Water Quality and Human Health: The role of Earth observation

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with contributions from:
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How does water quality relate to human health?

Beneficial Effects:

- Health benefits of the environment
- High quality food

Water Quality and Health

Beneficial Effects:

- Health benefits of the environment
- High quality food

Negative Effects:

- Harmful algal blooms
- Infectious diseases

Credit: Sciencing. Effect of water pollution on land

Credit: NOAA

10 Surprising Health Benefits of Going to The Beach

- Vitamin D
- Reduce symptoms of arthritis
- Increases creativity
- Reduce pain
- Soothing smell of air
- Walking on sand: great workout
- Takes away from screen time
- Better sleep
- Good for lungs
- Reduces depression

Jessica Booth, 28 July, 2020

https://www.redbookmag.com/life/g33396215/beach-health-benefits/

Some of these related to anti-inflammatory properties of seawater (salt therapy), and the smell of the ocean (rich in negative ions).

Water quality should be a key criterion for choosing your beach destination. Water clarity and colour are amenable to remote sensing.

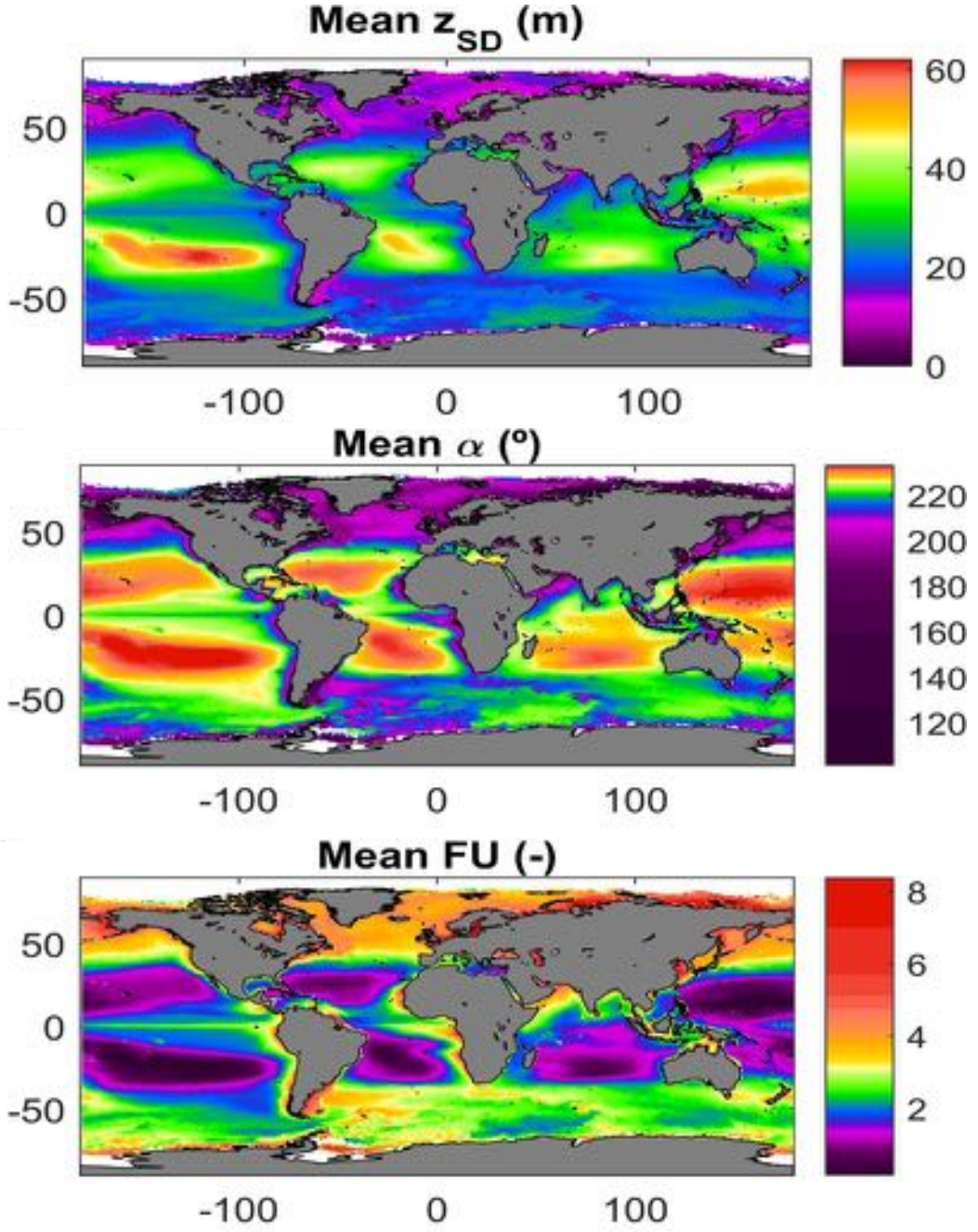
Credit: Good House Keeping

https://www.ecotherapyheals.com/benefits-of-walking-barefoot/

Water quality from space

Indicators of water quality	Some References
Diffuse attenuation coefficient (K_d)	Lee *et al.* (2005), Wang *et al.* (2009)
Turbidity	Nechad *et al.* (2009), Son and Wang (2019), Dogliotti *et al*. (2015)
Water colour (Forel-Ule scale)	Woerd *et al*. (2015); Pitarch *et al*. (2021)
Water clarity (Secchi Depth)	Pitarch *et al*. (2021), Son and Wang (2020)
Suspended sediment load	Volpe *et al.* (2011), Son and Wang (2012)
Euphotic zone	Lee *et al.* (2007)

Note: Chlorophyll concentration is also an excellent indicator of water quality.



Global Scale. Pitarch *et al.* (2021)

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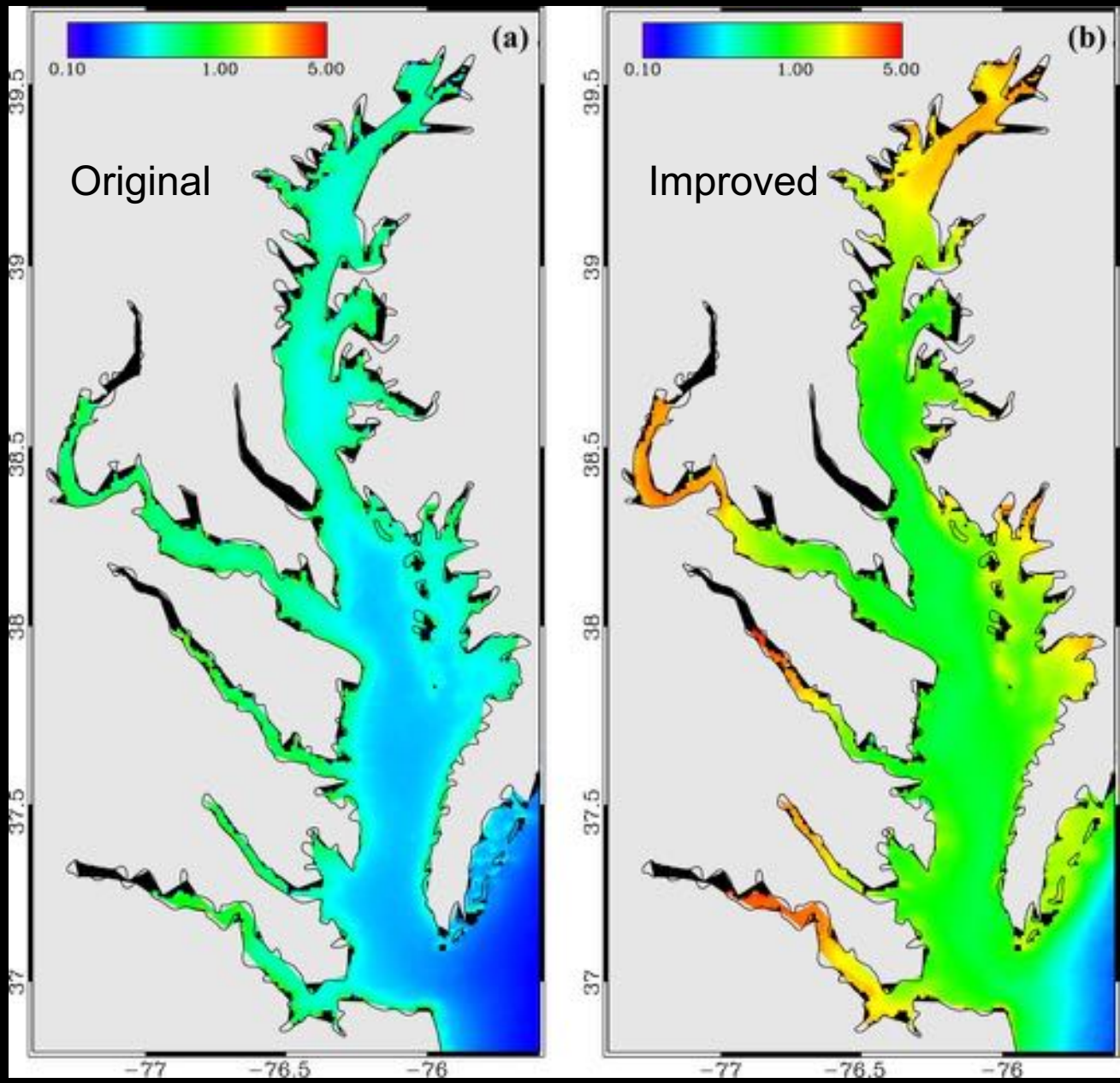

Regional scale. Chesapeake Bay K_d (490) Wang *et al*. (2009)

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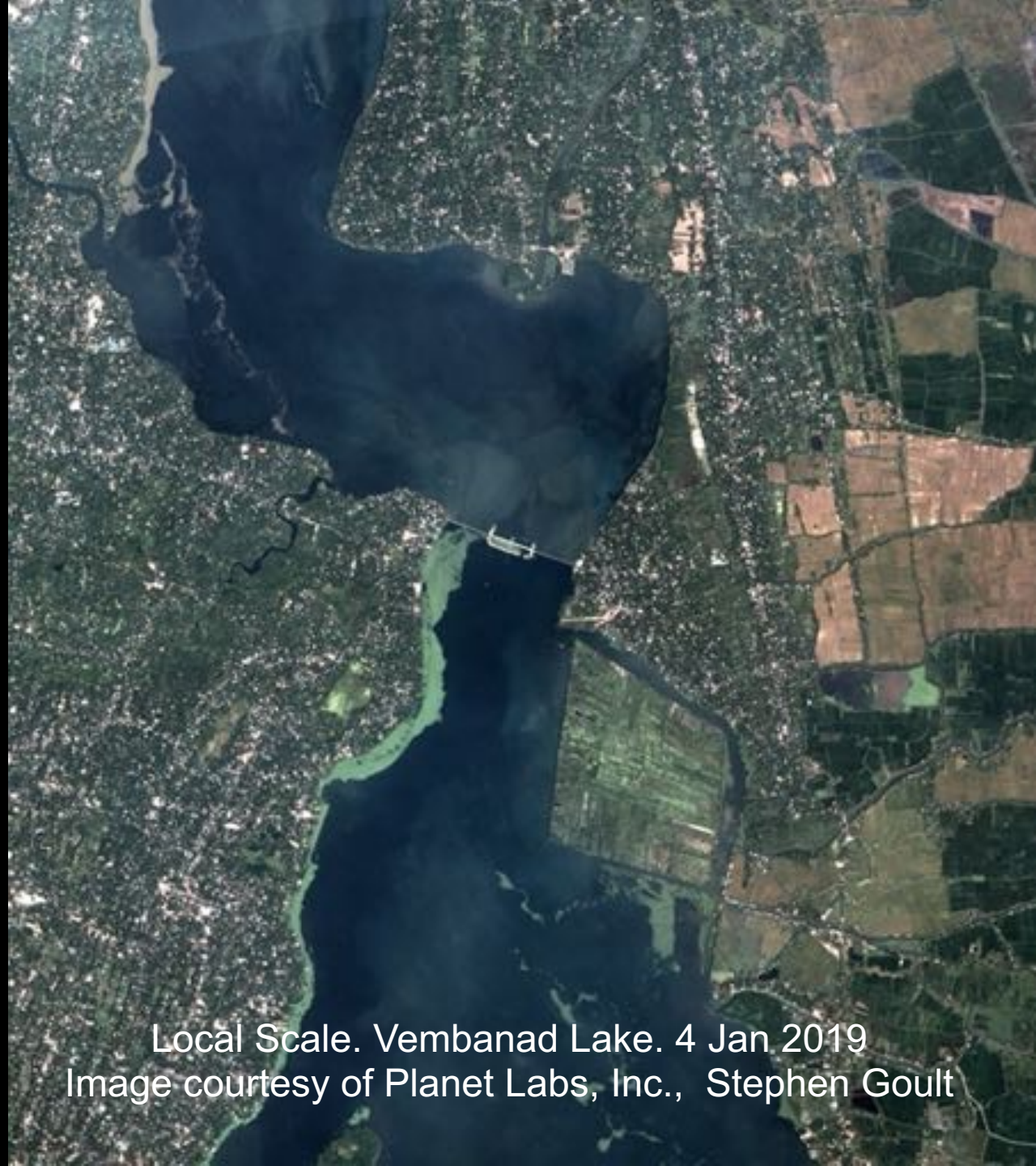


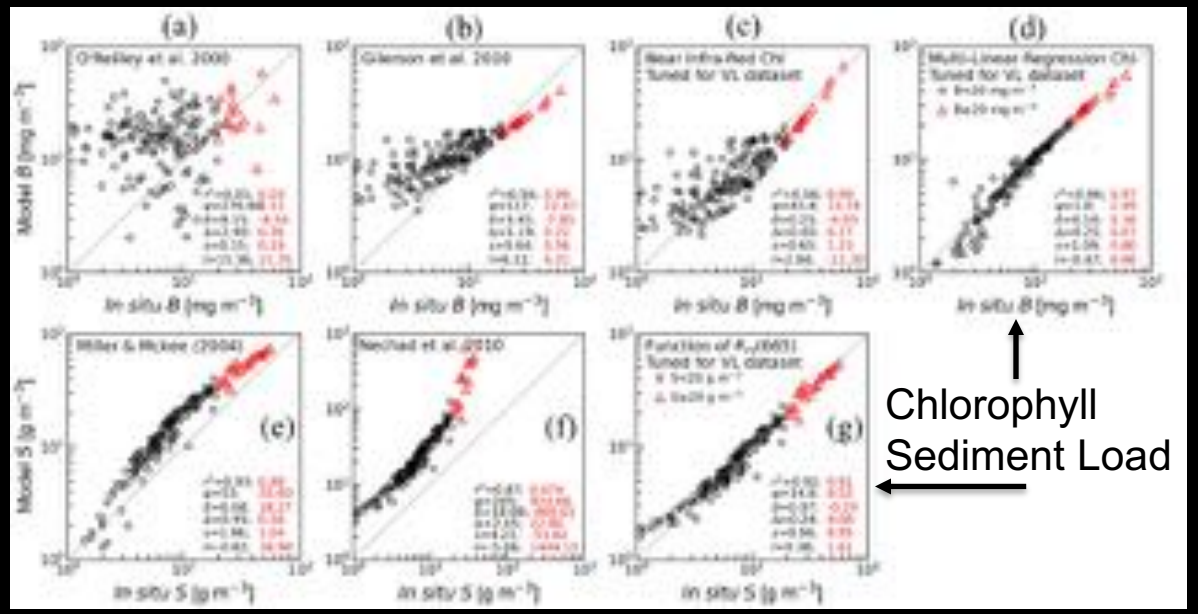
Local Scale. Vembanad Lake. 4 Jan 2019
Image courtesy of Planet Labs, Inc., Stephen Goult

Regional and Local Scales

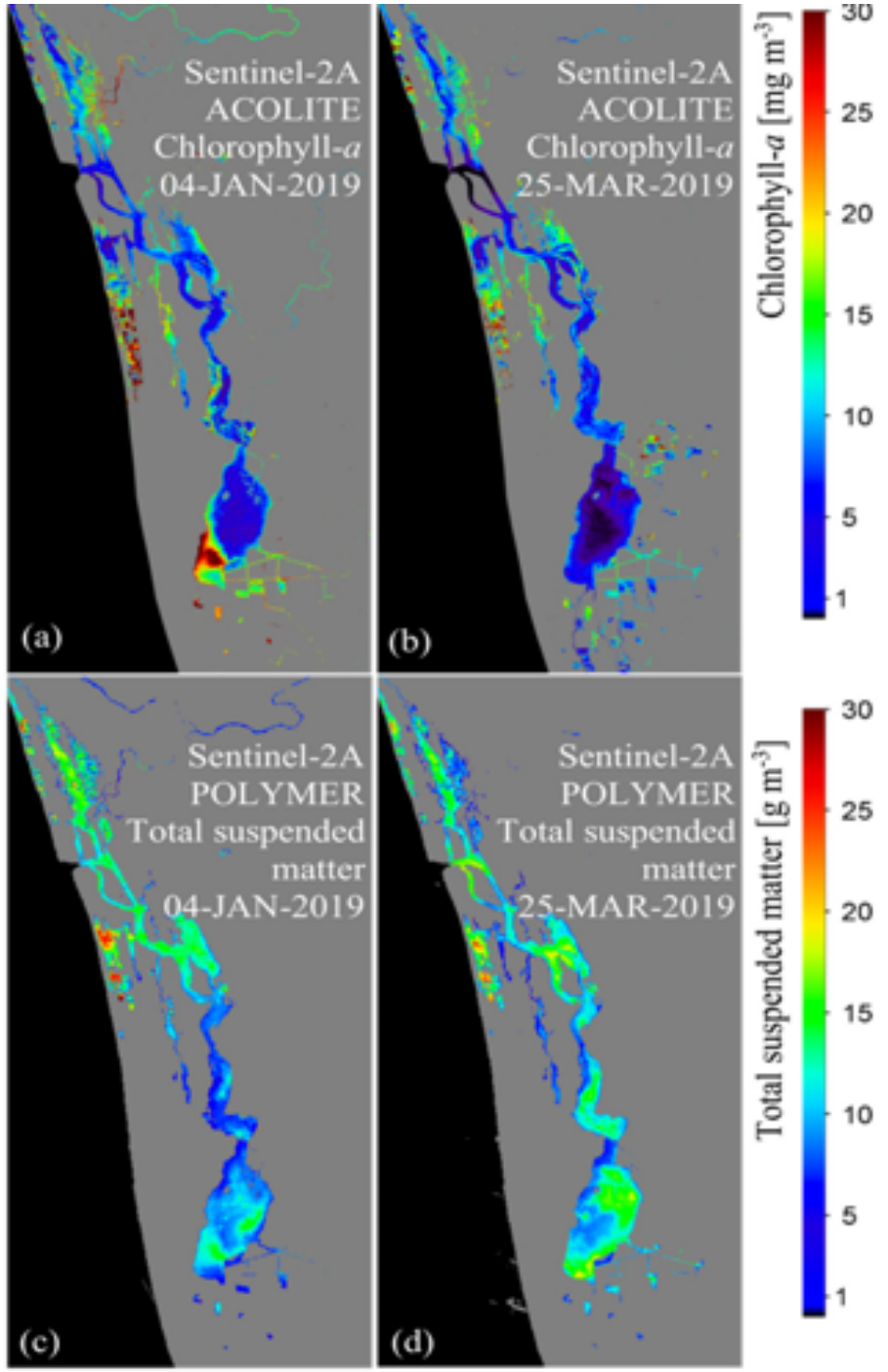
Always useful to have local observations
- Algorithm development
- Validation

Important to test various steps
- Atmospheric correction
- In-water algorithms

Note: you never have enough data!



