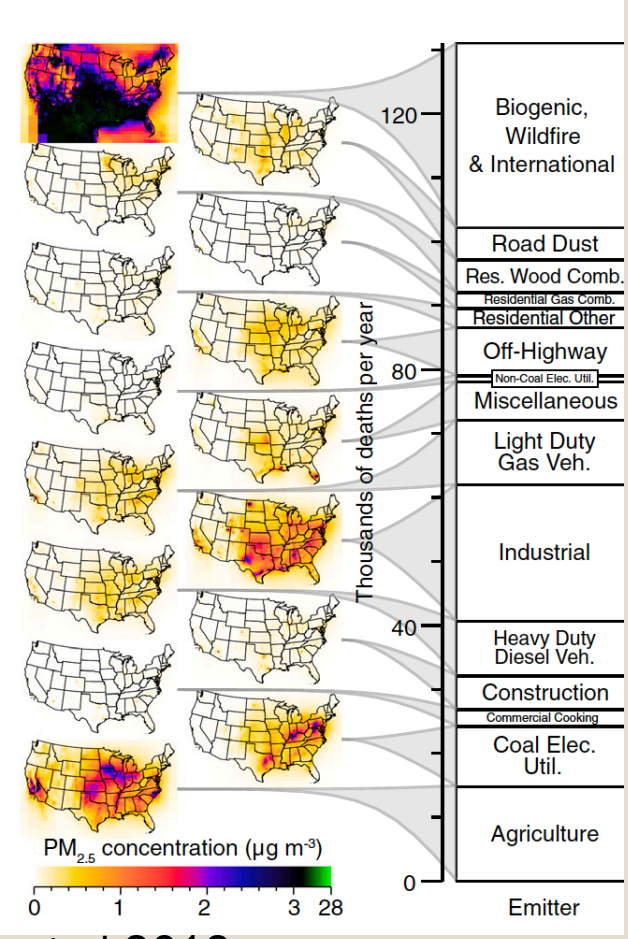
Bezerra de Araujo Filho et al. 2014

It's raining pathogens: smog from biomass-burning events in Sumatra contaminated rain water in Singapore



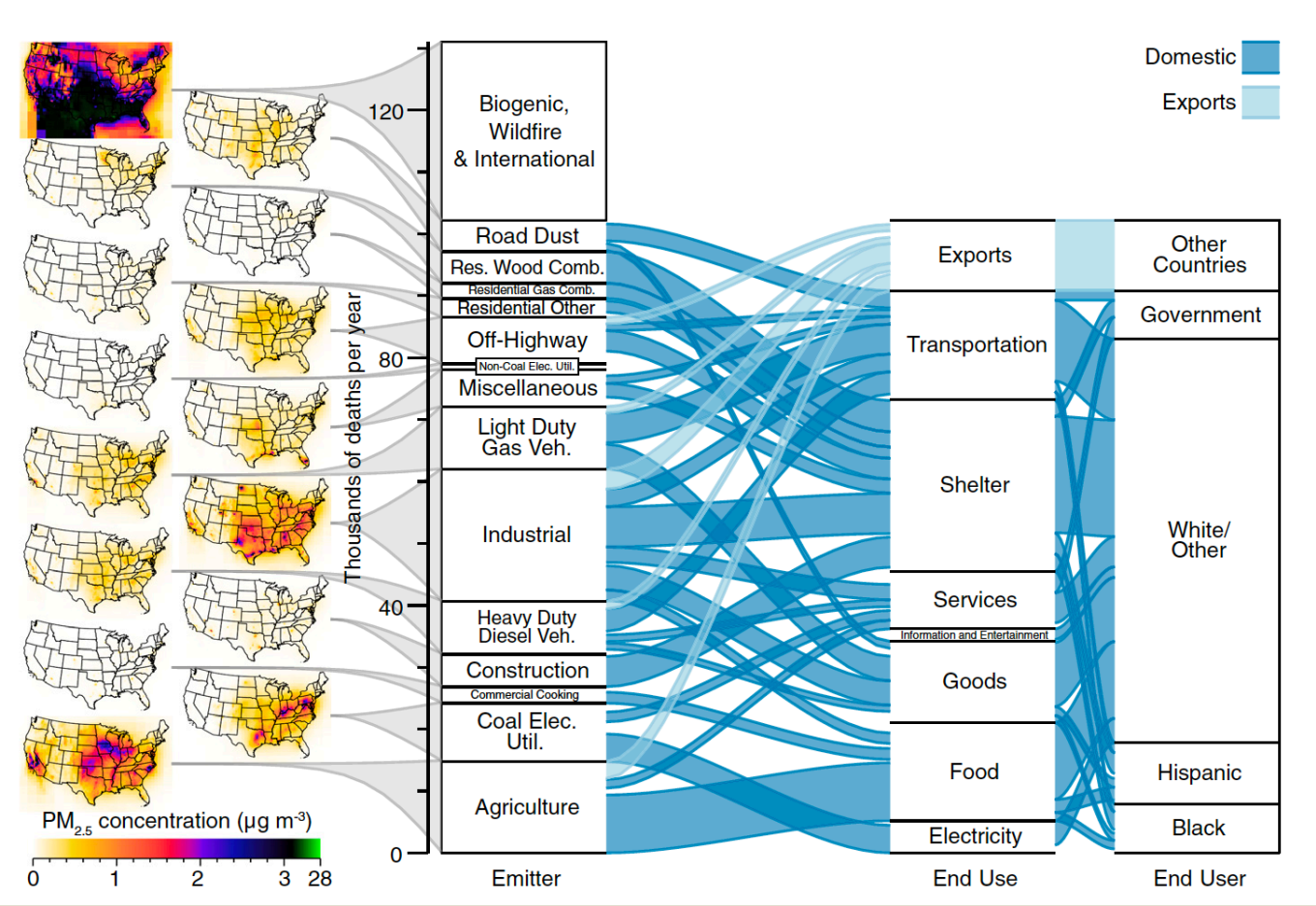
- Didn't specify if wildfire or intentional field burning
- Haze = smoke
- Kaushik et al. 2012