Example: Theenathayalan et al. 2023



Health benefits of food from the sea

Oceans and inland waters are a source of:

- High protein food
- High quality food

Image: World Atlas

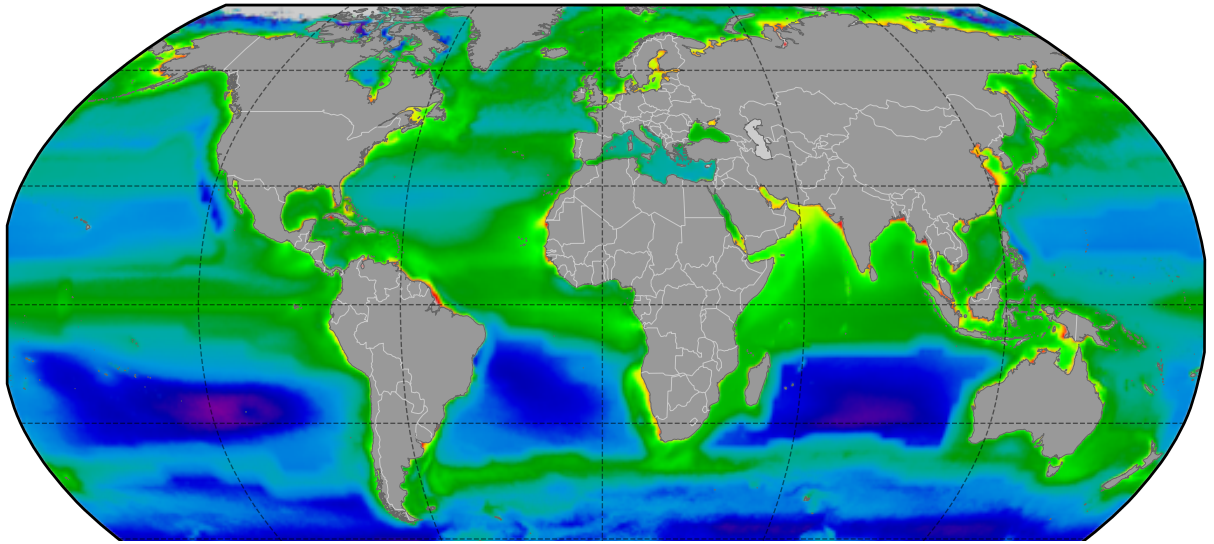
“Longevity Herbs and Superfoods
Marine Phytoplankton Powder
Raw Omega 3 EPA
Vegan ATP Energy Superfood”
£106 for 100 Grams

From Phytoplankton to Fish

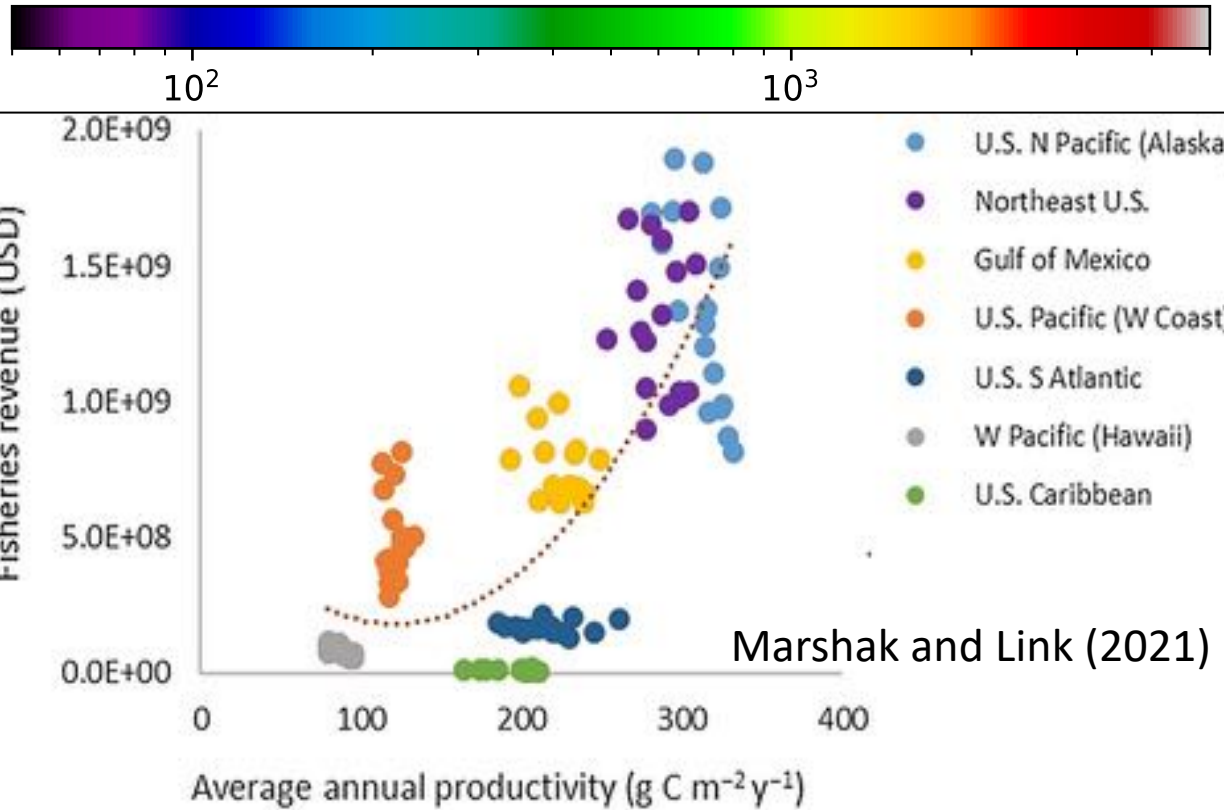
Fisheries production (and revenue) depends on:

- Primary production
  - Magnitude
  - Phenology

- Water quality
  - Light penetration
  - Water clarity
  - Water colour



Primary Production mg C m^{-2} day^{-1} (Kulk et al. 2020, 2021)



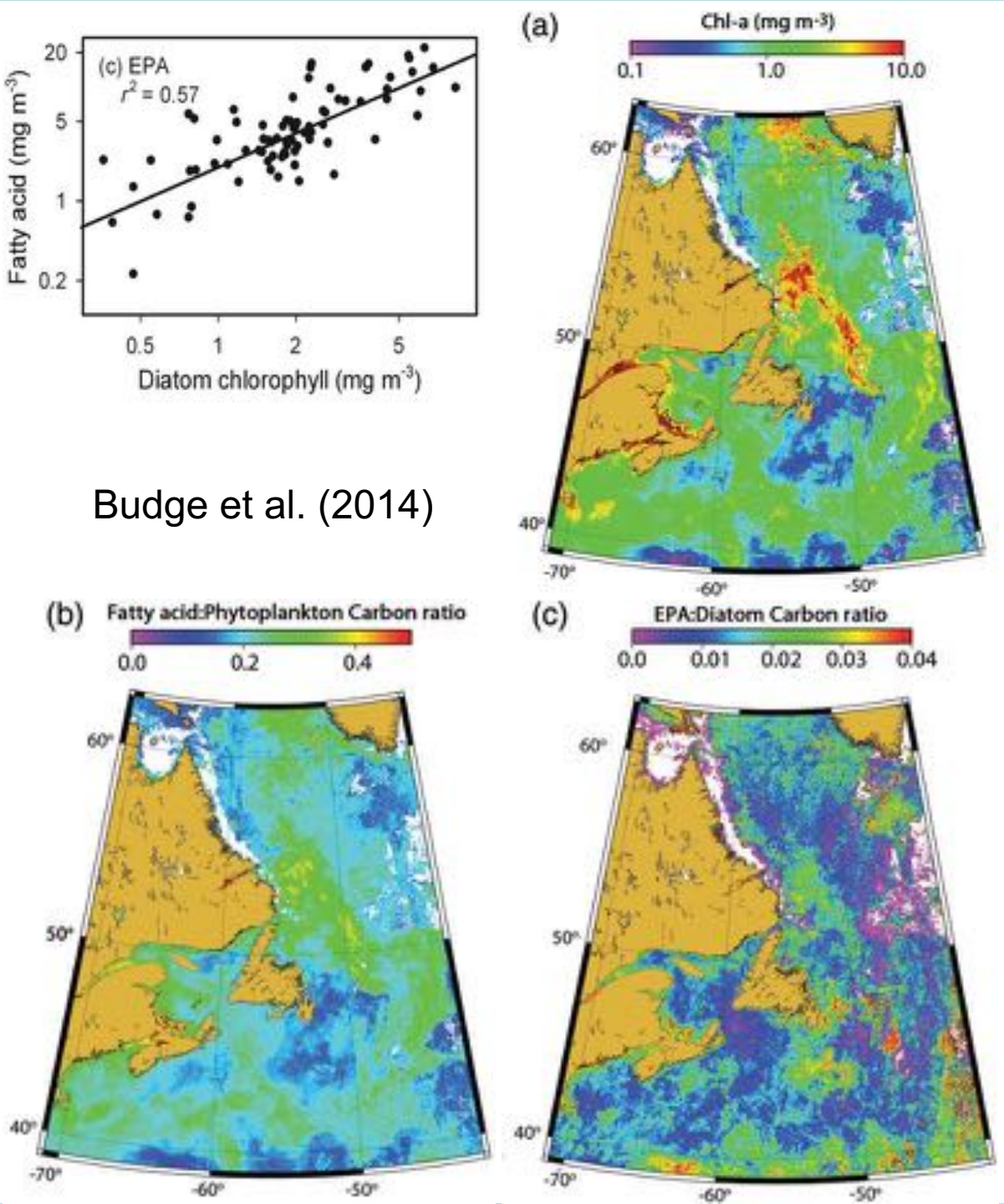
Marshak and Link (2021)

Essential Food from the Sea

Phytoplankton are a source of Essential Fatty Acids

- Essential for health and survival of vertebrates.
- Different classes of phytoplankton produce FAs with differing structures
- For example, 16:4n-1 is synthesized almost exclusively by diatoms
- Diatoms also produce EPA (Eicosapentaenoic Acid), an essential omega-3 FA
- Climate-induced fish community transitions could be linked to availability of essential FAs in the ocean (Litzow et al., 2006).

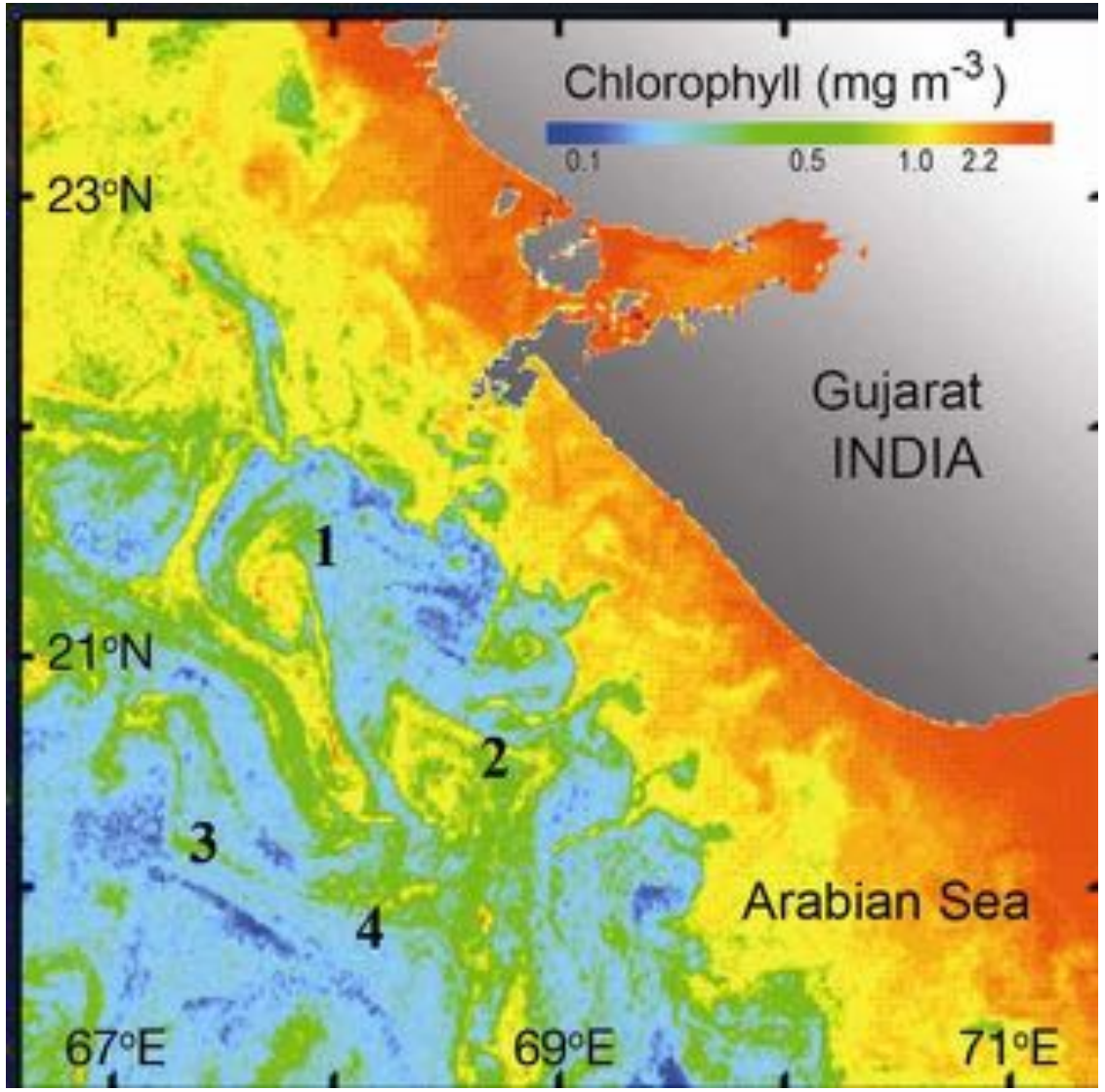
Remote sensing: from chlorophyll to diatom-chlorophyll to EPA (Budge et al. 2014).



Budge et al. (2014)

Support to Fisheries Operations

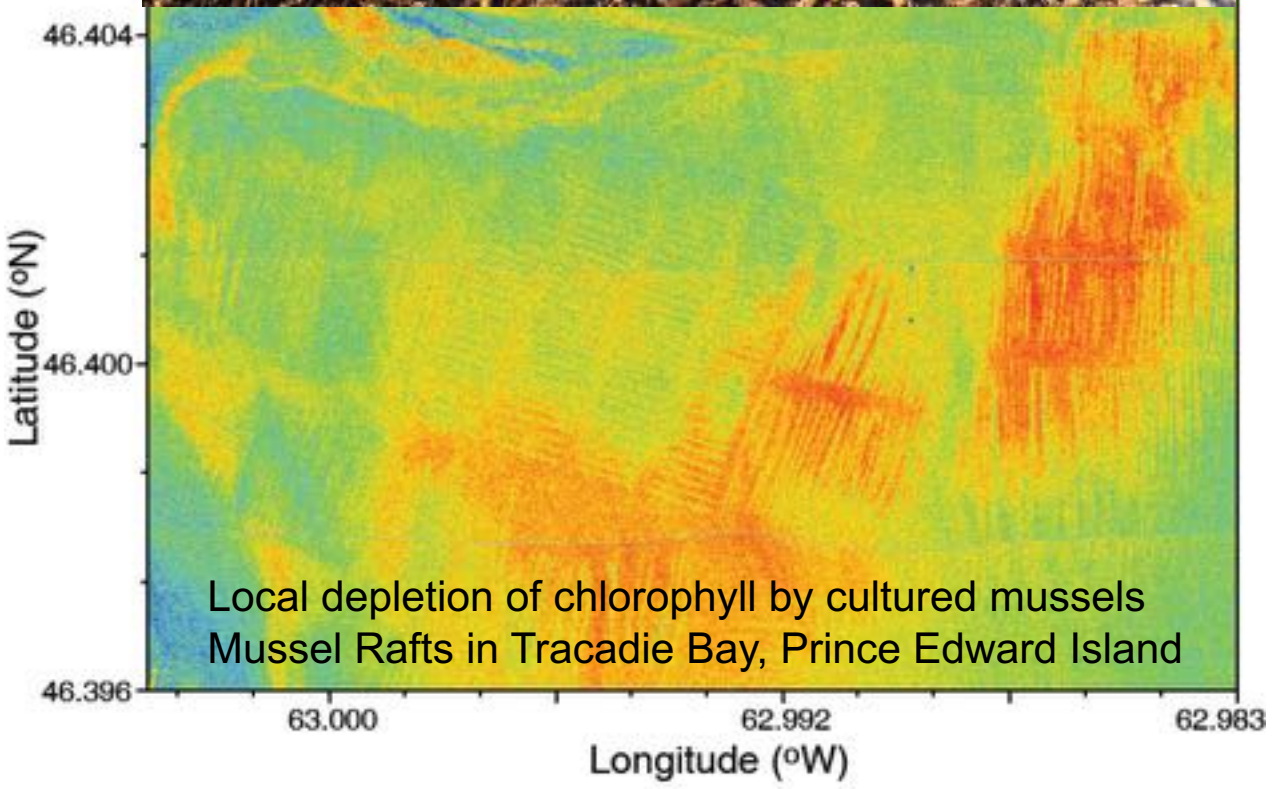
- Satellite-based predictions of potential fishing areas
- Objectives:
  - Improve efficiency of fishing effort
  - Contribute to sustainable management



Support for Aquaculture Industry

- Harmful algal bloom detection and warning
- Hypoxic events
- Carrying capacity of habitat for shellfish culture
- Water quality (for site selection, for monitoring impact)

Lobster walkout: Namibia



Local depletion of chlorophyll by cultured mussels
Mussel Rafts in Tracadie Bay, Prince Edward Island

Cities spring up around water

…or can die for lack of water

Fatepur Sikri built by Mughal Emperor Akbar in 1571.

Abandoned some ten years later for lack of water

Images: Lonely Planet

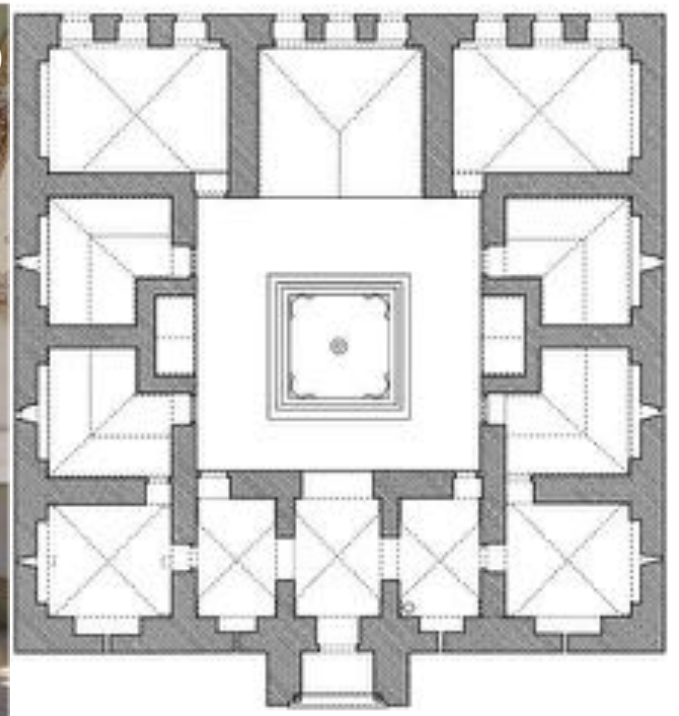
The concept that health is linked to water and air quality is not new

In the golden age of Islam, hospitals (or Bimaristans) were built on hills or by rivers. The river water was diverted to flow into their courtyards and halls and flow out into the river again.

In 10th Century, physician Abu Bakr al-Razy carried out an experiment for air quality (Al-Majari, 2017) to choose the location for a Bimaristan in Bagdad (evidence-based approach).

Flowing water was considered good, and incorporated into architecture.

Bāgh-e Fīn, Iran (Tehari 2021)



Al-Qaimari Bimaristan, Damascus (Maraqa et al. 2014)

Granada Hammam, Spain

Life Depends on Water

Water also takes away life when water unleashes its fury: 2018

Experts say extreme monsoon conditions, urban development, and environmental degradation responsible for the devastation caused by once-in-a-century floods

Images Courtesy: Various sources, including the Guardian 19 Aug 2018

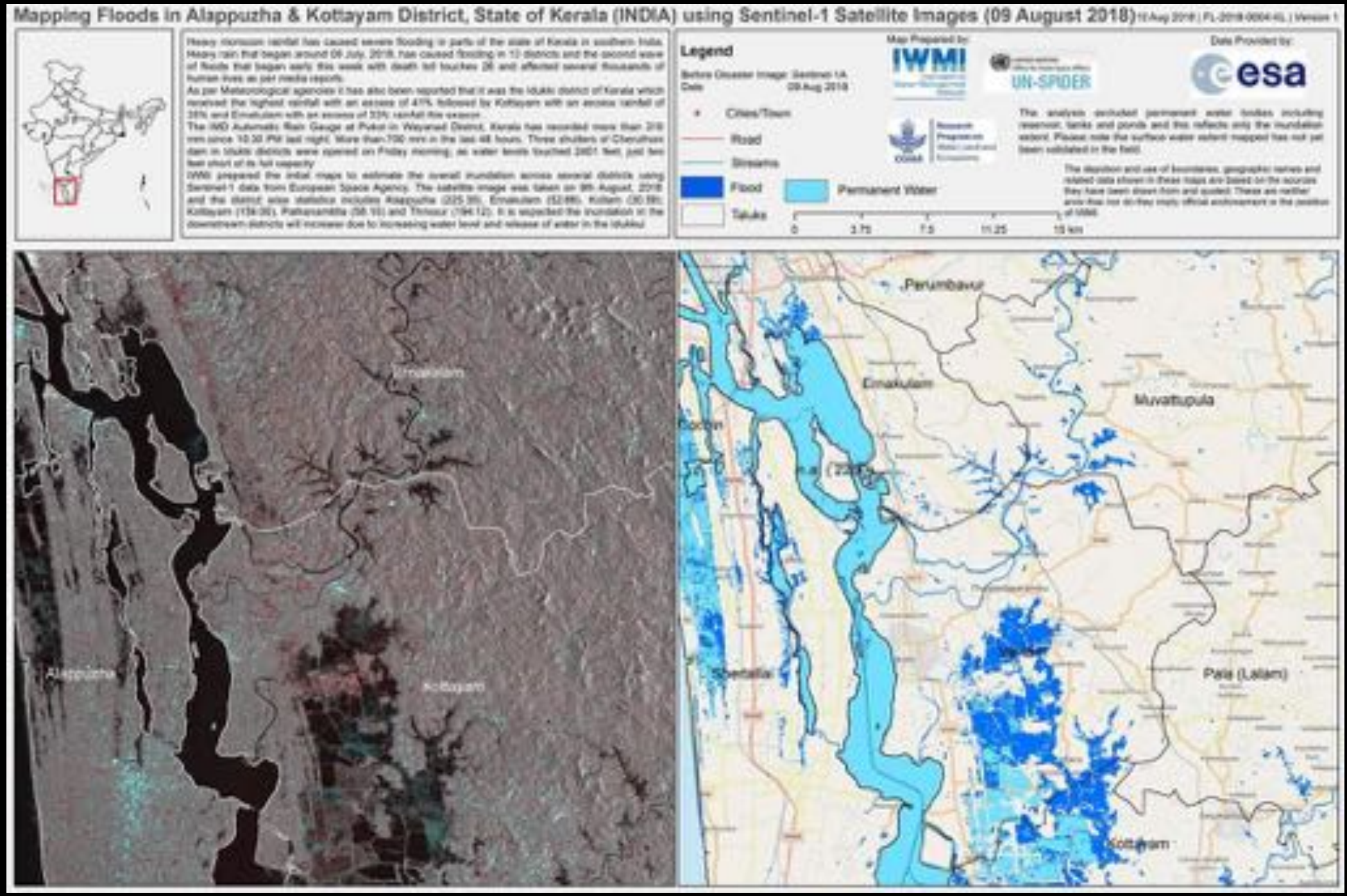
Part of the Solution:

Map Floods: Sentinel 1 Product provided by IWMI

Risk maps should:

- be timely
- be frequent
- be reliable
- reach decision makers

See lecture by Gemma Kulk, next week



Climate refugees of Kuttanad

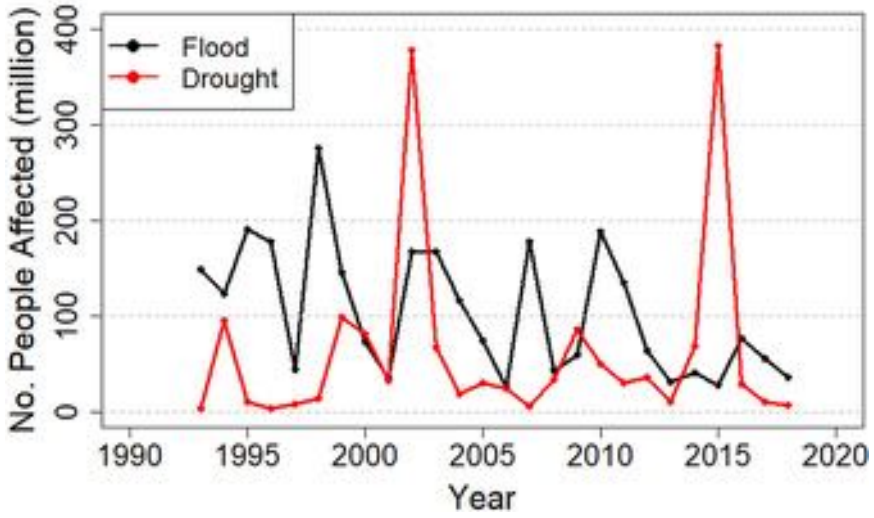
A. Sam Paul & U. Hiran, The Hindu, 20 April 2022:

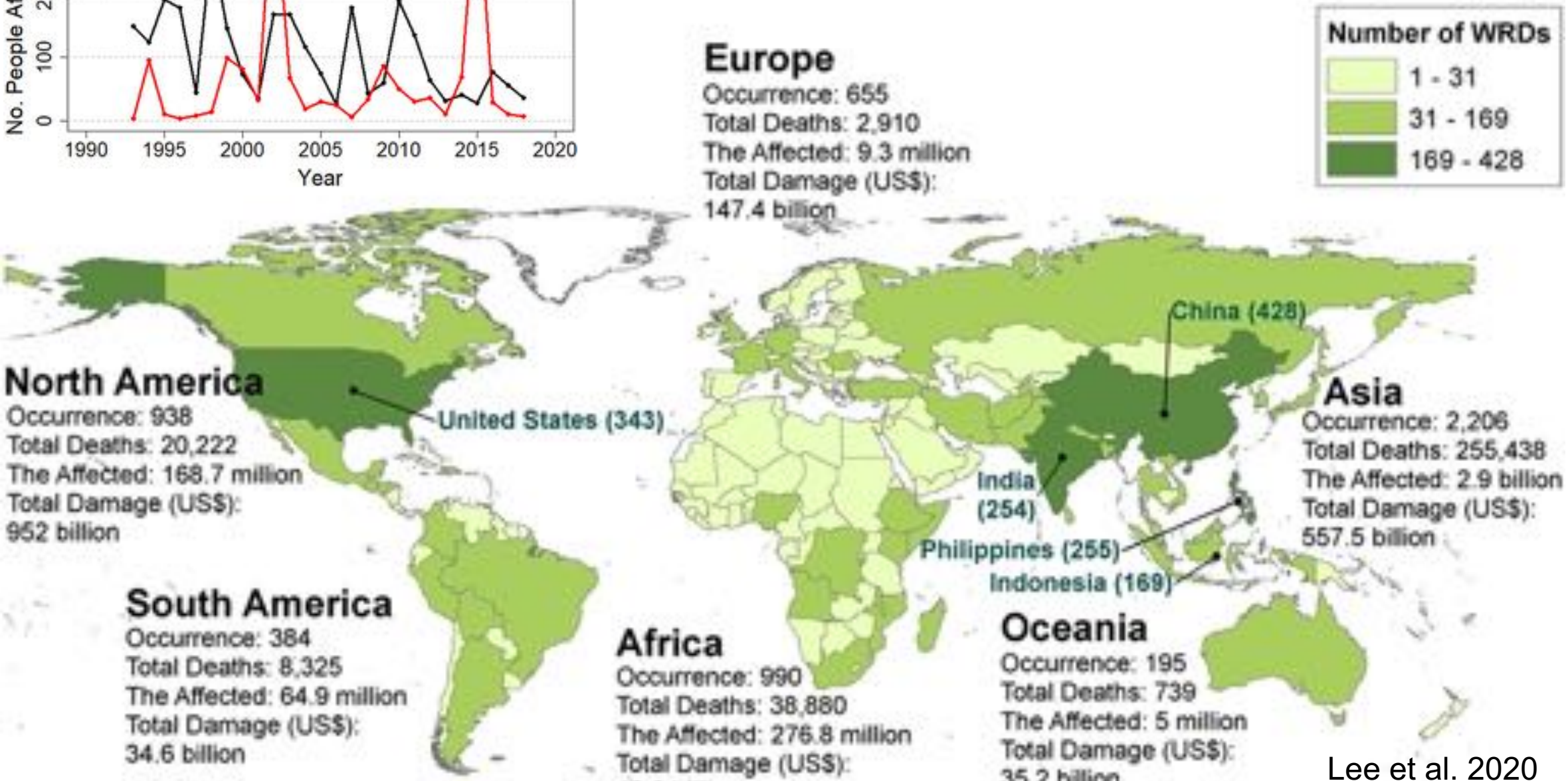
“For the people of Kuttanad, recurring floods, torrential downpours, and intrusion of saline water are at the forefront of their minds nowadays, as they face the dire impacts of climate change. Some 15% of people have left…”

Hence the need to address the resilience of human communities to perturbations under extreme weather events associated with a changing climate.

Partially flooded house. © Suresh Alleppey

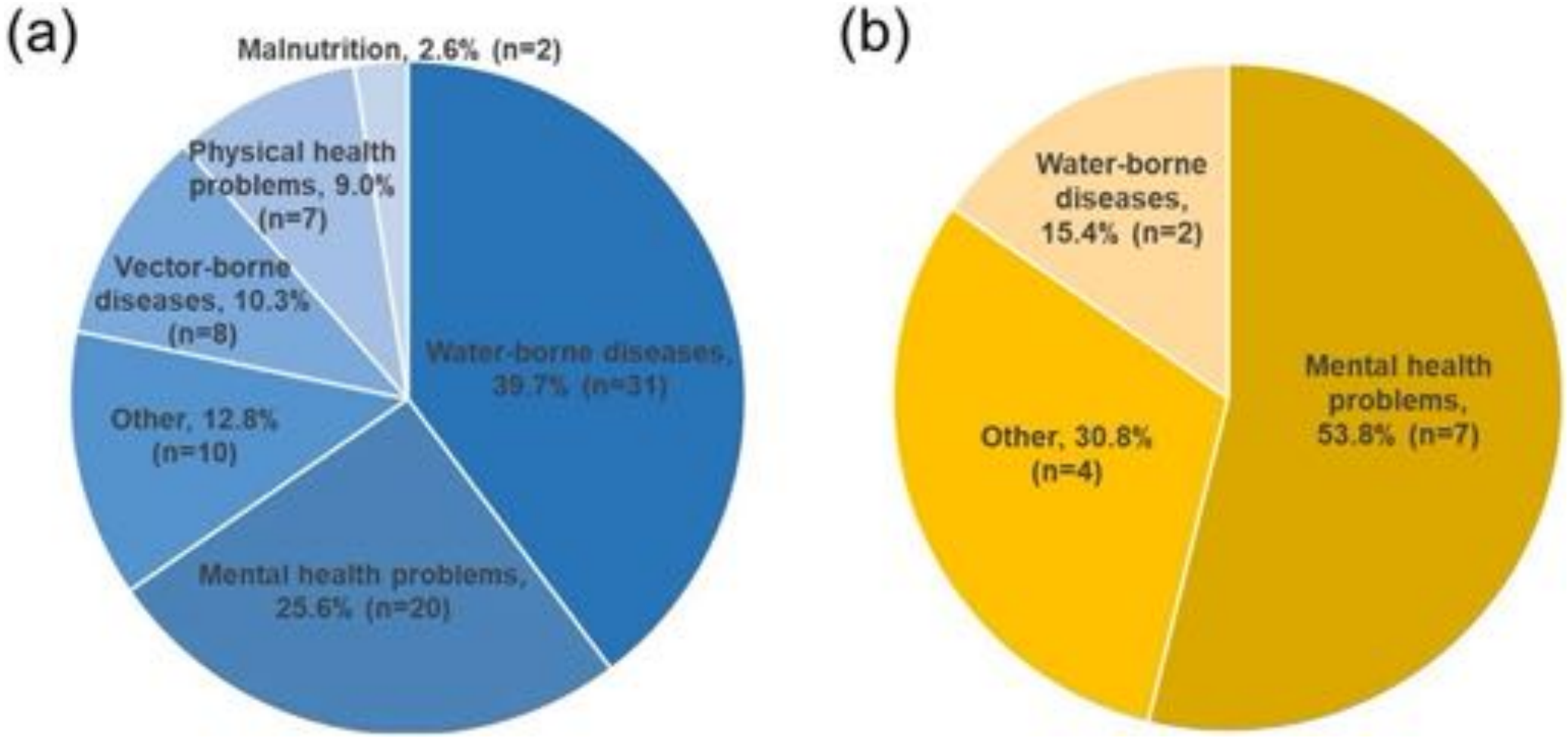
Water-Related Disasters 2001–2018





Lee et al. 2020

Health Impacts of Water-Related Disasters



Number of case studies for each health category following
(a) floods
(b) droughts

Lee et al. 2020

Relevance

According to World Health Organisation:

- In 2020, 241 million cases of malaria and 627,000 deaths worldwide
- Each year 1.3-4.0 million cases and 21,000-143,000 deaths worldwide estimated due to cholera

Child in slum in Kampala (Uganda) next to open sewage.

Relevance

According to World Health Organisation:

- Drinking water: 785 million people lack even a basic service, including 144 million people who are dependent on surface water
  - Globally, at least 2 billion people use a drinking water source contaminated with faeces
  - Contaminated drinking water causes 485,000 diarrhoeal deaths each year
  - By 2025, half of the world's population will be living in water-stressed areas
- Provision of safe drinking water often breaks down in extreme weather and flooding

Child in slum in Kampala (Uganda) next to open sewage.

Role of environment in dictating public health

- Many key determinants of health and infectious diseases lie outside the direct control of the health sector (WHO)
- Other sectors involved are those dealing with sanitation and water supply, environmental and climate change, education, agriculture, trade, tourism, transport, industrial development and housing
- What can space technology contribute?
- Integration with other sectors is crucial: How can we achieve that integration?

Photo credit: WHO

Role of environment in dictating public health

- Importance of environment is particularly true of water-borne and vector-borne diseases
- Diseases within animal populations are crossing into human populations with increasing frequency (zoonotic diseases)
- Germs can spread from animals to humans by:
  - Direct contact
  - Indirect contact
  - Vector-borne
  - Food-borne
  - Water-borne


Photo Credit: WHO

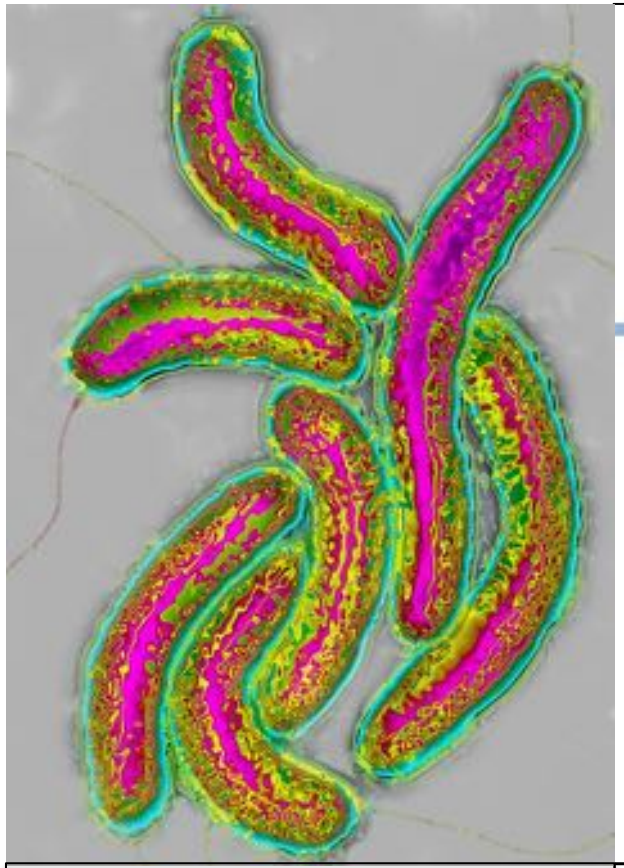
Water Associated Diseases

“Water-associated" diseases are a diverse group, including:

- Diarrhoeal diseases such as cholera;
- Skin diseases associated with water-borne bacteria or metazoan parasites;
- Vector-borne diseases such as malaria and dengue fever; and
- Others such as hepatitis

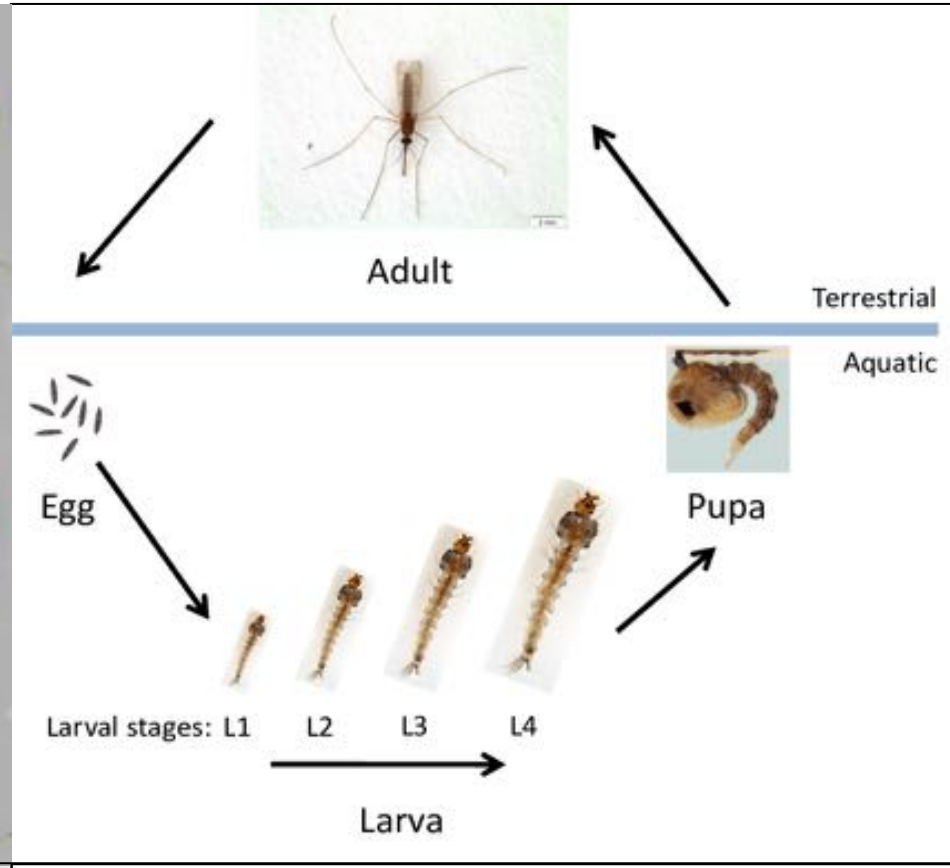
Photo Credit: WHO

Water fosters many water-borne and vector-borne diseases



Vibrio Cholerae: Many known reservoirs of the bacteria in water

Colour-enhanced transmission electron micrograph of *V. cholerae*.

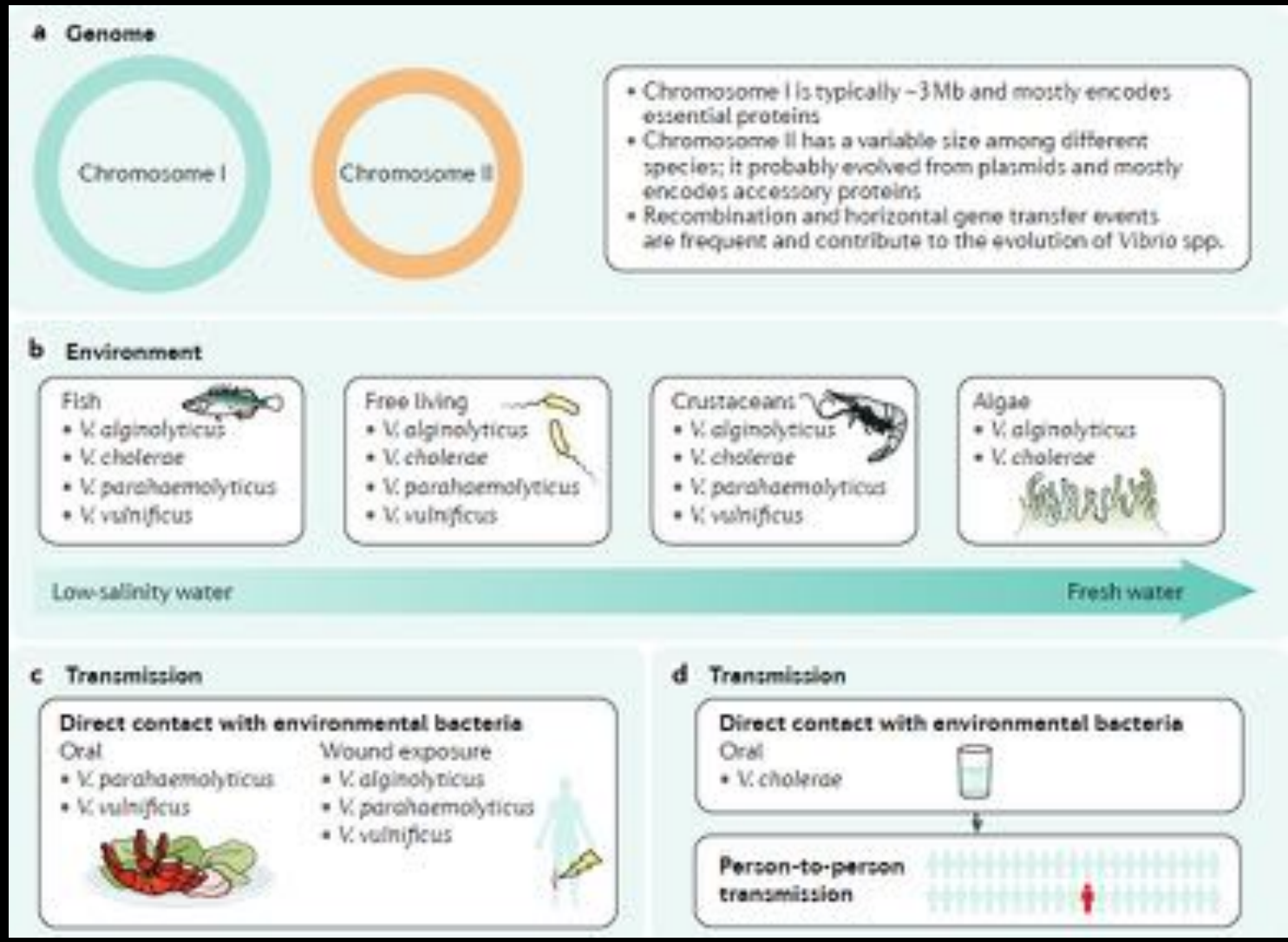


Mosquito life cycle. Egg and larval stages in water. Mosquito is vector for malaria, dengue, chikangunya, zika …

Water hyacinth, invasive species in Lake Vembanad, creates stagnant pools, facilitating breeding of mosquitoes. Water hyacinth known to be associated with *V. cholerae*.

Pathogenic *Vibrio* bacteria

- *Vibrio cholerae*: Of some 200 serotypes of *V. cholerae* bacteria that have been identified, only two (O1 and O139) are associated with major cholera outbreaks
- *V. alginolyticus* causes wound and ear infections when exposed to contaminated water
- *V. parahaemolyticus* is associated with food poisoning from consumption of seafood, causing acute gastroenteritis, with symptoms including cramps, diarrhoea, headache, fever, chills
- *V. vulnificus* infests wounds leading to septicaemia (high mortality)



Baker-Austin et al. 2018

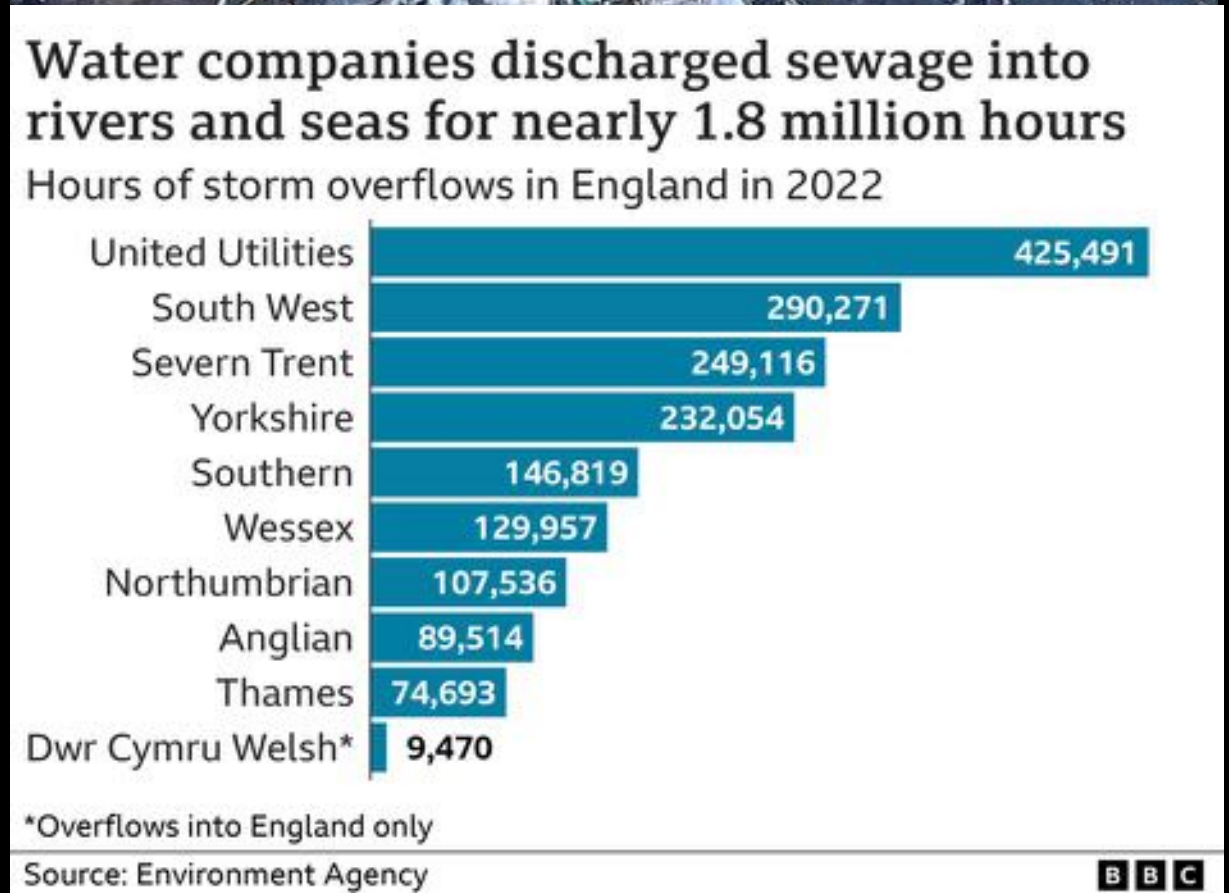
Water quality is not just a developing country problem

UK: Water quality makes headlines
Citizens are becoming the voice of change.

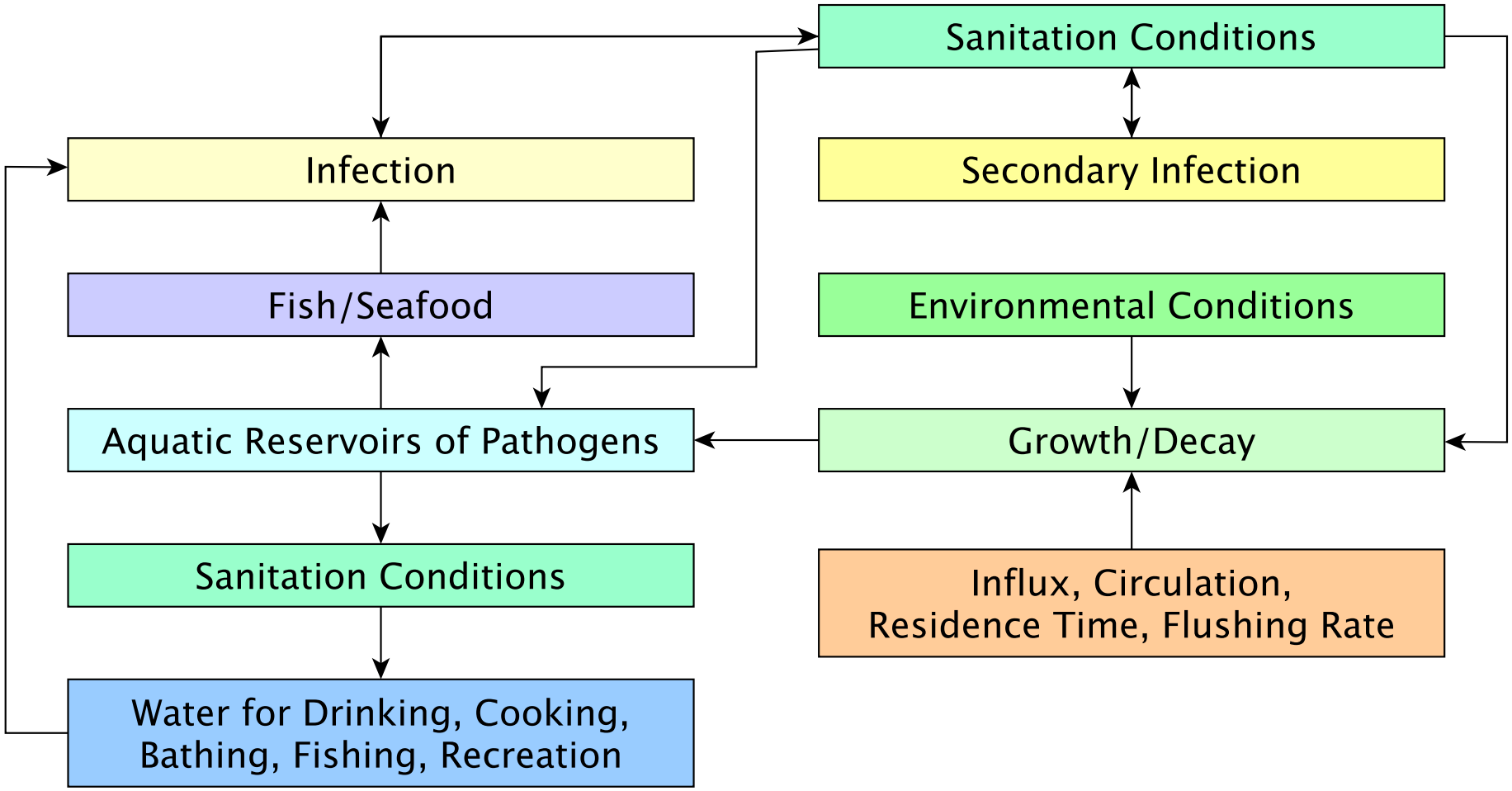
See lecture by George, in two weeks.

Surfers against sewage

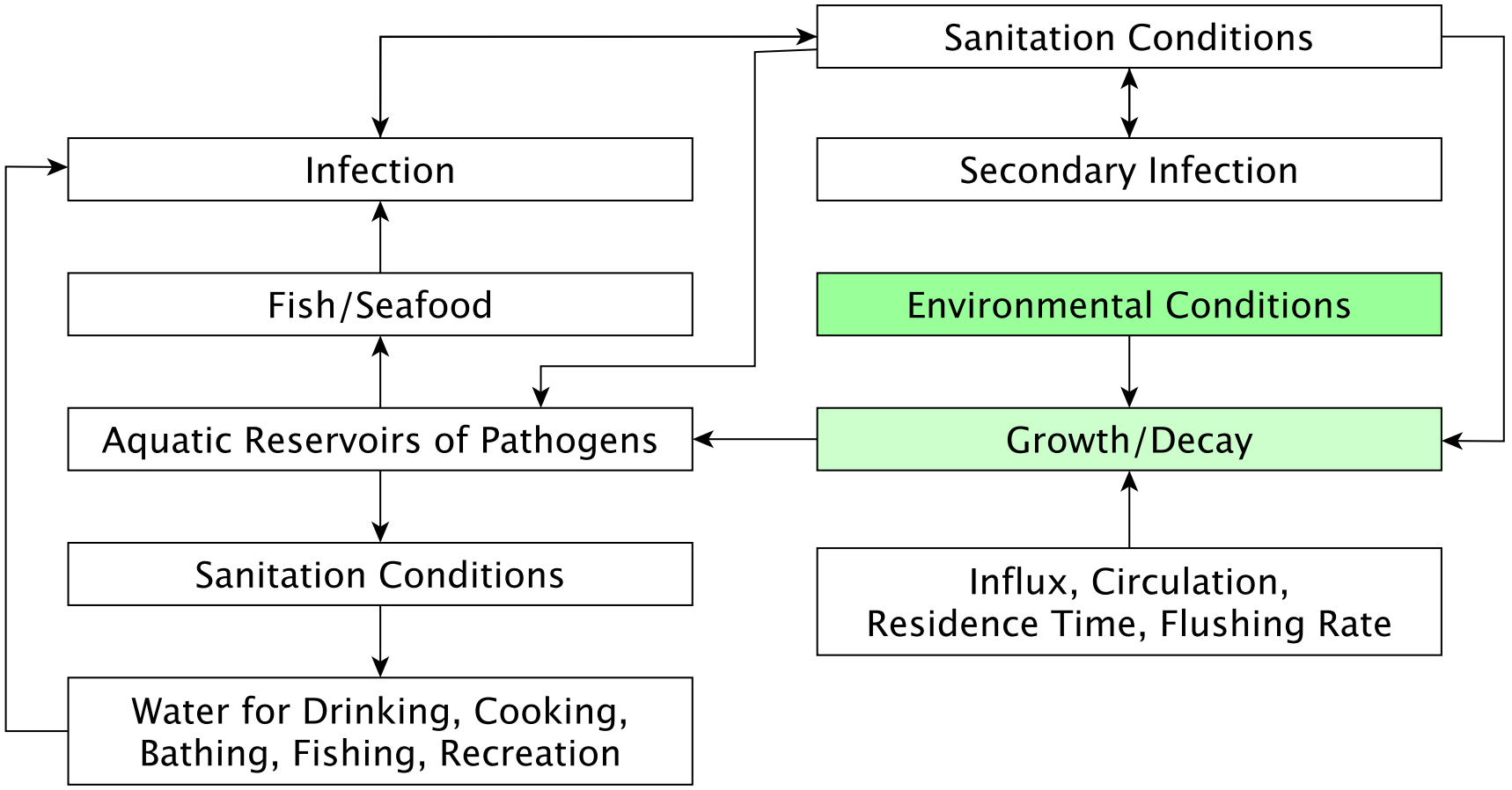
Local elections 2023: How sewage topped the political agenda
https://www.bbc.co.uk/news/uk-politics-65190097
BBC News 24 April, 2023



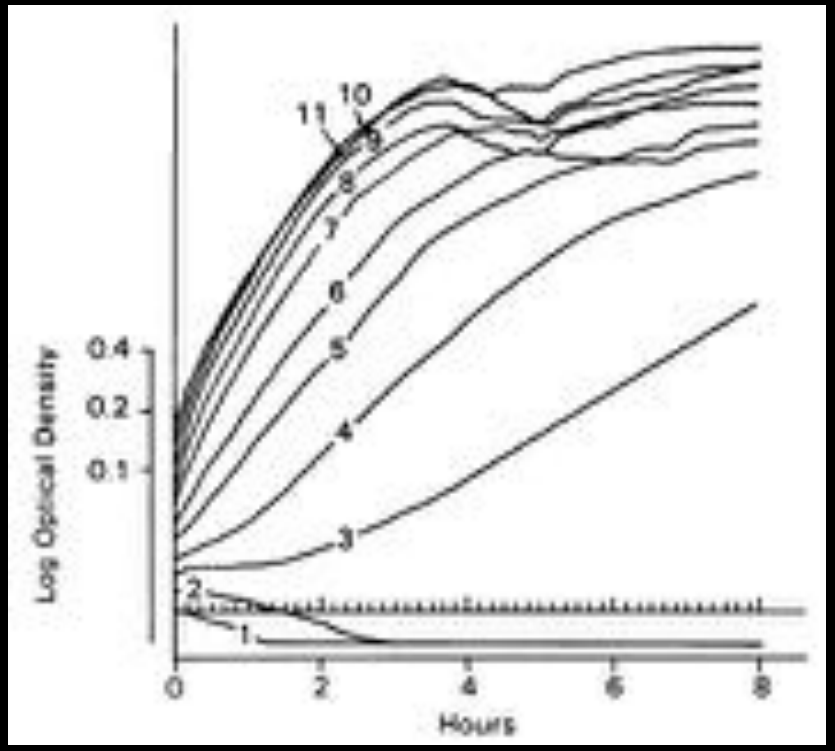
An Overview of the Role of the Environment



Environmental Conditions from Satellites

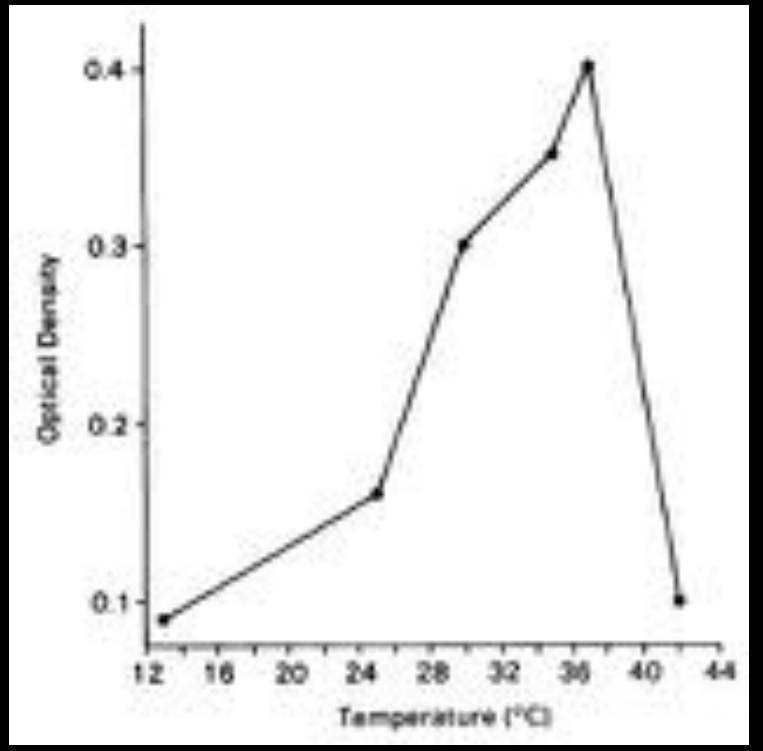


Effect of Temperature and Salinity on *Vibrio* Growth Rates



Decreasing Salinity

Effect of salinity on *V. vulnificus* grown in cultures at various levels of salinity



Optimal temperature for *V. vulnificus* grown in cultures for 12 h at various temperatures

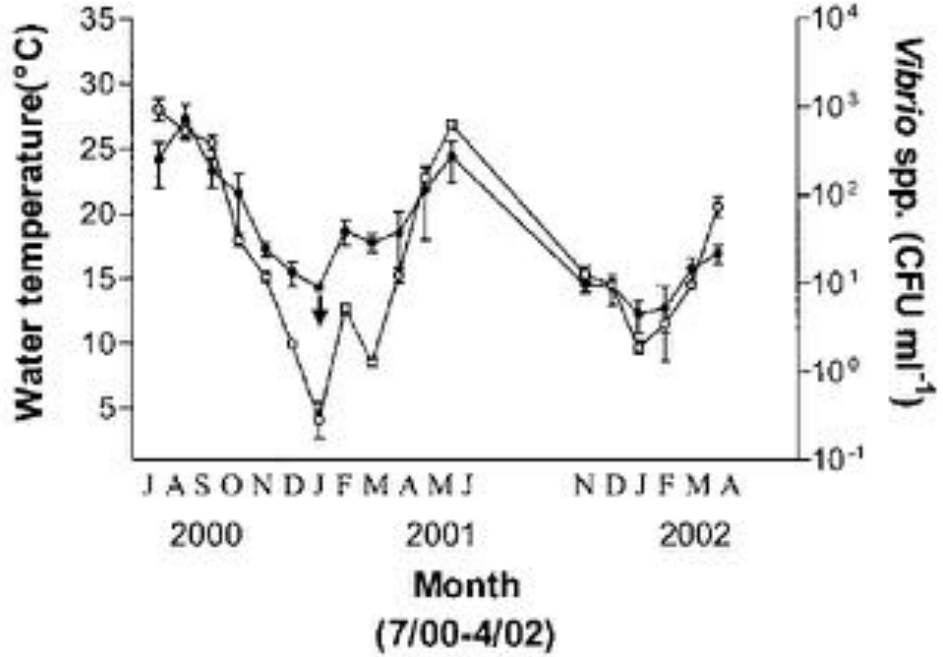
Kelly 1982

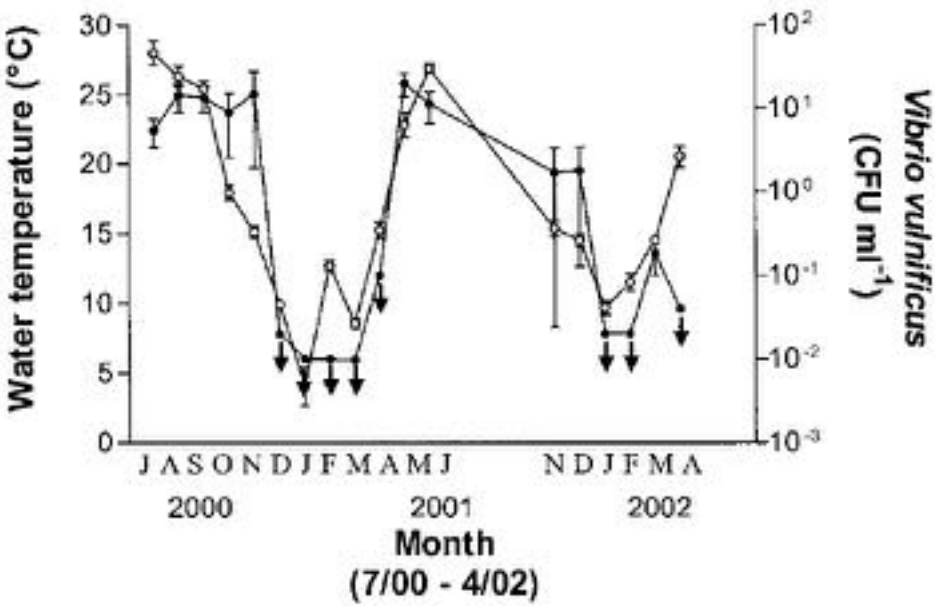
Surface water temperature and salinity are amenable to remote sensing

Vibrio and Temperature in the natural environment: North Carolina Estuarine Waters

- Seasonal study at six estuarine sites
- Temperature explained 48% variation in abundance of *Vibrio* spp.
- Temperature also explained 47% of variance in abundance of *Vibrio vulnificus.*
- *V. vulnificus* only isolated from samples only when water temperature was between 15 and 27°C.
- Each of the other environmental variables measured
    - Estuarine bacteria count
    - Phosphorus
    - Ammonia
    - Salinity
    - Turbidity

  explained <10% of variance in *Vibrio* spp.





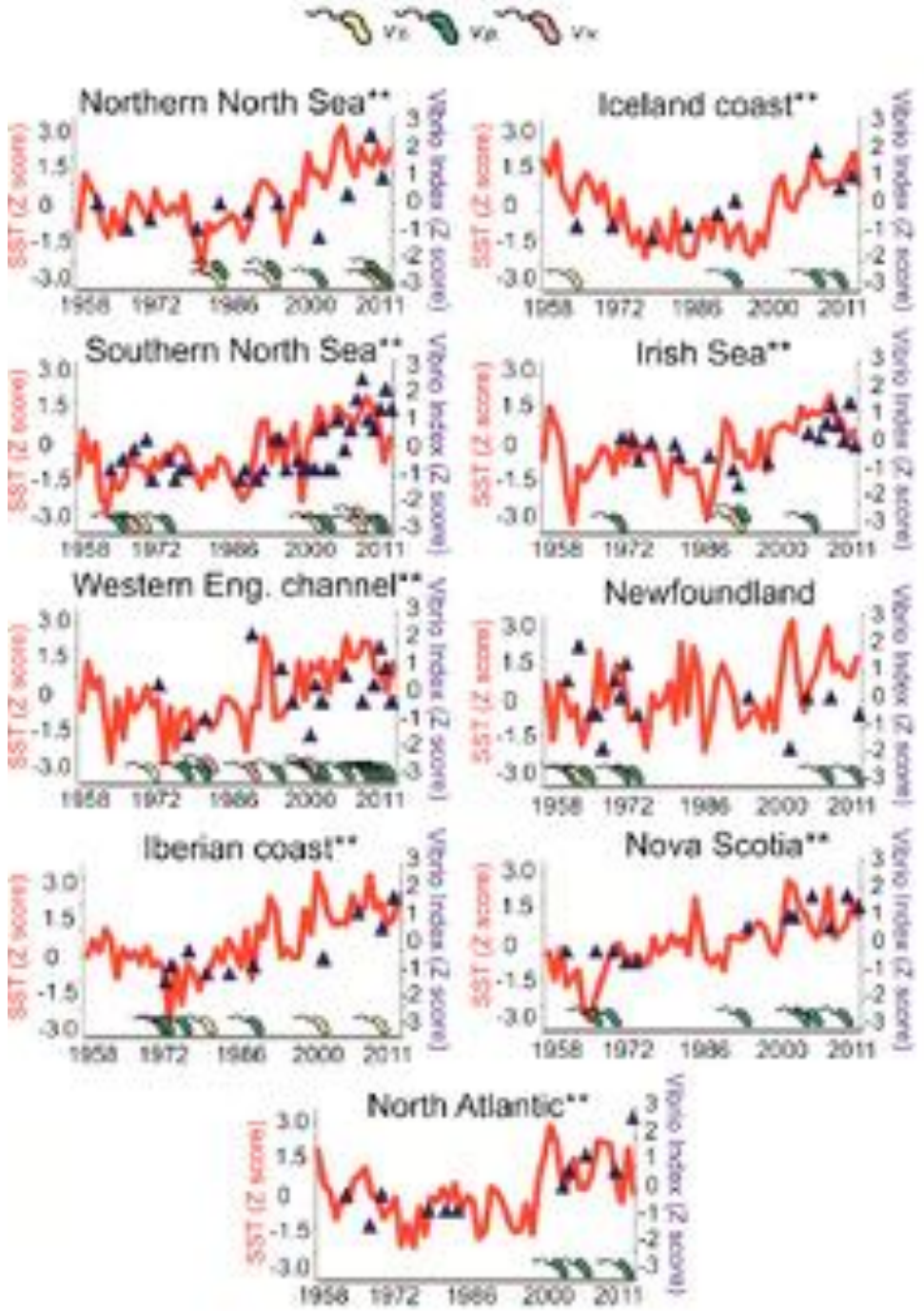
Pfeffer et al. (2003)

DOI: 10.1128/AEM.69.6.3526–3531.2003

Vibrio and Temperature in the natural environment: North Atlantic

- Vibrio abundance in water increases with sea surface temperature (SST)
- Generalised additive model: SST and the Atlantic Multidecadal Oscillation (AMO) explained 30% of variance

Vezzulli et al. (2016) PNAS

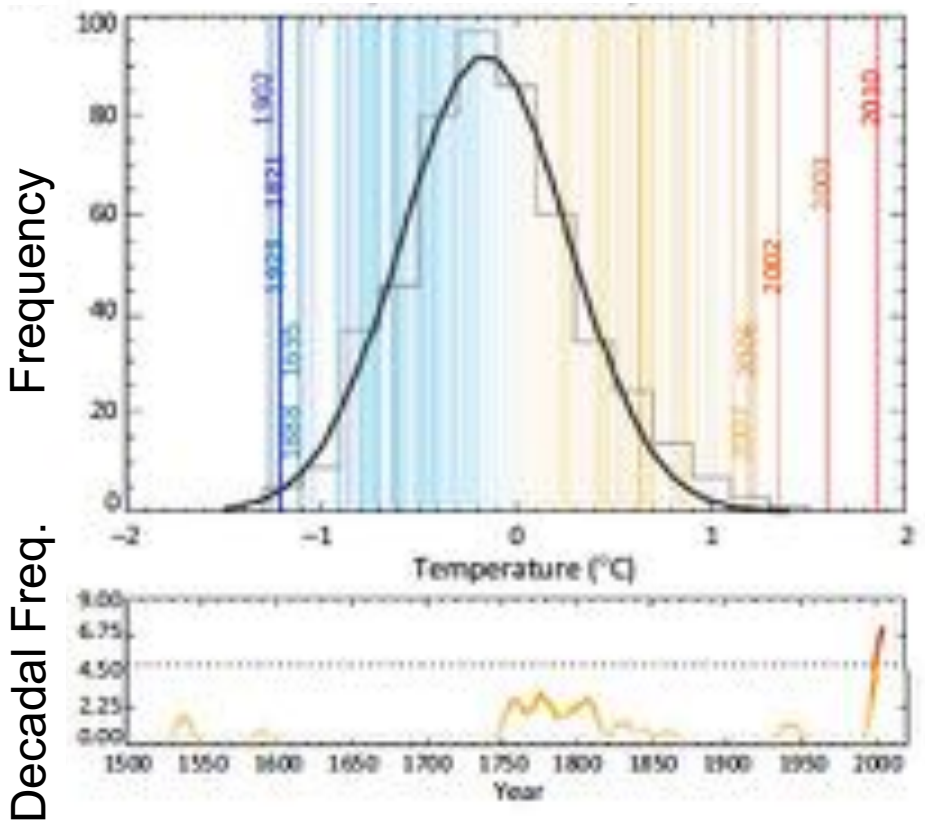


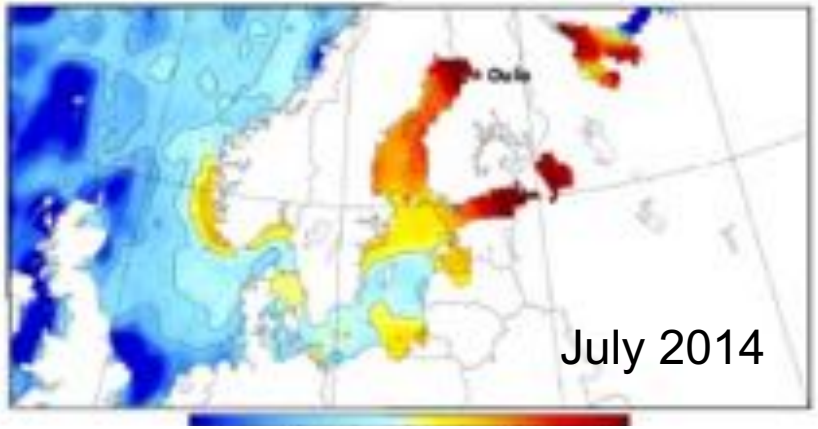
Vibrio and Temperature in the natural environment: Northern Europe and World