Air quality in the US often from wildfires, industry, agriculture



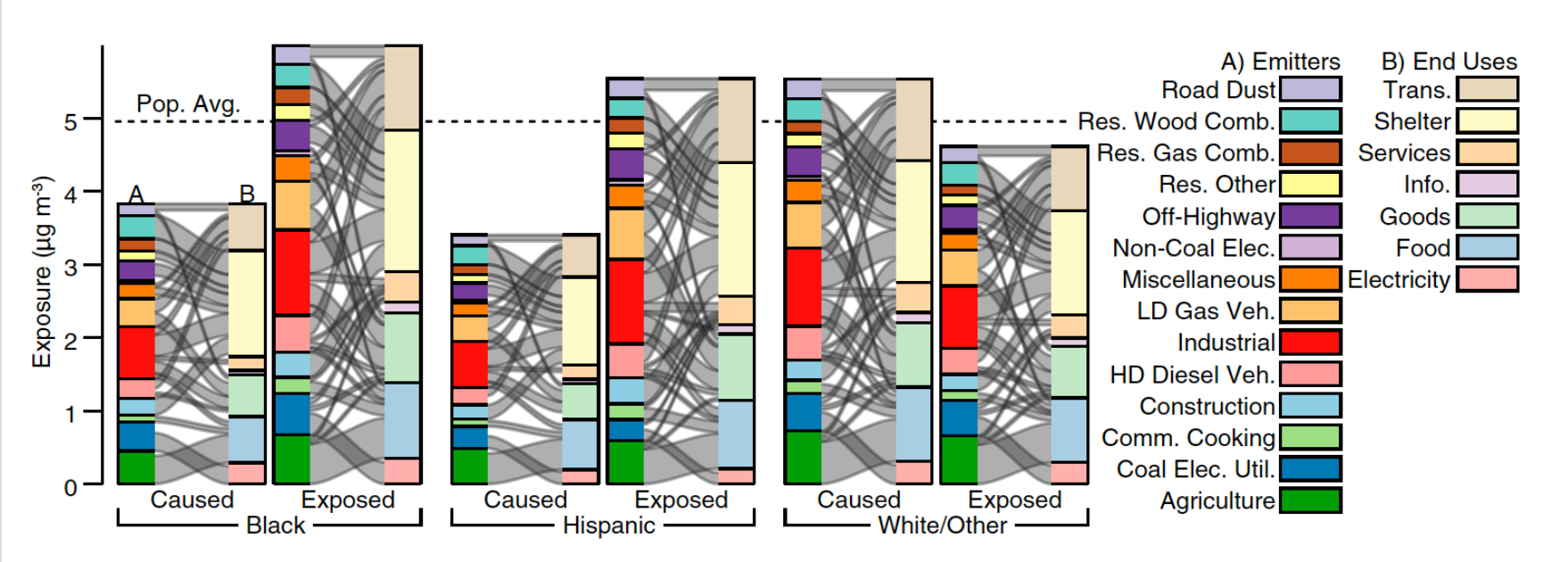
Tessum et al.2019

Race disparity in who is end user for goods/services produced during creation of air pollution