- Reported incidences of *Vibrio* infections in Finland and Sweden increased with positive temperature anomalies
- Ocean heatwaves increasing in frequency and magnitude
- Distribution of *Vibrio* bacteria predicted to expand northward under warmer climate
- Poleward spread of vibriosis associated with higher water temperatures

Baker-Austin et al. 2018
Trends in Microbiology

European summer temperature

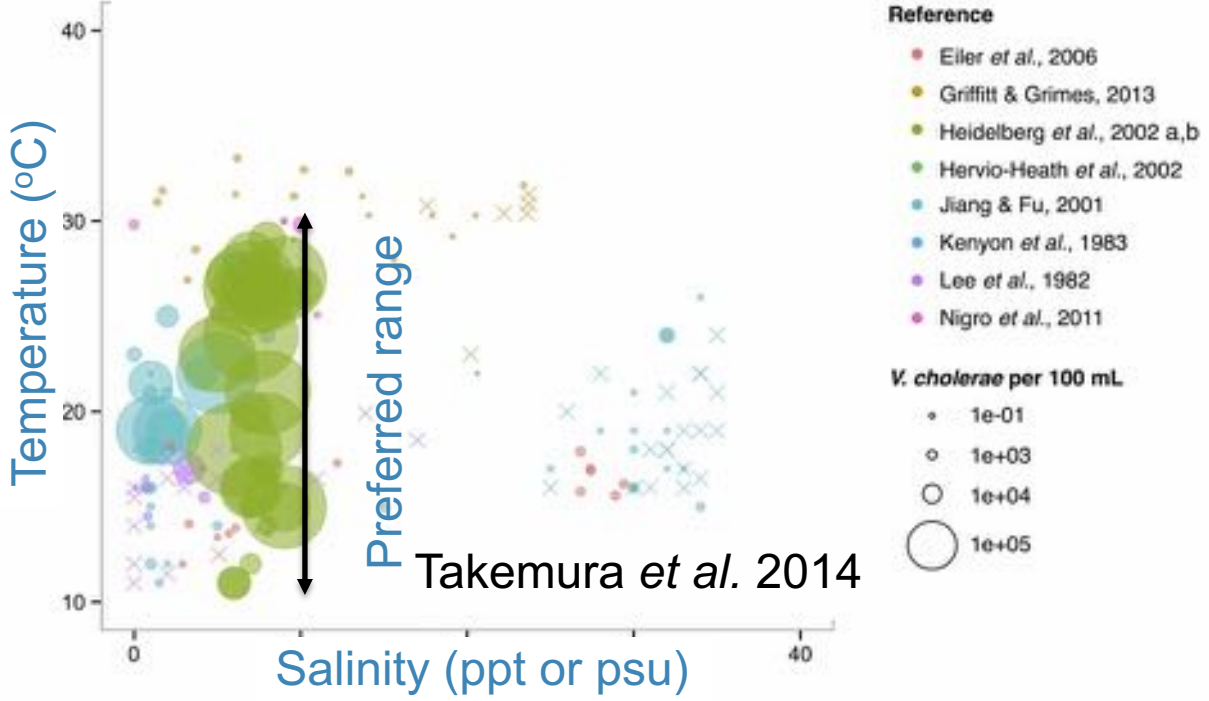


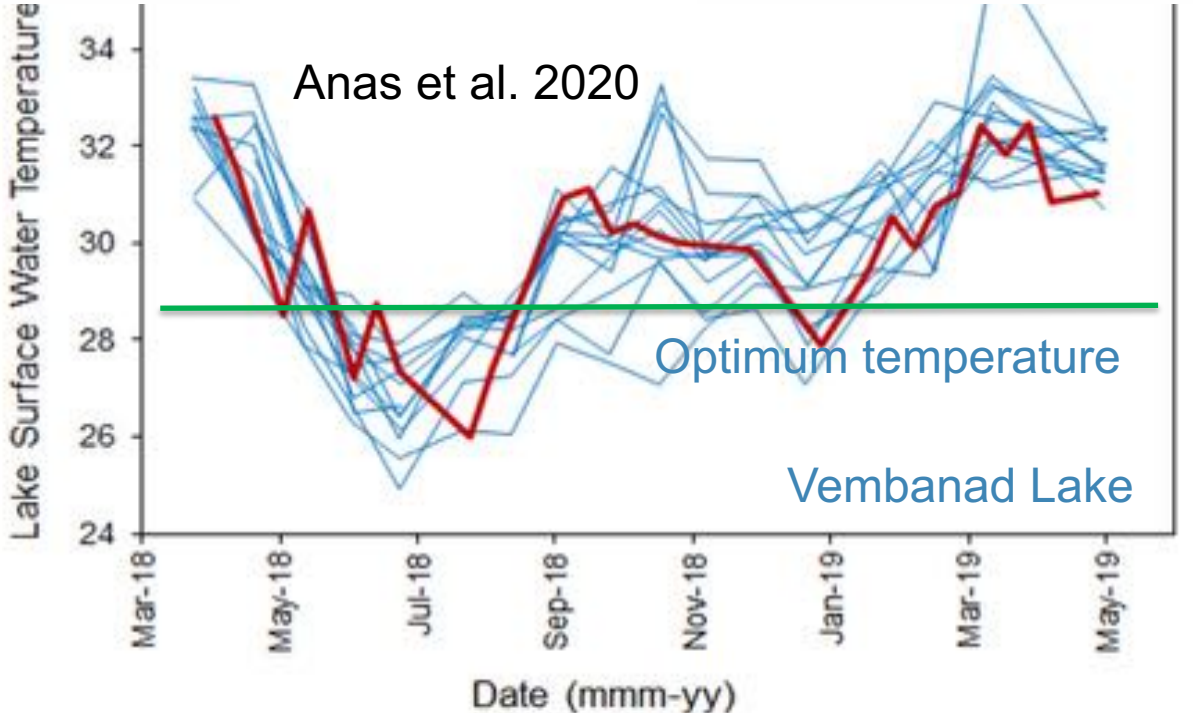


Daily sea surface temperature anomaly (°C)

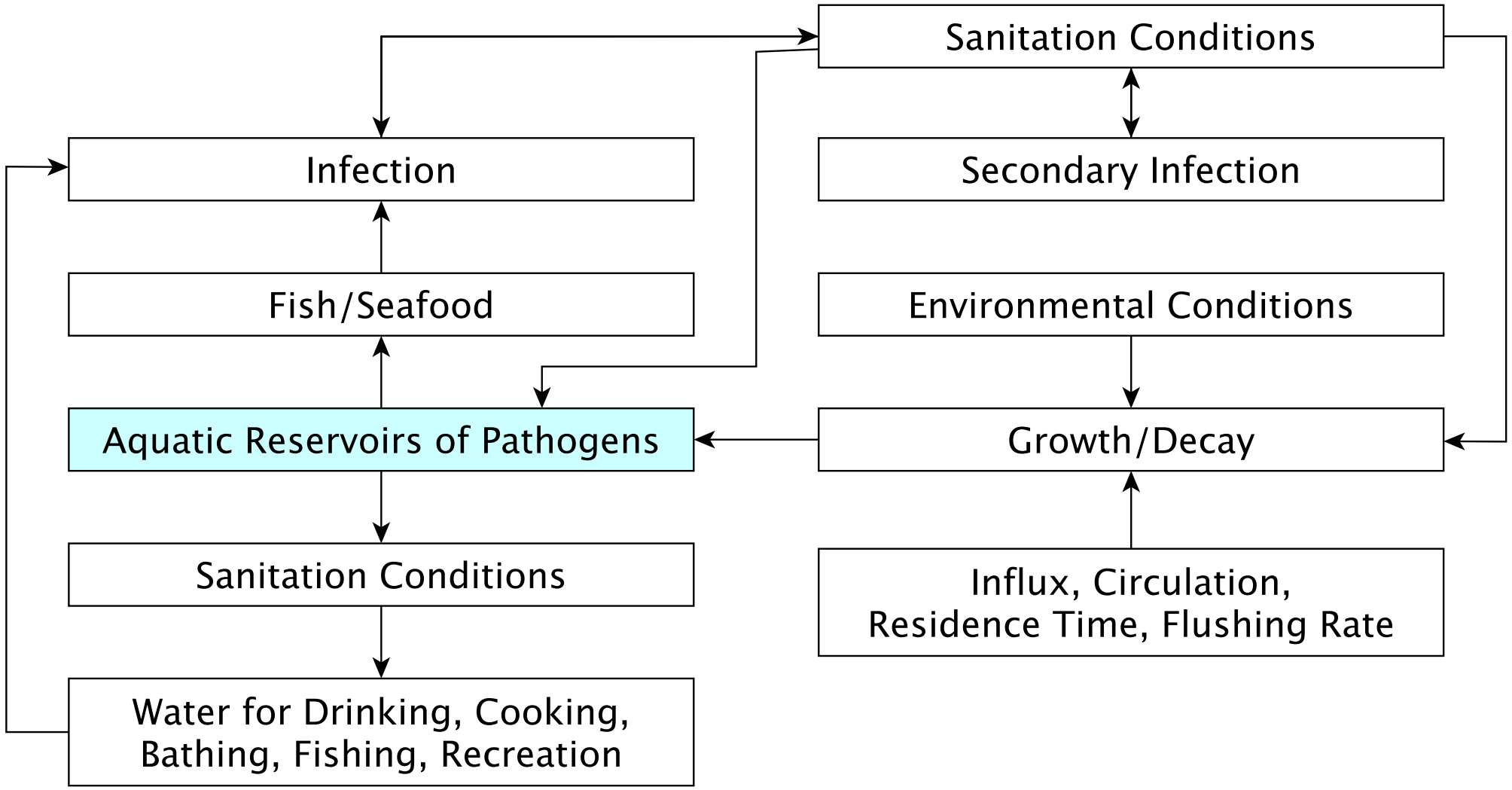
Effect of temperature on *Vibrio cholerae* abundance and growth

- From a compilation of available data, it appears that the preferred temperature range for *V. cholerae* bacteria is 10–30 °C (Takemura et al. 2014)
- Materna et al. (2012) report an optimum growth temperature of 28.3°C for *V. cholerae* (maximum 41 and minimum 18°C), based on lab experiments.
- What happens when water temperatures overshoot the optimum temperature?
- Vembanad Lake is already experiencing heat waves in the water, with temperatures as high as 36°C (Anas et al. 2020).
- But *V. cholerae* survive very well inside the human body at 38°C!



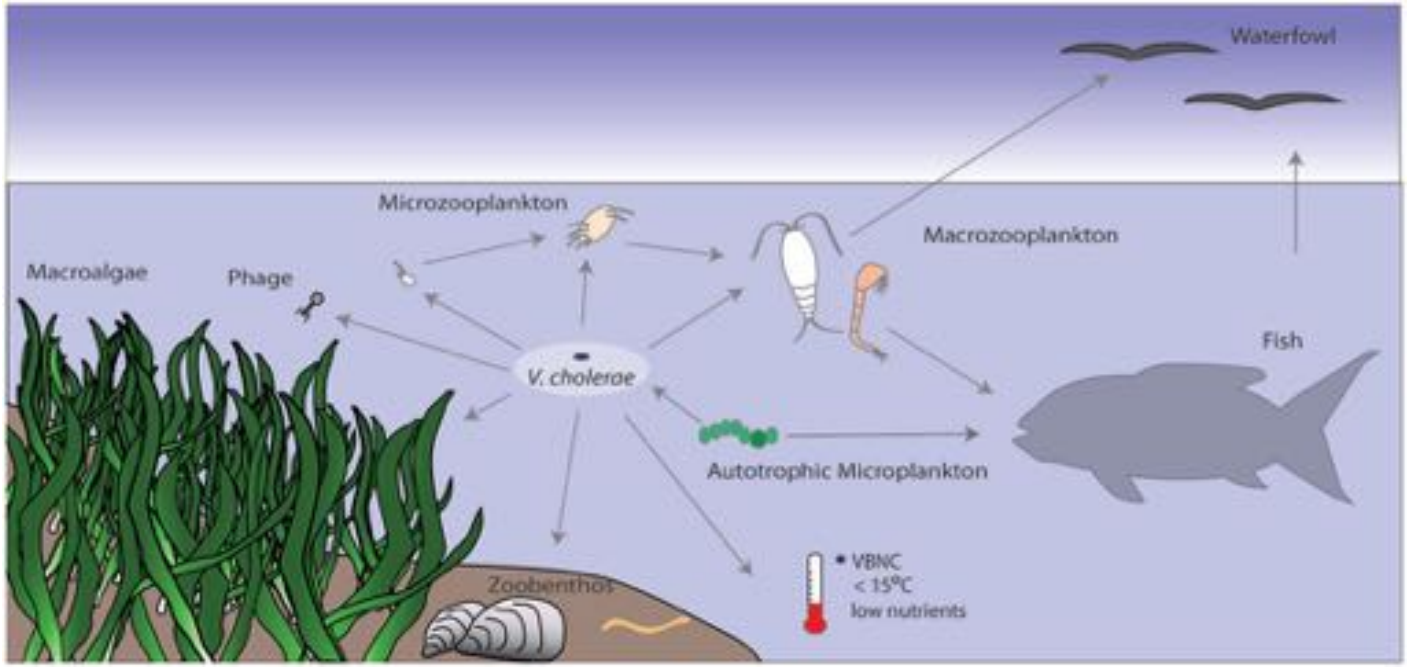


Aquatic Reservoirs of Pathogens

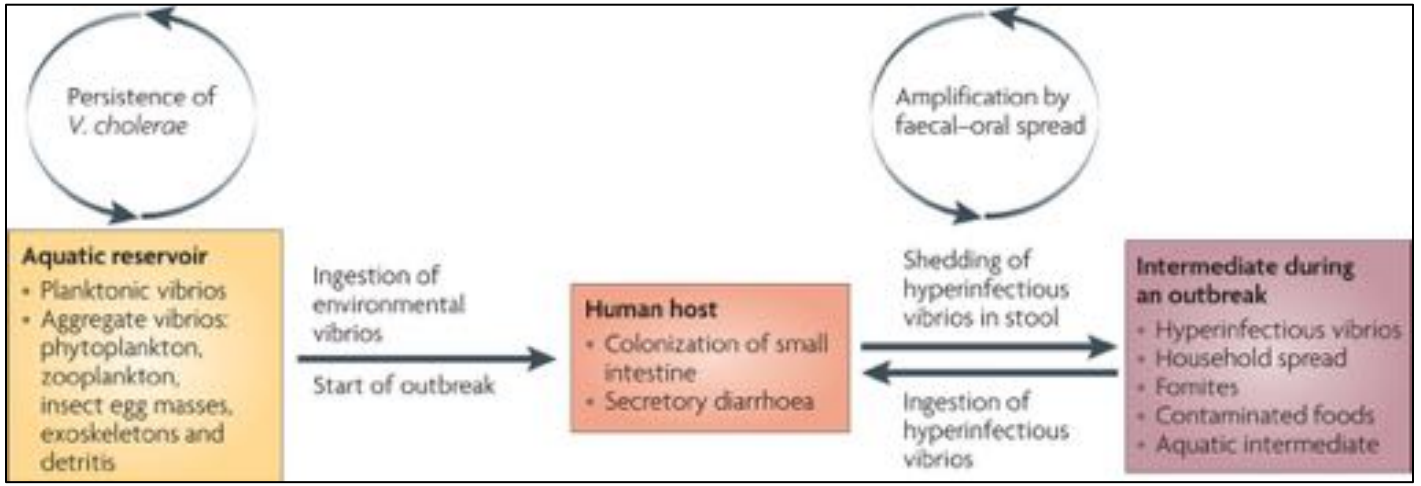


Role of *Vibrio cholerae* in the natural environment

- Naturally-occurring component of brackish and fresh-water aquatic systems
- Known to interact with many components of the ecosystem, including phytoplankton, zooplankton, macroalgae
- Fish consuming infected plankton can transport the bacteria over long distances
- It has a complex life cycle, surviving for long periods in aquatic reservoirs, until ingestion of contaminated material, leading to a disease outbreak
- During an outbreak, it can spread through contaminated material.



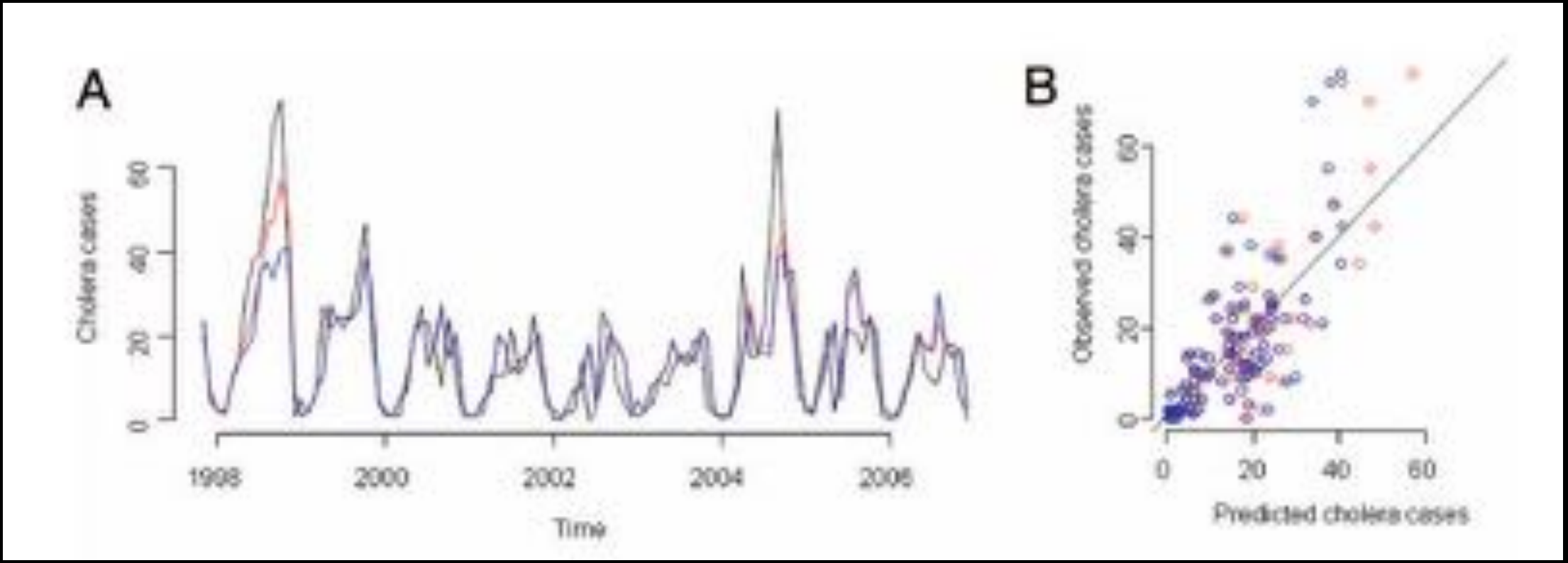
Vibrio cholerae interactions with other organisms and the environment
Lutz *et al*. 2013. Frontiers in Marine Biology



Life cycle of pathogenic Vibrio cholerae
Nelson *et al*. 2009. Nature Reviews. Microbiology

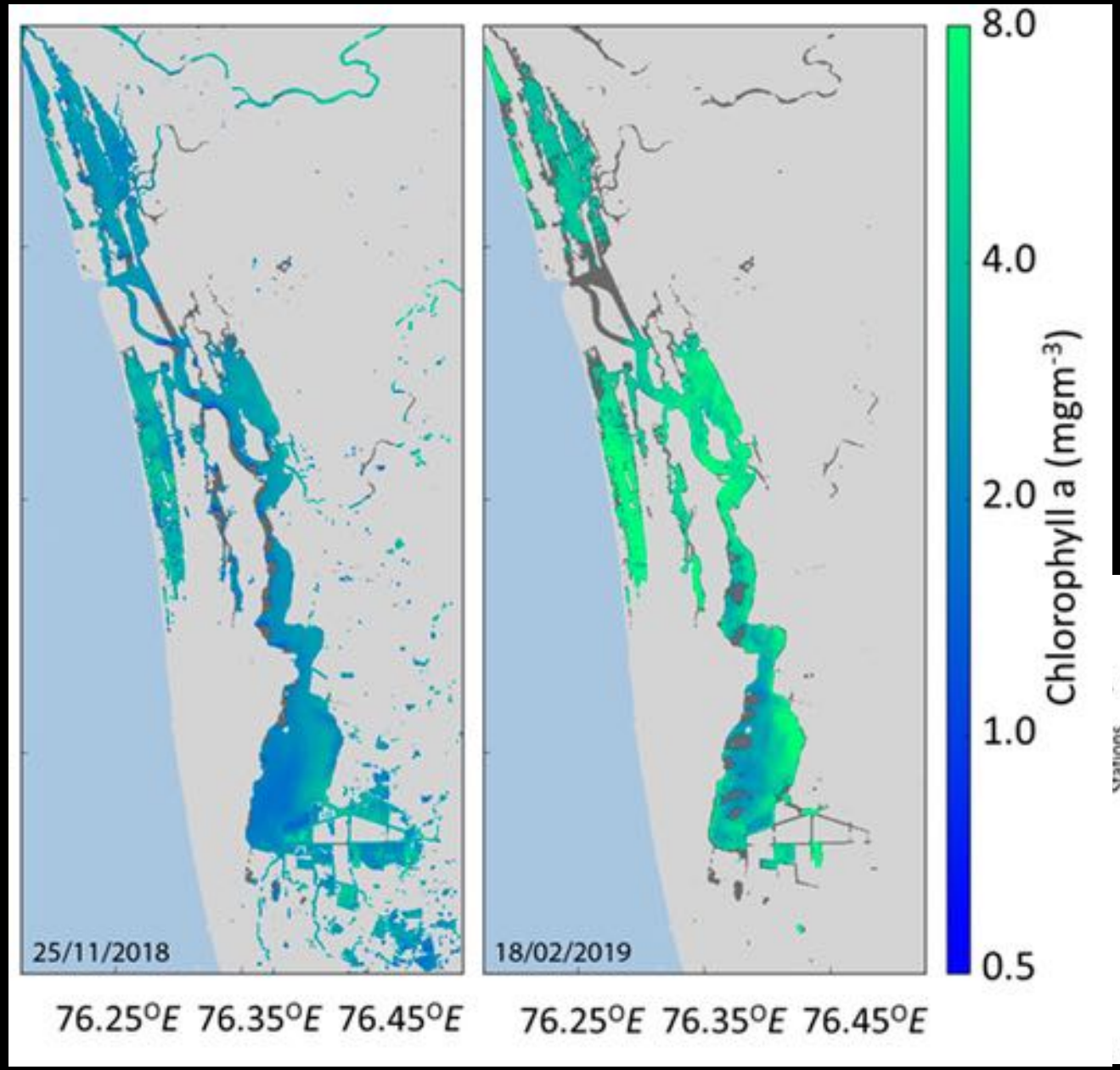
Reported Cholera Cases and Relationship to Environmental Conditions