Tessum et al.2019

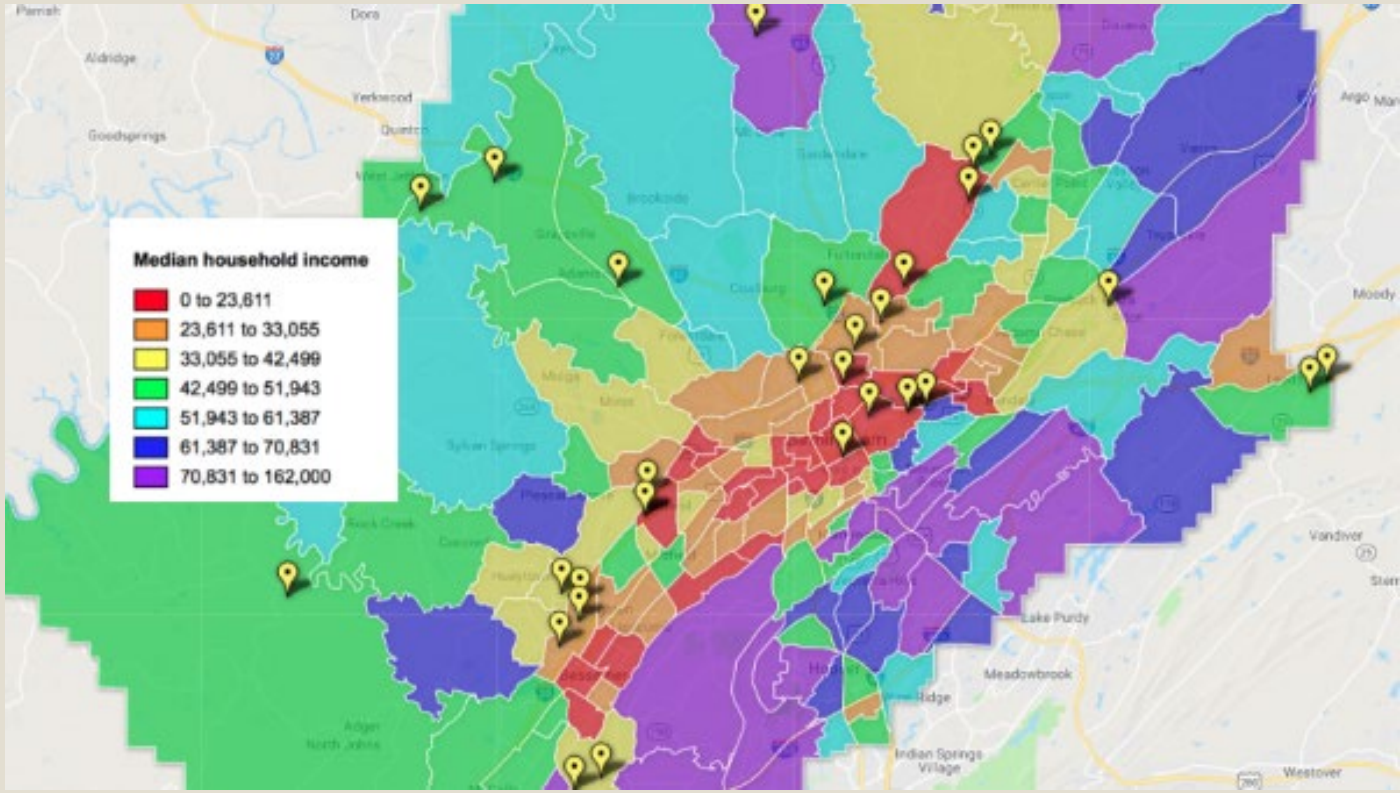
Disparity in how much air pollution is created on your behalf vs. how much you are exposed to



Tessum et al.2019

Air quality disparity is tied to socioeconomic status and zoning

Also see:
Clark et al. 2014
Hajat et al. 2015

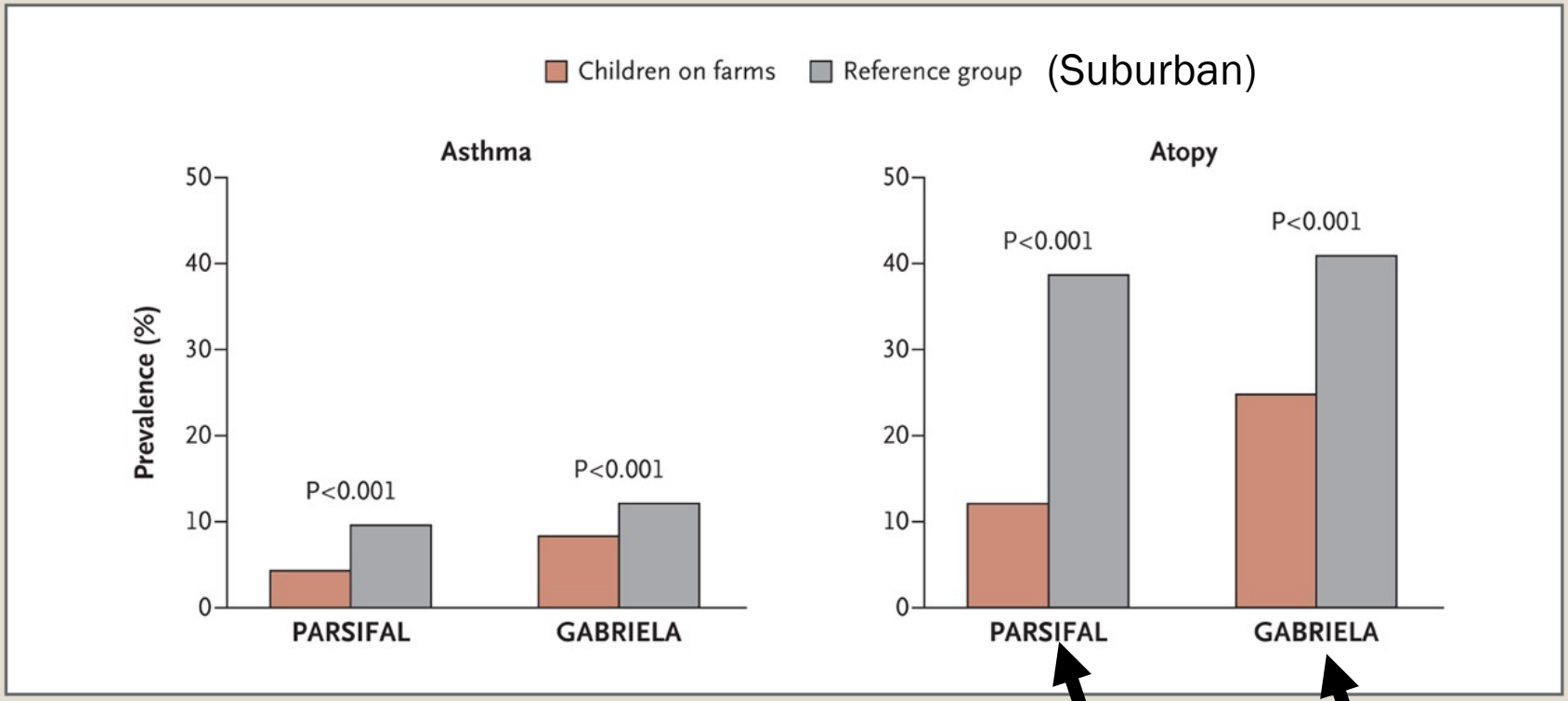


Licensed Polluters: Yellow markers identify potential major pollution emission sites. Map is color-coded to show median incomes in Birmingham, AL, 2018.
Source: Clay Carey, BirminghamWatch, https://wbhm.org/2018/countys-major-air-polluters-concentrated-in-low-income-minority-neighborhoods/

BENEFICIAL ENVIRONMENTAL EXPOSURE

Rural vs. urban and good microbial exposure

Studied 16,500 children in Germany



Ege et al. 2011

Names of the cohorts

INCREASING OUR IMMUNE SYSTEM

How would microbial exposure be beneficial?

- Very high diversity of microbes in soil
  - *Regular exposure to them builds up our antibodies against them*
  - *Tested using sensitivity tests, exposure you to an antigen and measure your immune reaction*
  - *“sensitivity” means your immune system reacts to something*

Why would environmental microbial exposure be beneficial?

- People in Malawi, Africa have antibodies to many different fungi found in the environment
- Exposure to slow-growing fungi (like this one) was not associated with lower rates of tuberculosis or leprosy (both caused by bacteria)
- Exposure to fast-growing fungi (like this one) **was** associated with lower rates of tuberculosis or leprosy (both caused by bacteria)

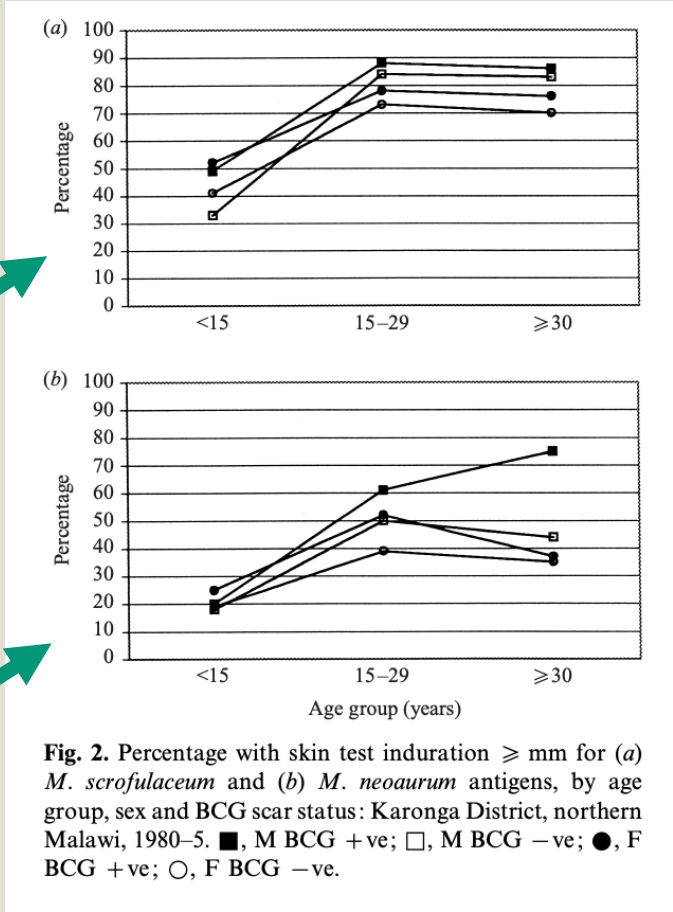


Fig. 2. Percentage with skin test induration ⩾ mm for (*a*) *M. scrofulaceum* and (*b*) *M. neoaurum* antigens, by age group, sex and BCG scar status: Karonga District, northern Malawi, 1980–5. ■, M BCG +ve; □, M BCG −ve; ●, F BCG +ve; ○, F BCG −ve.

Fine et al. 2001

INCREASING OUR MICROBIAL DIVERSITY?