- Satellite-based chlorophyll concentration, sea-surface temperature and rainfall data (both *in situ* and satellite-based) were used in the analysis of data from Kolkata (India)
- One-month lag was reported between chlorophyll concentration and reported cholera outbreaks
- Statistically-significant results, suitable for developing early-warning systems



de Magny et al. 2008 PNAS

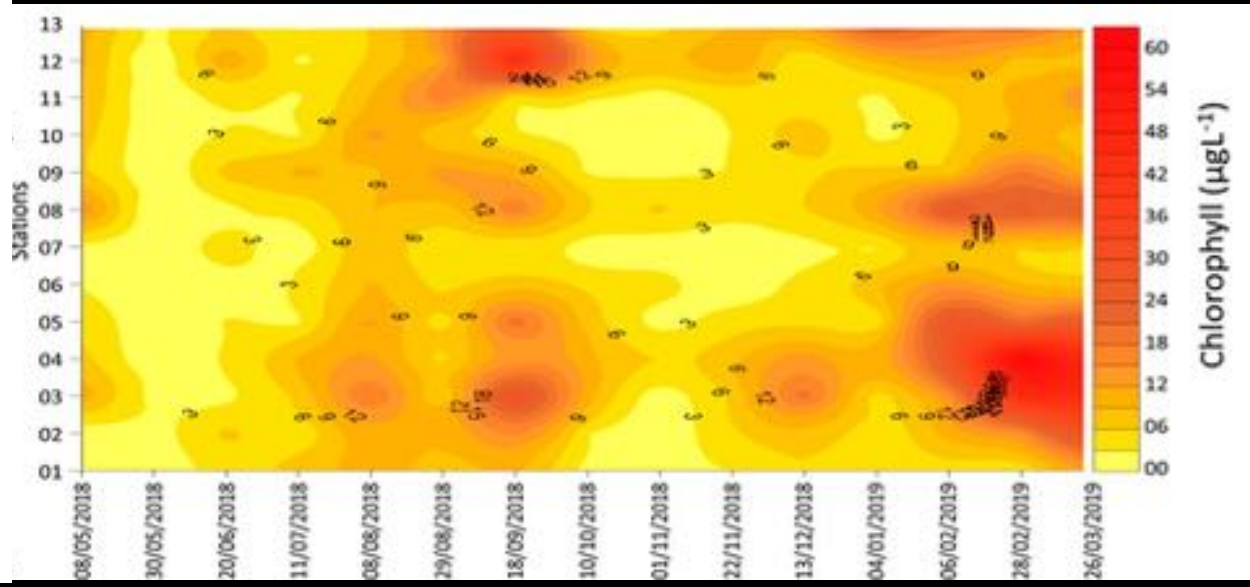
Chlorophyll concentration from Satellites



Chlorophyll concentration is a standard product from ocean-colour sensors on satellites.

But:
In areas of persistent cloud cover, we have to rely on in situ observations to fill gaps.

We also need *in situ* observations to obtain data at depth.



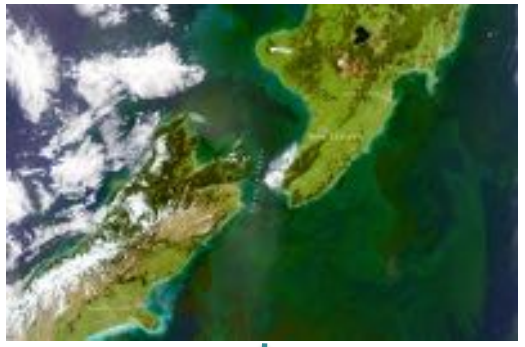
What is the ecological link between phytoplankton and *Vibrio cholerae?*

One hypothesis: Indirect link *via* zooplankton

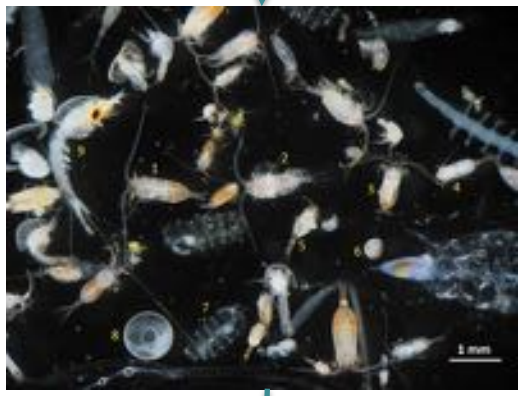
- Explains why there is often a lag of several weeks between chlorophyll blooms and cholera outbreaks (Huq et al. 2005)
- Chitin contained in the carapace of zooplankton serve as food to *V. cholerae.*
- Many lab experiments provide evidence that *V. cholerae* can grow successfully on copepods.

Images courtesy:
NASA
Wikipedia
Huq et al. 1984
Colwell and Huq

First step:
Phytoplankton bloom



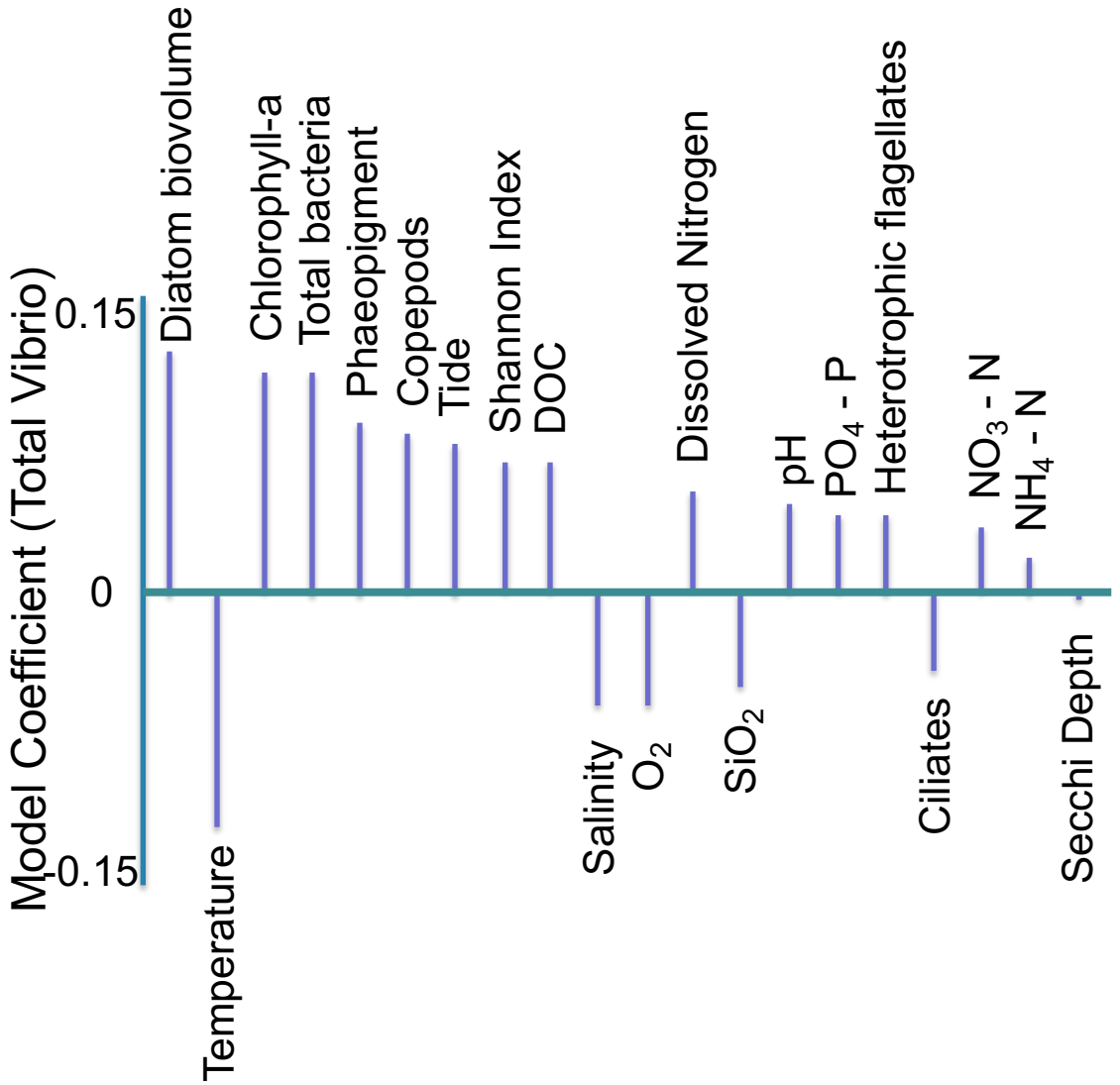
Second step:
Zooplankton follow
(delay 1-2 months)



Vibrio cholerae attach themselves to zooplankton in high densities

Strong Vibrio-phytoplankton association

- Study off south-west coast of India (Asplund et al. 2011)
- Correlation with diatoms and chlorophyll-a stronger than that with copepods
- Suggestion that resource supply from primary producers are more important than top-down control by predators
- Asplund et al. (2011) cite many reported mechanisms that sustain association between phytoplankton and Vibrio bacteria

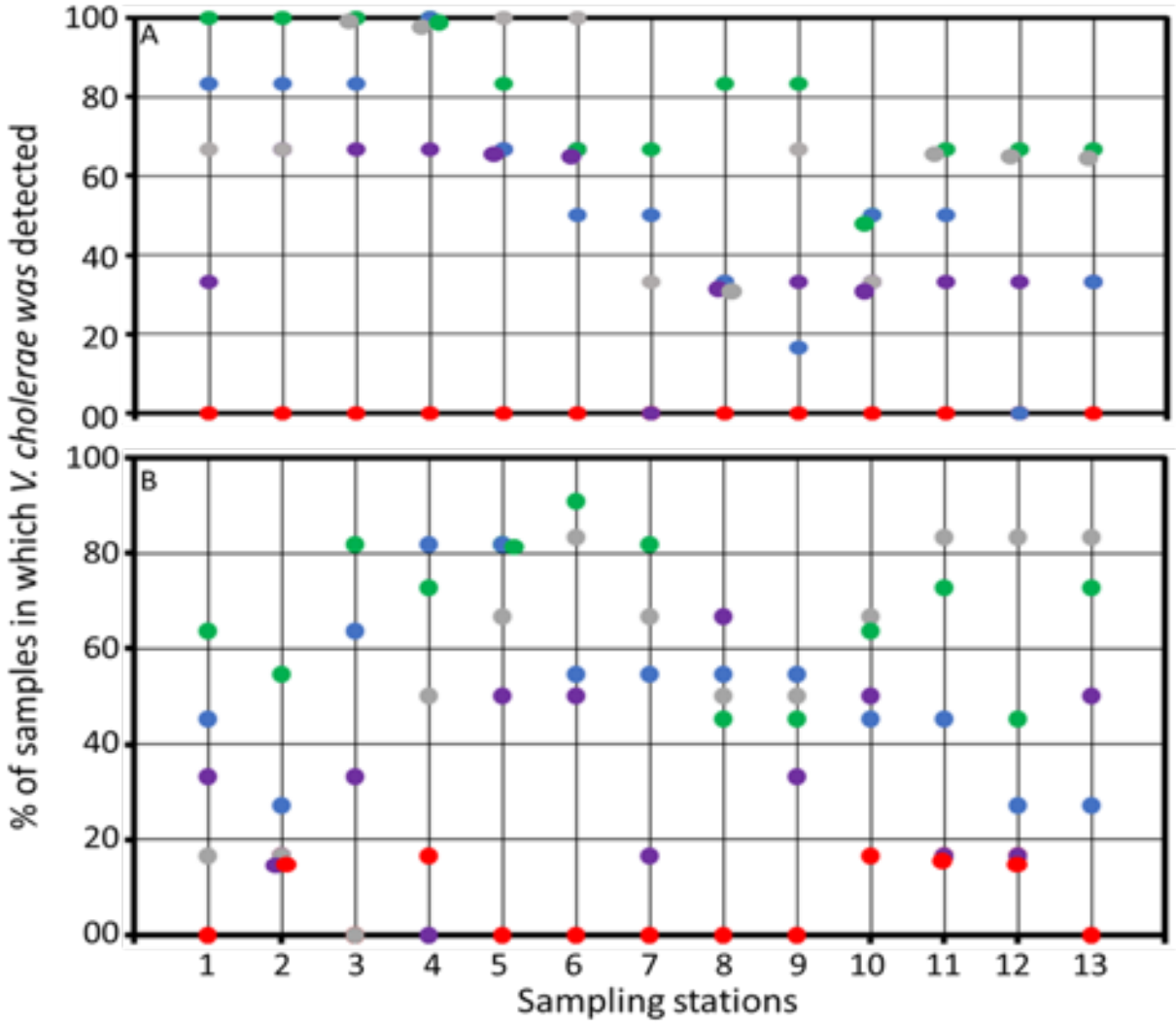


Asplund et al. (2011)
Environmental Microbiology

Environmental reservoirs of *Vibrio*

- *Vibrio cholerae* are found more frequently in association with phytoplankton than zooplankton, sediment, macrobenthos or water in Vembanad Lake
- Vibrio – phytoplankton association could be related to laminarinase and chitinase activities

Anas Abdulaziz et al. (2021)



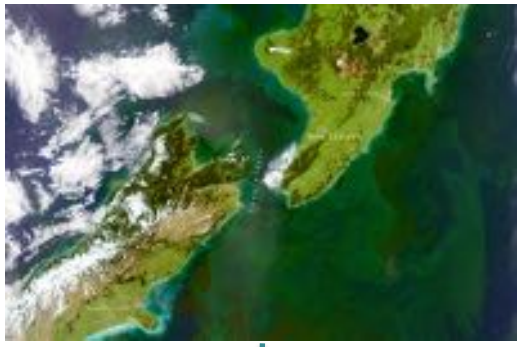
Distribution of *Vibrio cholerae* in sediment (red), macrobenthos (purple), zooplankton (ash), phytoplankton (green) and water (blue) samples during wet (A) and dry (B) seasons in the Vembanad Lake (Anas Abdulaziz *et al.* 2021, Remote Sensing)

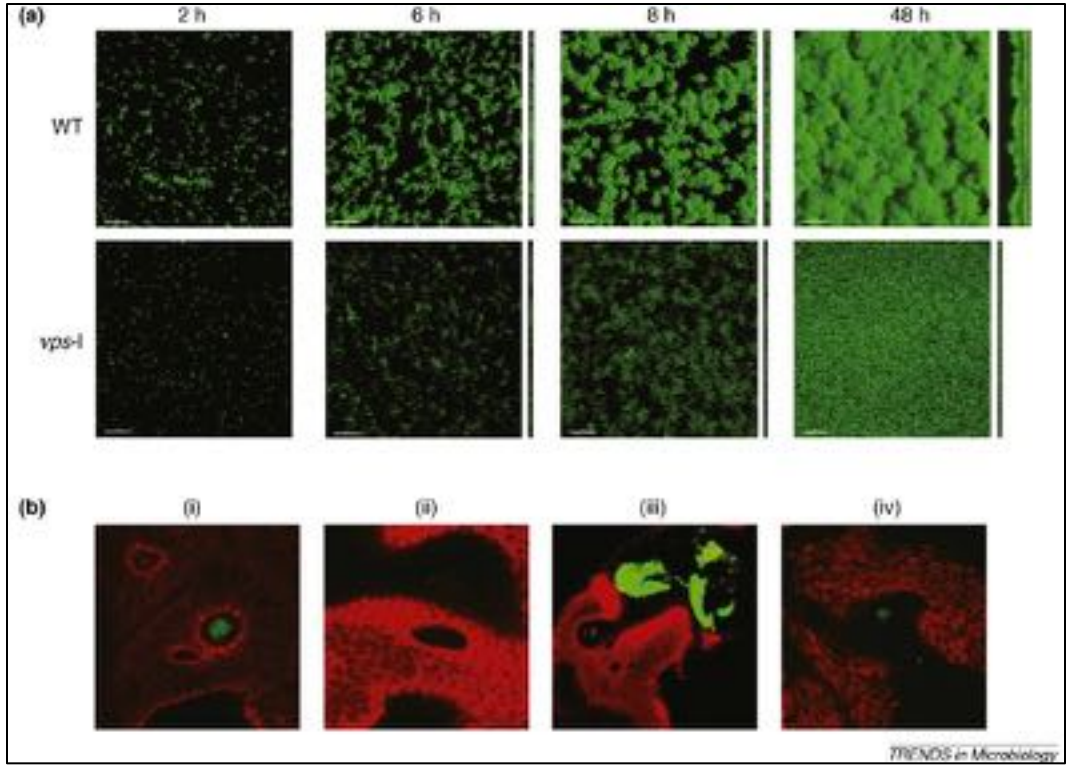
What is the ecological link between phytoplankton and *Vibrio cholerae?*

Another hypothesis: Link *via* biofilms formed by *V. cholerae* around phytoplankton

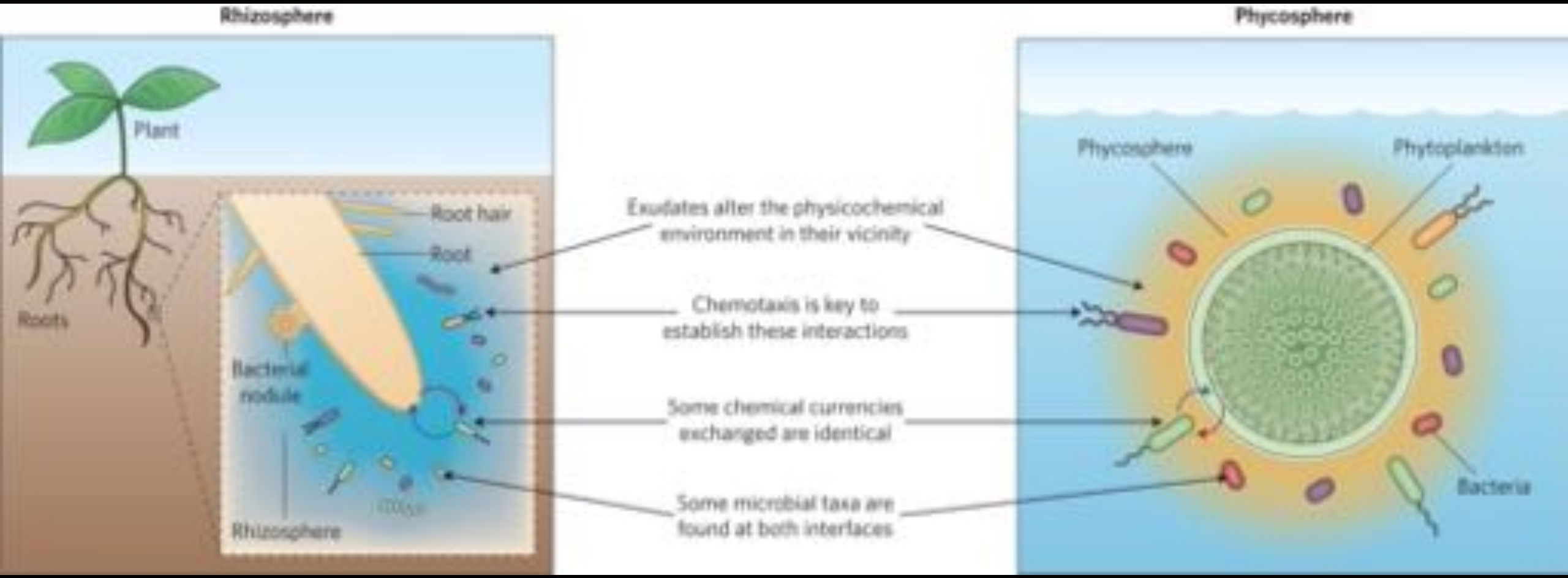
- Vibrio cholerae has the ability to form biofilms around many biotic and abiotic surfaces to access nutrients and avoid predators.
- Formation of biofilms (Yildiz and Visick 2009) or many other direct interactions could underpin strong association between *V. cholerae* and phytoplankton (Asplund *et al.* 2011, Anas *et al.* 2021).