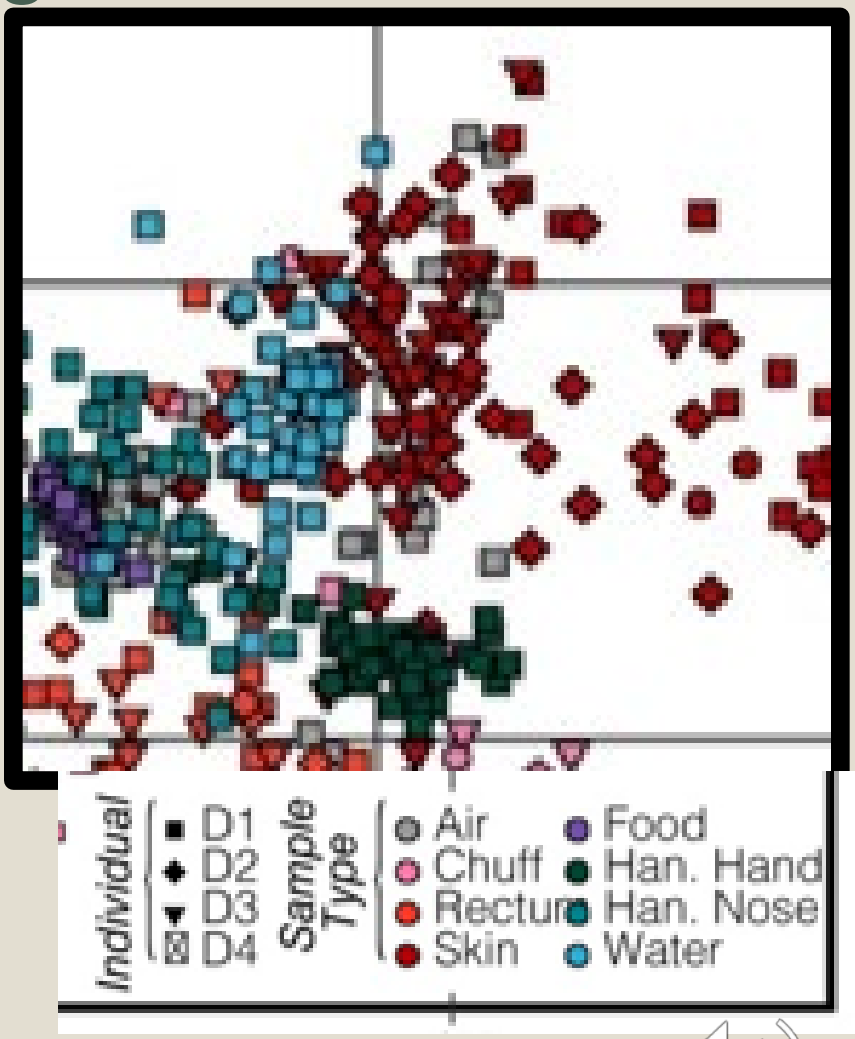
Skin maybe short term, gut maybe yes?

Environmental sources of bacteria can affect host communities

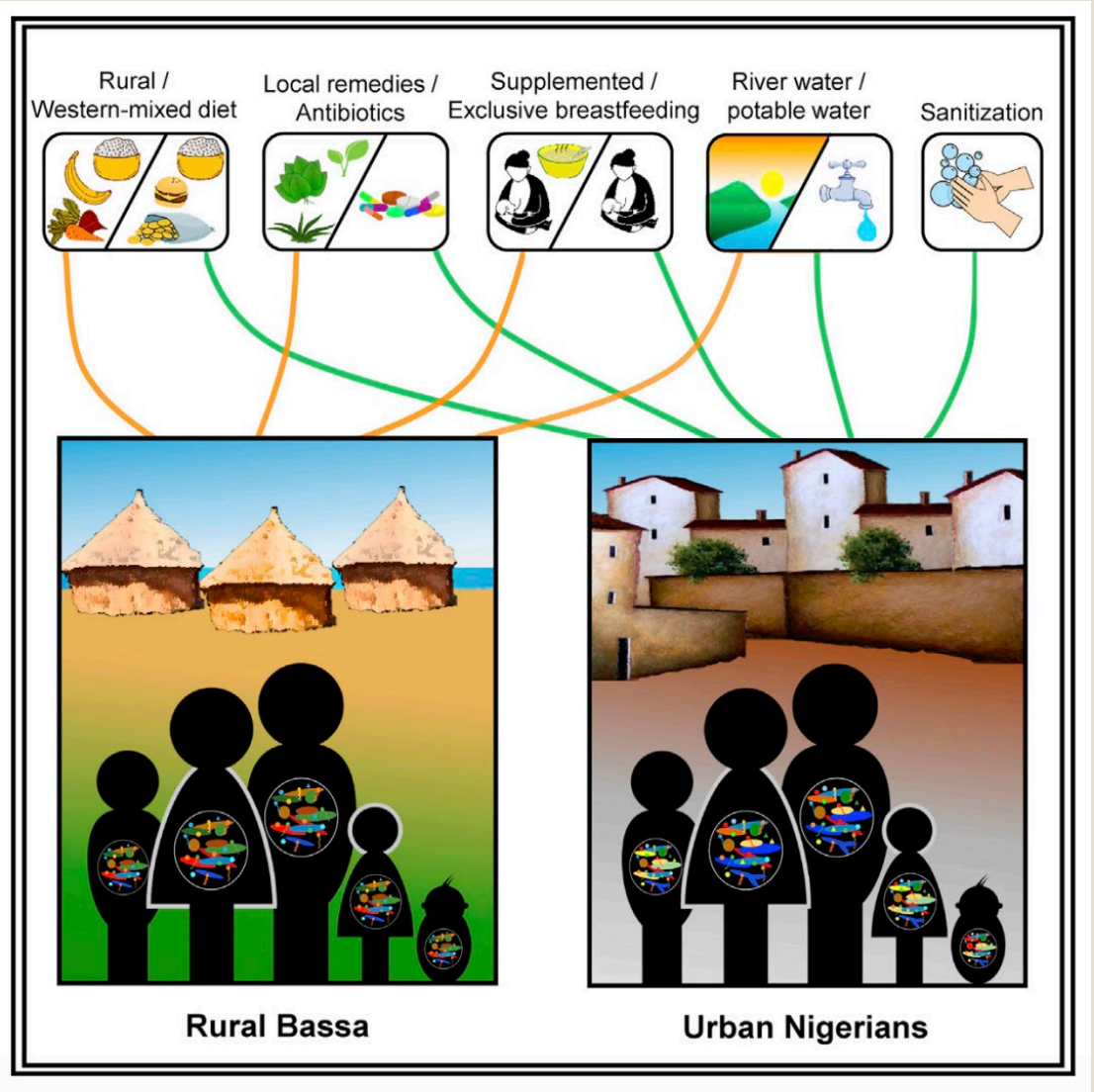
Cardona et al. 2018

- Bacteria on dolphin skin similar to bacteria in air and in aquarium water

- Change in water chemistry caused change in water bacteria
- But only slight increase in skin richness
- No change in overall skin community
  - Not many interactions between env. And skin result in colonization

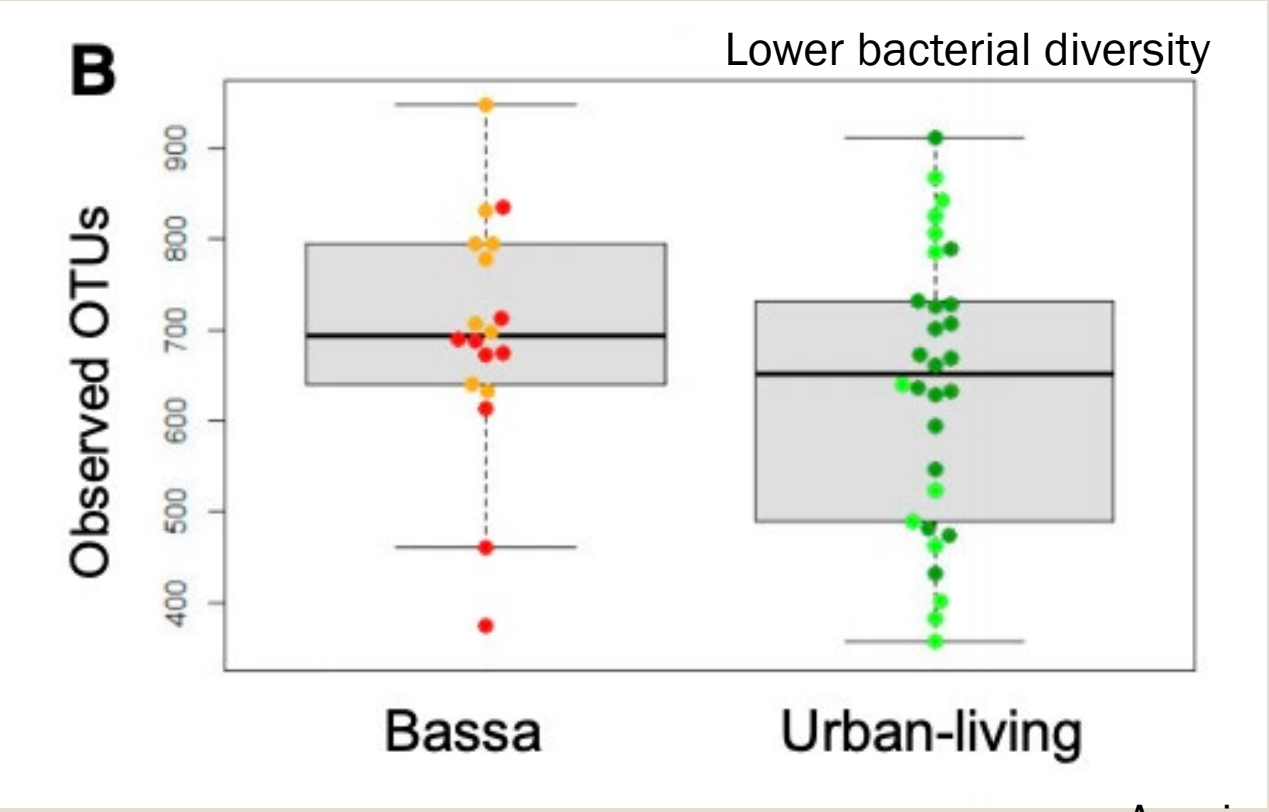


Urban living conflated with different diet, social interactions, exposure to environment