Images courtesy:
NASA
Yildiz and Visick, 2009



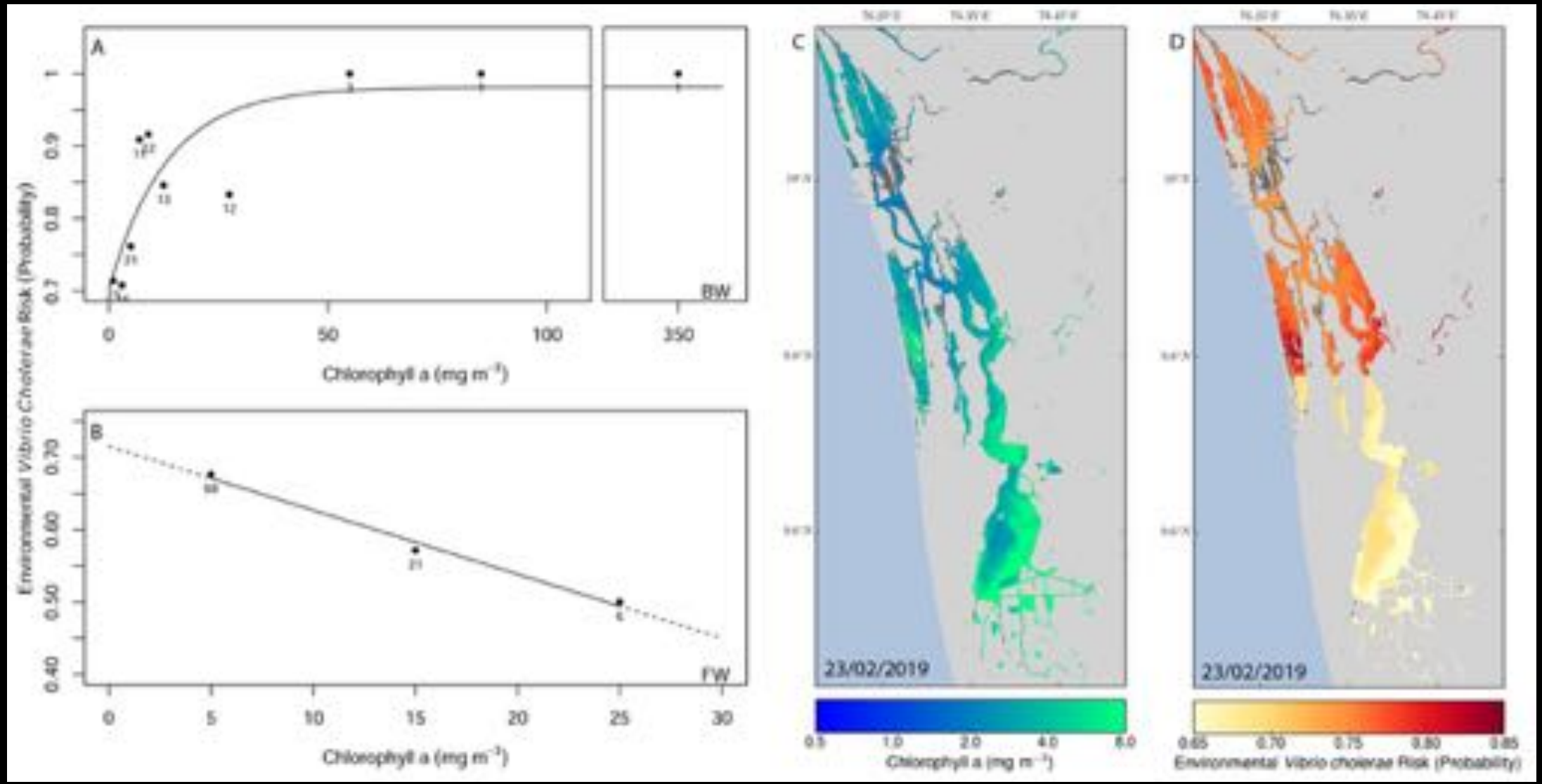


Rhyzosphere and Phycosphere



Seymour et al. (2015) Nature Microbiology

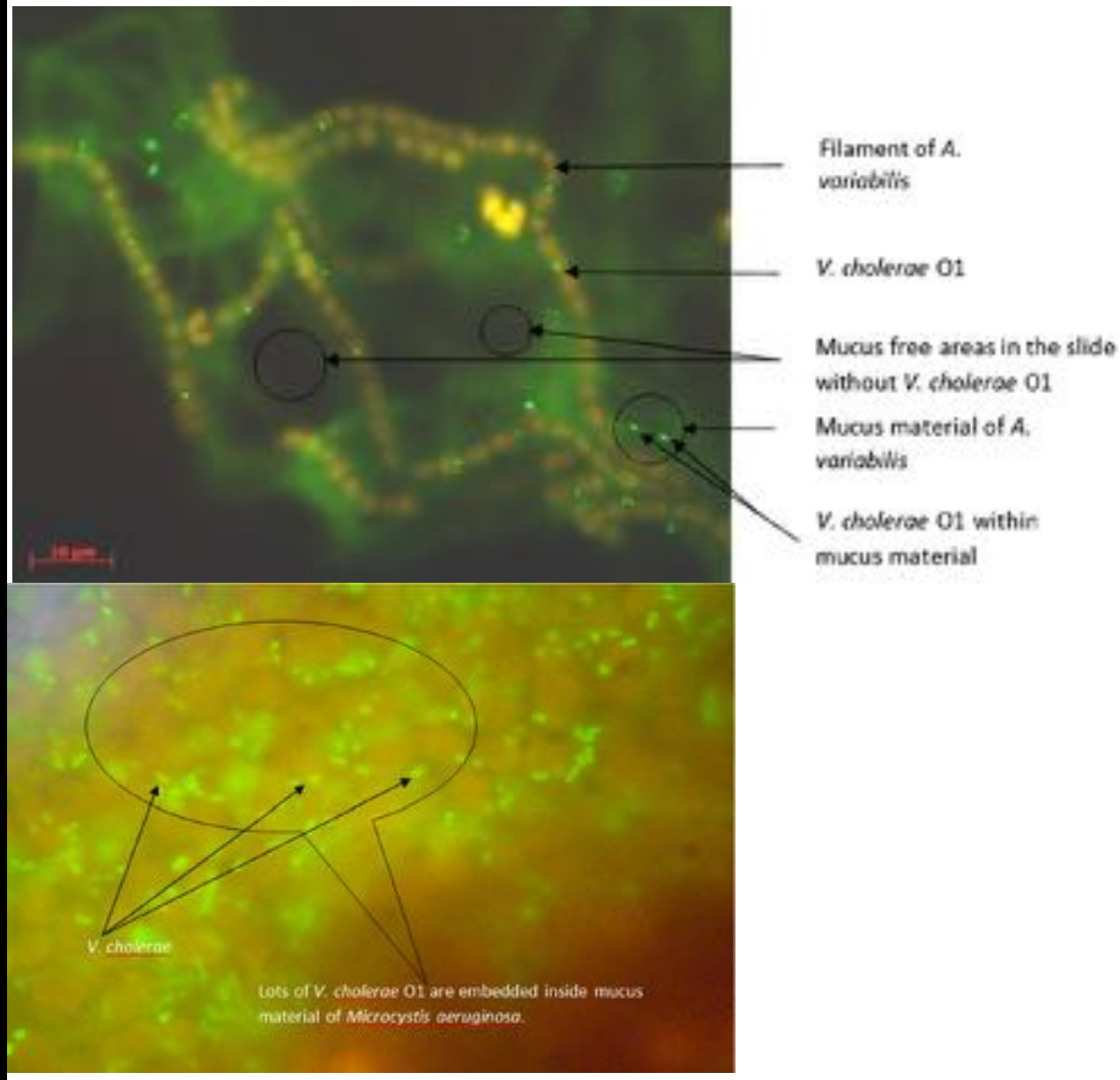
Vembanad Lake: Chlorophyll-Vibrio Association may be positive or negative



Abdulaziz et al. (2021)

Vibrio cholerae association with phytoplankton

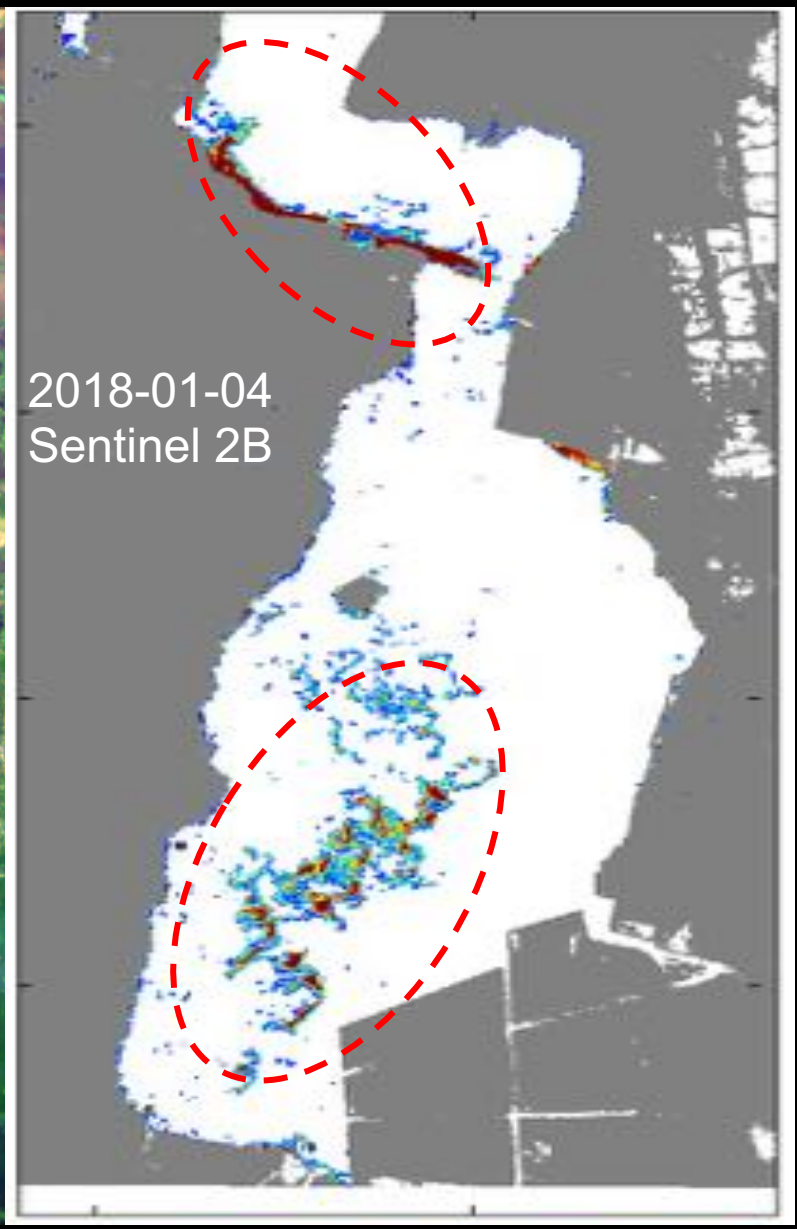
- Islam et al. (2019) and many others have shown that Vibrio cholerae can be associated with some types of phytoplankton (e.g., *Anabaena variabilis, Microcystis Aeruginosa*)
- The musilaginous sheaths of the phytoplankton provide protection and nutrients to the bacteria
- But Olofsson et al. (2013) have shown that some phytoplankton can have an inhibitory effect on growth of *Vibrio parahaemolyticus*.
- In the experiment of Olofsson et al. (2013), *Prorocentrum micans* promoted growth of the bacteria, whereas *Skeletonema costatum* inhibited it.
- Potential explanation of our observations in Vembanad Lake might lie in the differing interactions between phytoplankton and Vibrio.



Islam et al. (2019)

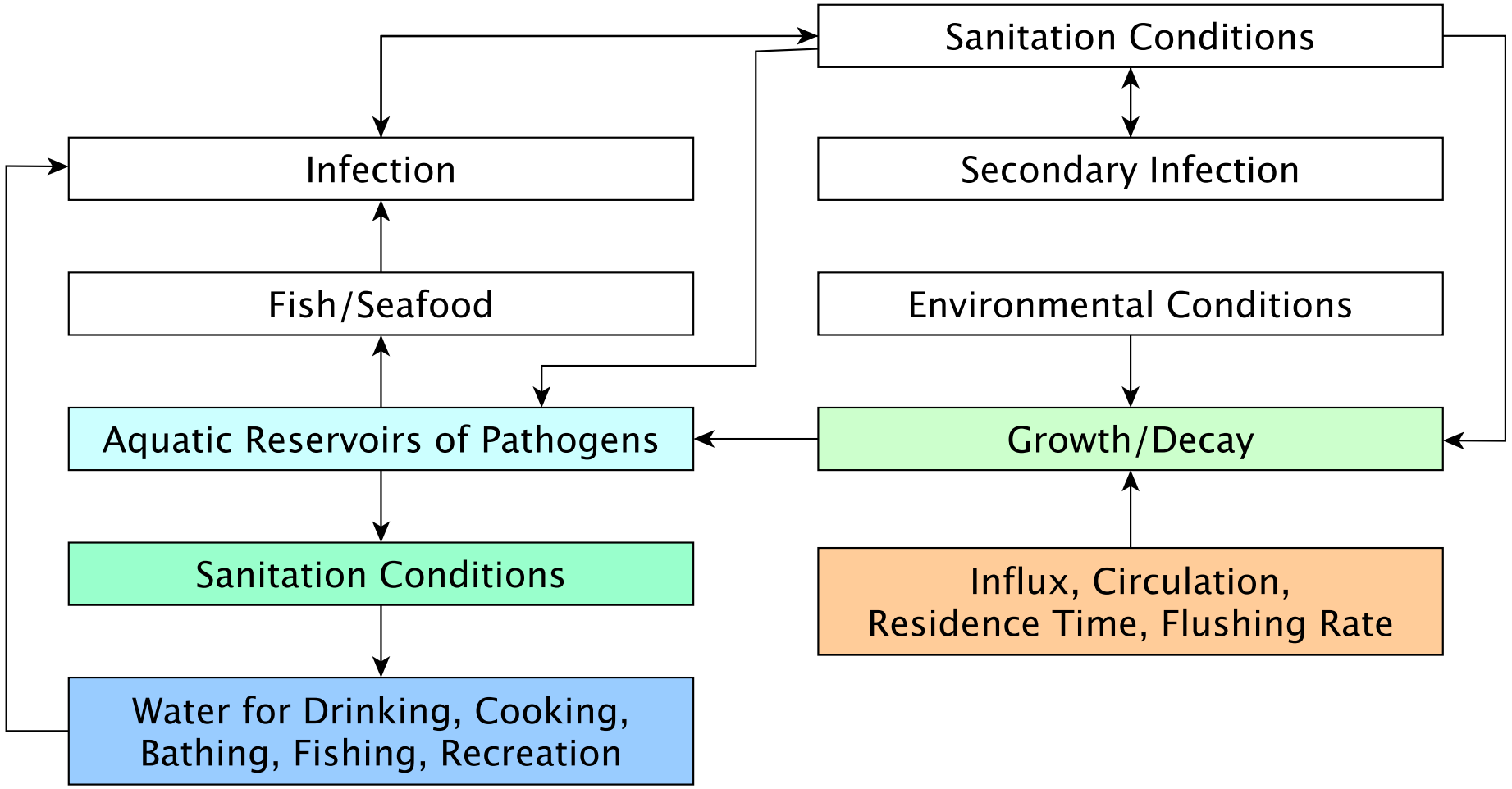
Floating Algal Index

- Algorithms exist for mapping floating vegetation on water bodies.
- One of them was proposed by Hu *et al.* (2009).
- Potential to explore its use for malaria-related work.
- Invasive species of floating vegetation serve as micro-reservoirs of water for mosquito larvae.
- Mosquitoes are vectors for transmission of vector-borne diseases such as malaria.