Ayeni et al. 2018

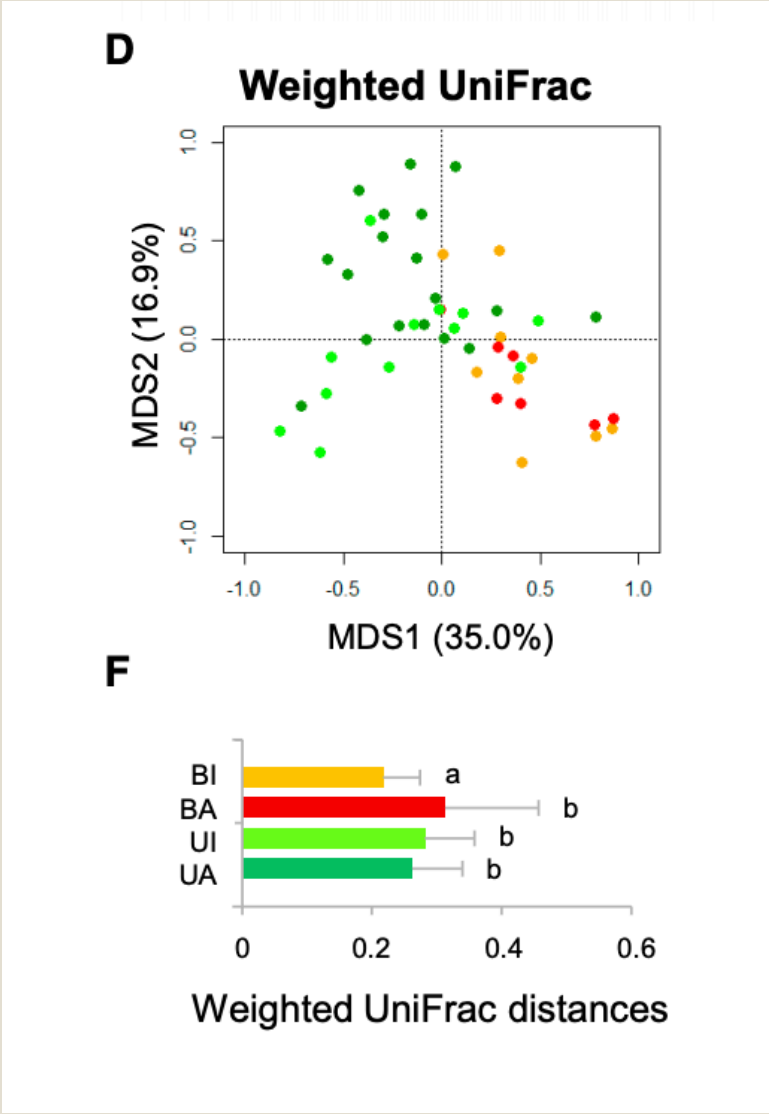
Urban living associated with changes in gut microbiome



Ayeni et al. 2018

Urban living associated with changes in gut microbiome

- Bacterial community was less similar between adults in urban area
  - Green dots spaced further apart
- Meaning urban adults had more unique gut community
- Maybe less transmission of typical host-associated microbes and reinforcing good microbial transmission?



Ayeni et al. 2018

MICROBIAL/TOXIN CO-EXPOSURE MODULATES OUR CELLS

“Biogenics” hypothesis

- (paraphrased) Regular exposure to low concentrations of mixtures of natural compounds and toxins in natural environments confers health benefits by altering the activities of humans cell

- Moore, 2015

Microbial products (from natural environments) interact with our cells

Table 1
Summary of various types, sources and targets/effects of potential airborne biogenic chemicals that could influence human health if ingested (see references below).

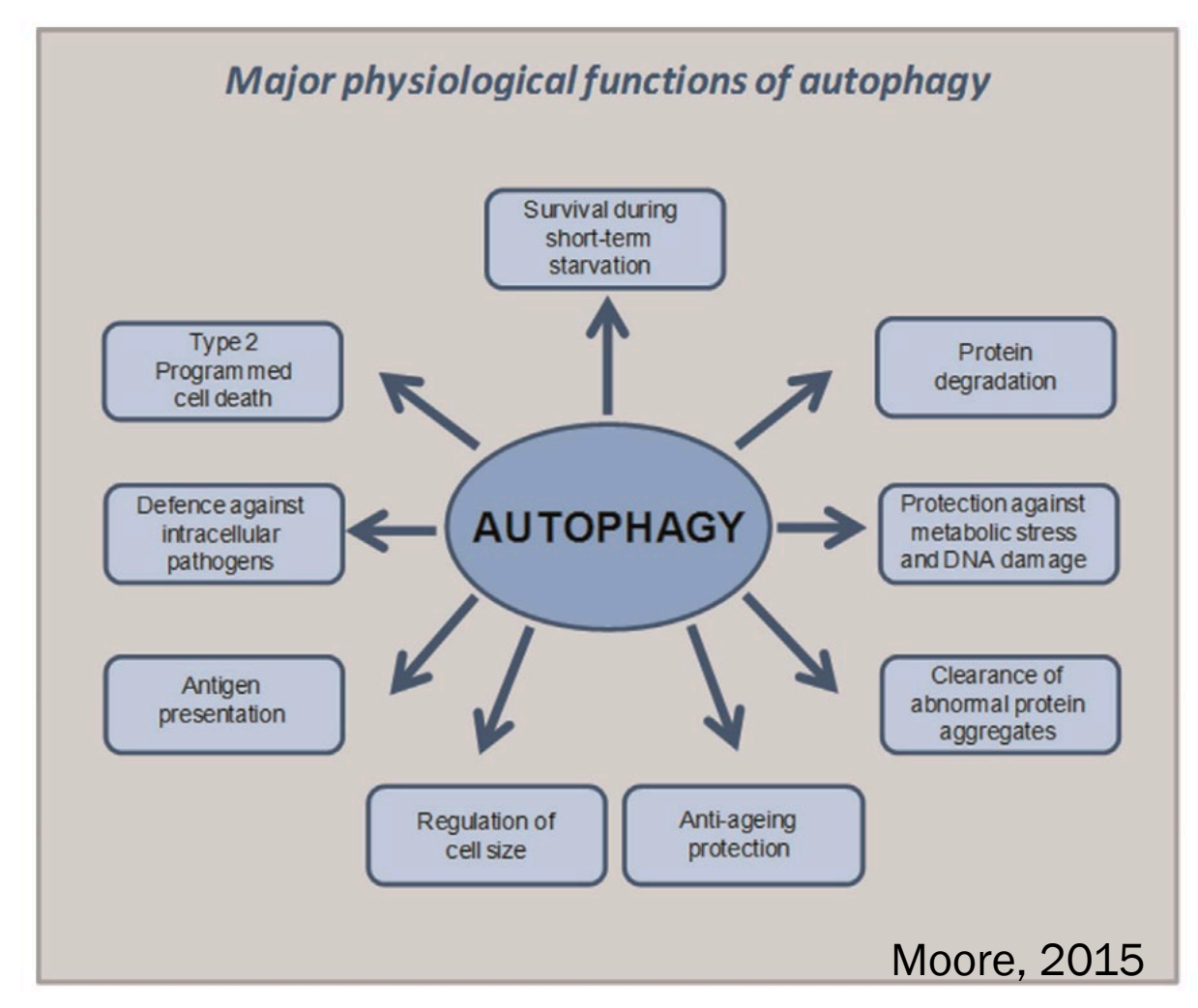
Biogenic product	Origin	Potential biological target or effect
Bacterial toxins	Soil particles, seawater aerosols	Inhibition of specific cell signalling systems (PI3K, mTORC1)
Cyanobacterial toxins	Seawater aerosols, soil particles	Inhibition of specific cell signalling systems (PI3K, mTORC1)
Antibiotics	Soil particles	Inhibition of specific cell signalling systems (PI3K, mTORC1)
Polyphenolics (flavonoids, anthocyanins, procyanidins, proanthocyanidins, catechins, tannins, humics, etc.)	Soil particles, higher plant abrasion particles, pollen grains, fern spores, fungal spores, macroalgal fragments (brown, green & red)	Inhibition of specific cell signalling systems (PI3K, Akt, mTORC1), PTEN, MAPK/ERK (related to cancer), COX-2, AMPK autophagy, apoptosis, anti-cancer properties, cardiovascular protection, enhanced brain function
Mycotoxins	Fungal spores, soil particles, hay-derived particles	Inhibition of specific cell signalling systems (PI3K, mTORC1)
Pyrrolizidine alkaloids	Higher plant abrasion particles, pollen grains	Carcinogenic, tumorigenic & anti-cancer properties
Terpenoids (monoterpenes, diterpenes, triterpenes)	Higher plants (volatiles)	Apoptosis, autophagy, others
Viral particles or protein fragments	Marine viruses in airborne aerosols	Immune system, inhibition or activation of PI3K, mTORC1, mTORC2

Reviewed in Moore, 2015

Plant/microbial produced products beneficial to our cells

- Volatile phytochemicals (volatile organic chemicals – VOCs)
  - *Ex. terpenoids (terpenes) may benefit human health, possible anti-cancer properties*
- Some terpenoids inhibit NFκB signaling in our cells
  - *NFκB is a protein that increases immune reaction (cytokine production)*
  - *Inhibiting NFκB reduces inflammation and activates autophagy (cell regeneration from removing degraded cell parts)*
- The Japanese practice of "Forest Bathing" or Shinrin-yoku
  - *More on this from Gwynne*
- Reviewed in Moore, 2015

Autophagy – cell regeneration



Moore, 2015

DISCUSSION AND HOMEWORK

Discussion

- Air quality is a global issue – dust, microbes, pollution don't stay put
- Is city planning (ex. location of waste management facilities) a public health issue? An income inequality issue?
- Should we guarantee access to natural environments and their microbes for health?

Homework

- **Reading (pick 1):**
  - *Ideno_2017_forest bathing*
  - *Mills_2019_urban biodiversity and health*
  - *Leong_2018_biodiversity and socioeconomics*

- **Reminder:** Peer-review of someone else's essay. Due 7/10.

Looking for more info?

- POLICY ANALYSIS NO. 823, Zoning, Land-Use Planning, and Housing Affordability, By Vanessa Brown Calder, October 18, 2017: https://www.cato.org/publications/policy-analysis/zoning-land-use-planning-housing-affordability
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Wong 2017 https://www.sciencedirect.com/science/article/pii/S102194981730057 1#fig1

Zhang et al. 2018 https://www.pnas.org/content/115/37/9193