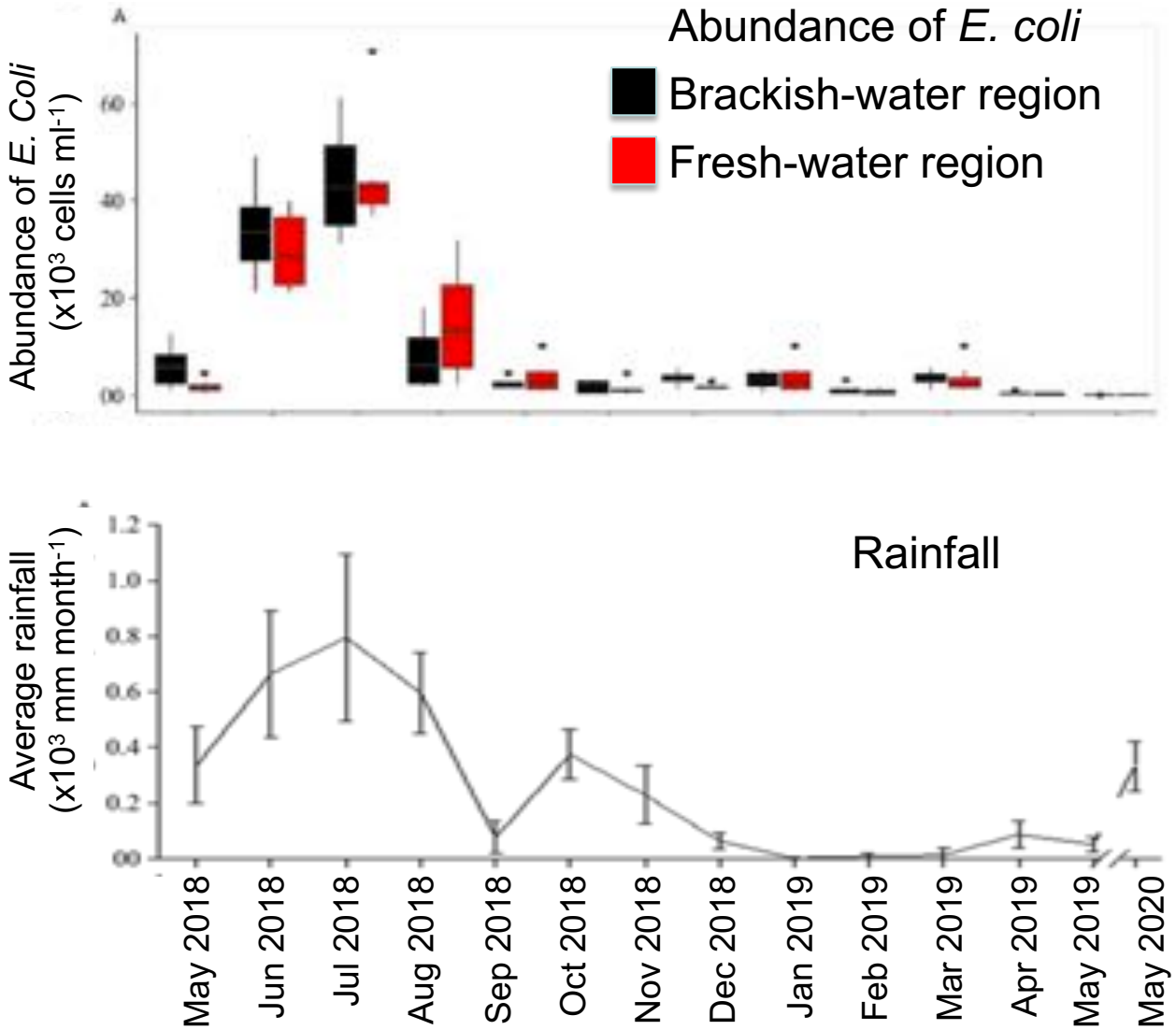
Images from Varunan Theenathayalan

Influx/outflow of Pathogens from Satellites

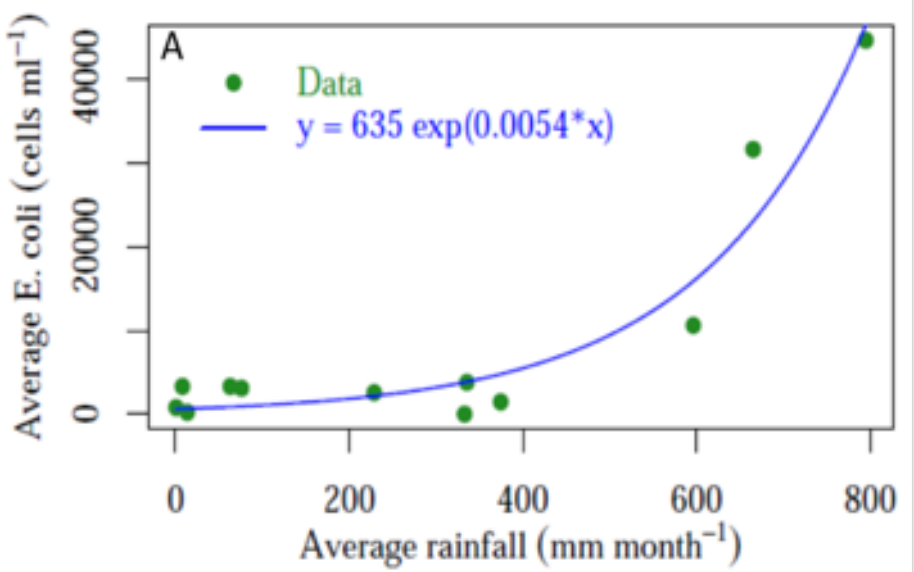


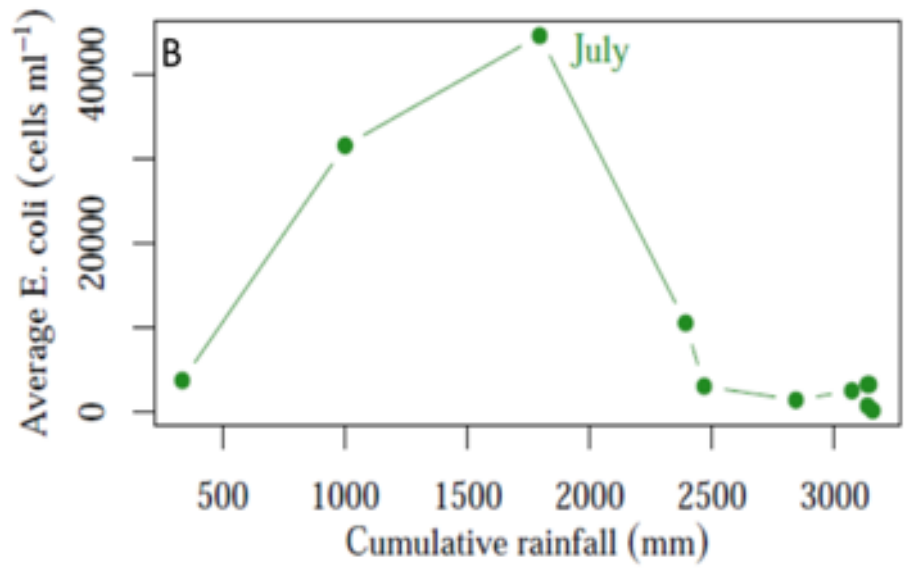
Faecal Contamination in Vembanad Lake

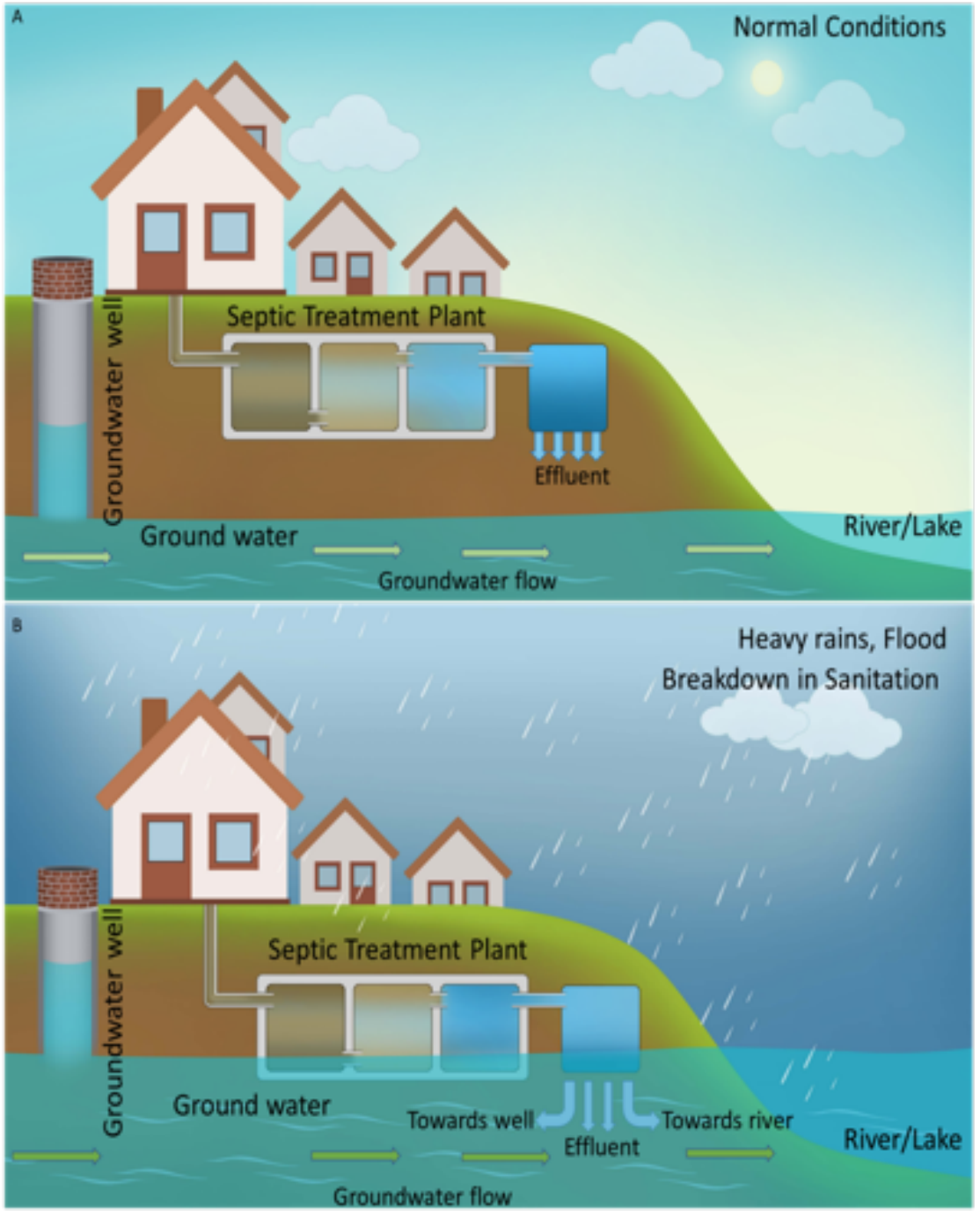
- *Escherichia Coli* is generally considered an indicator of faecal contamination
- *E. Coli* well above acceptable levels at all times
- Minimum values recorded just after lockdown
- Maximum values during the south-west monsoon



Relationship between *Escherichia coli* in water and rainfall







Abdulaziz *et al.* (2023)

Prospects for a Mathematical Model

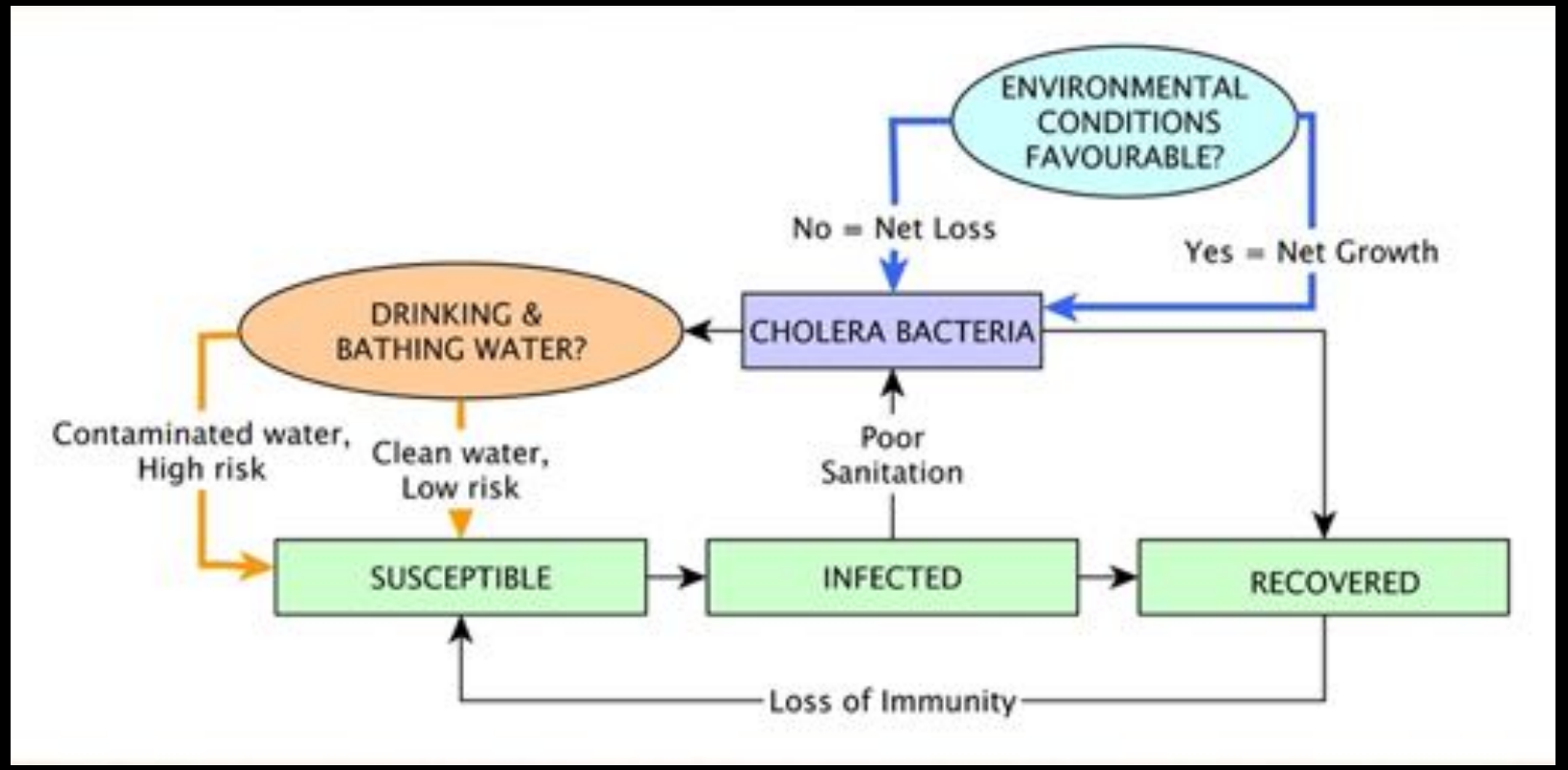
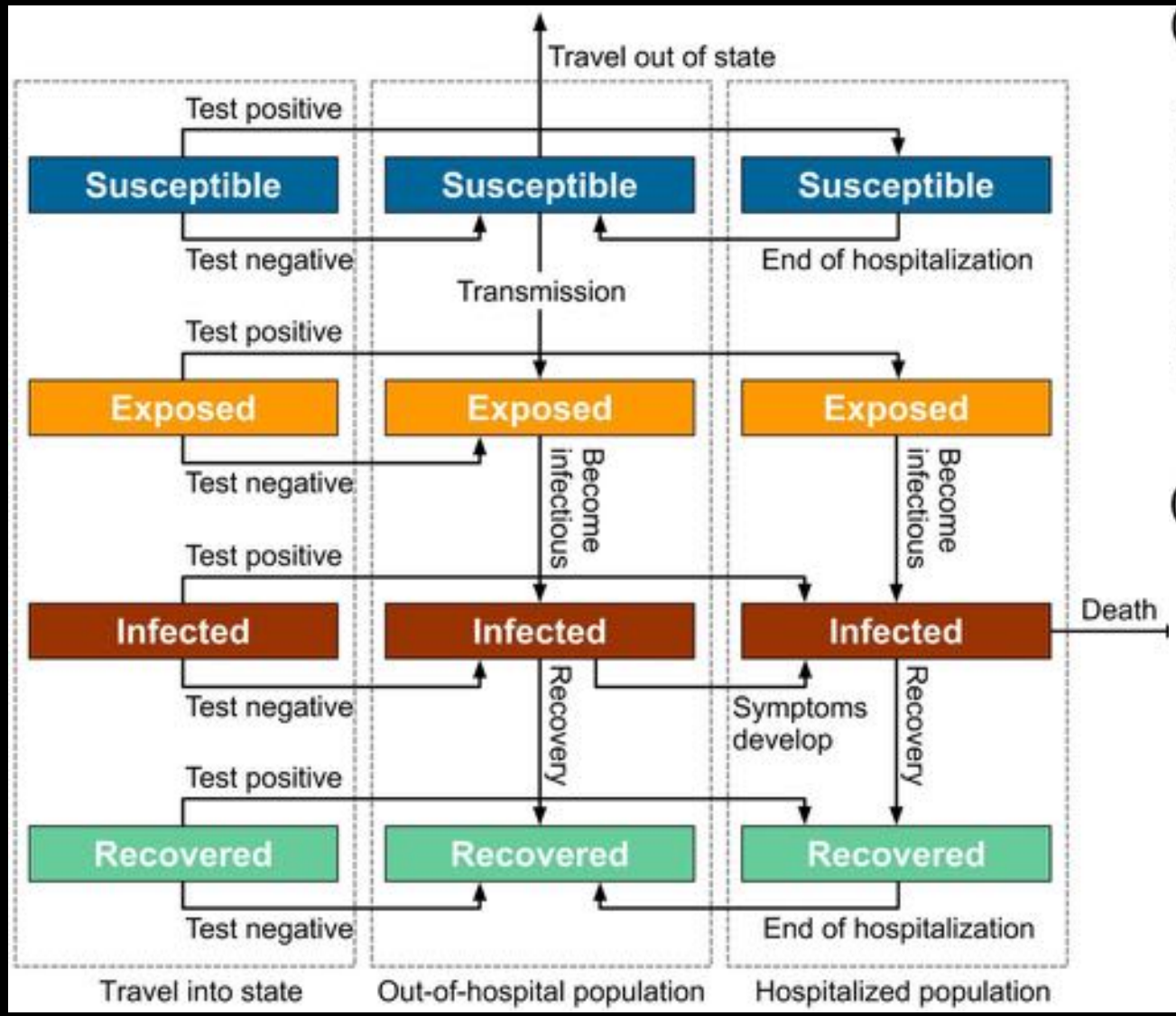
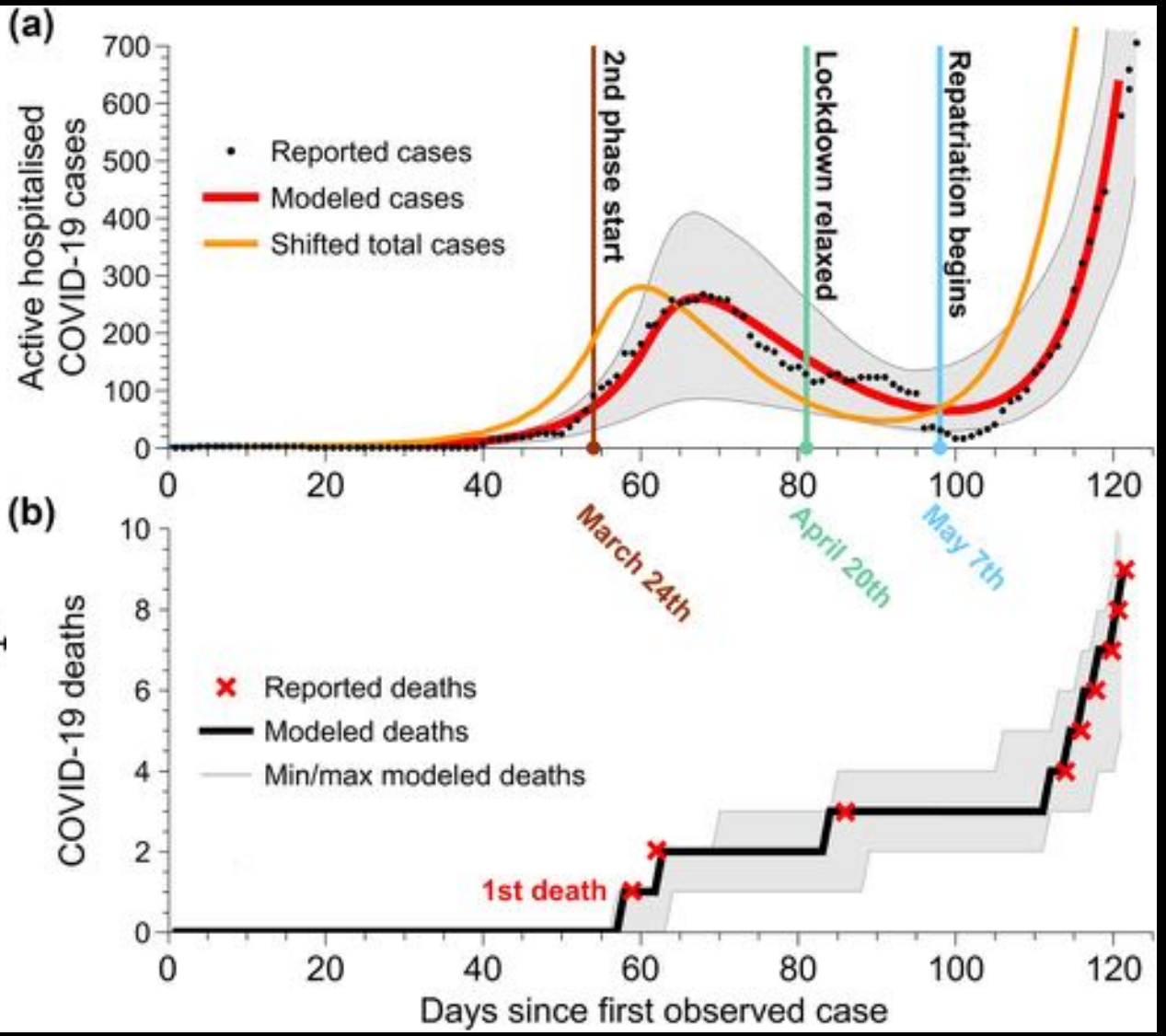


Figure from Goult and Platt

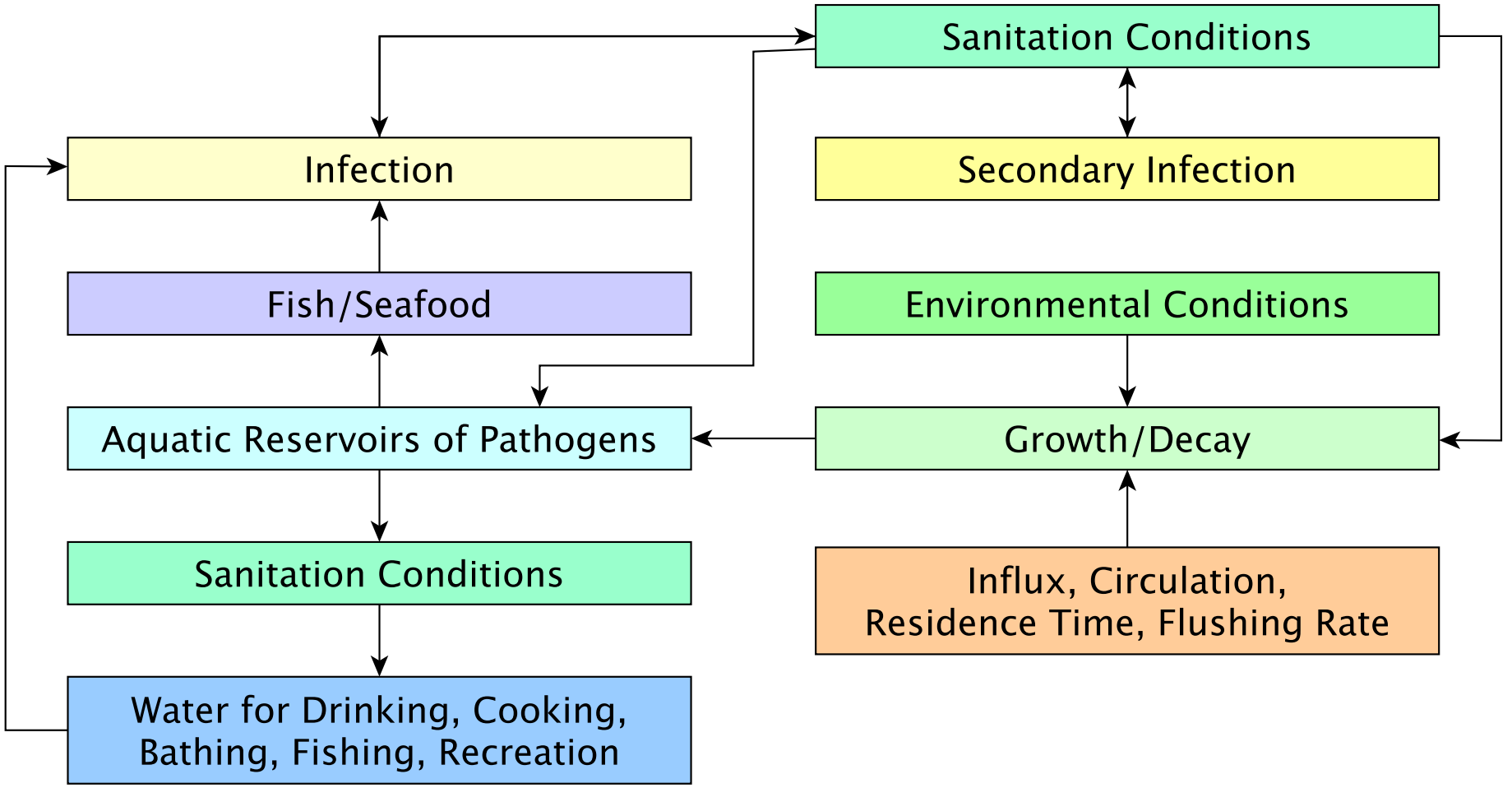
COVID in Kerala





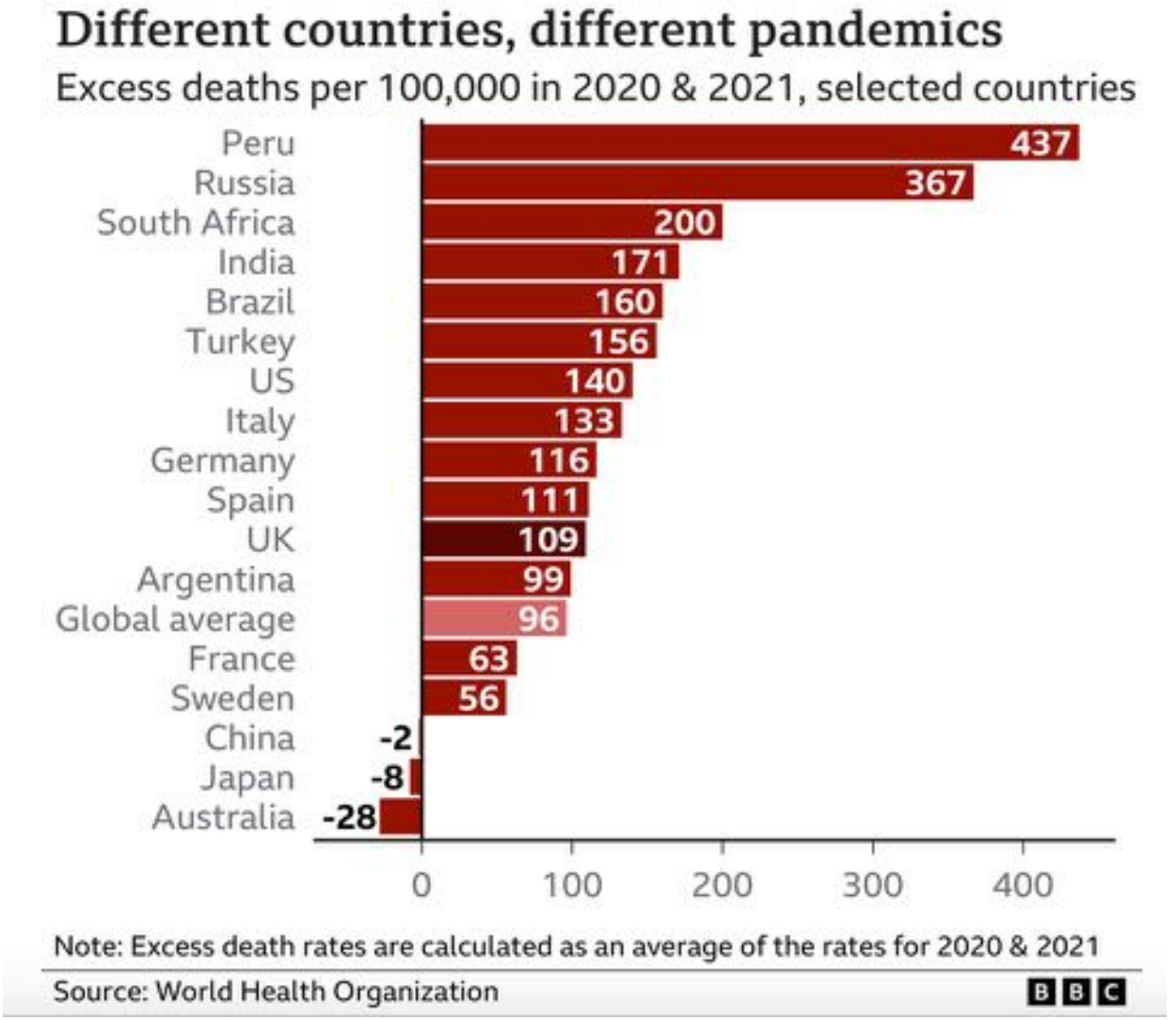
Goult et al. 2022

An Overview of the Role of the Environment

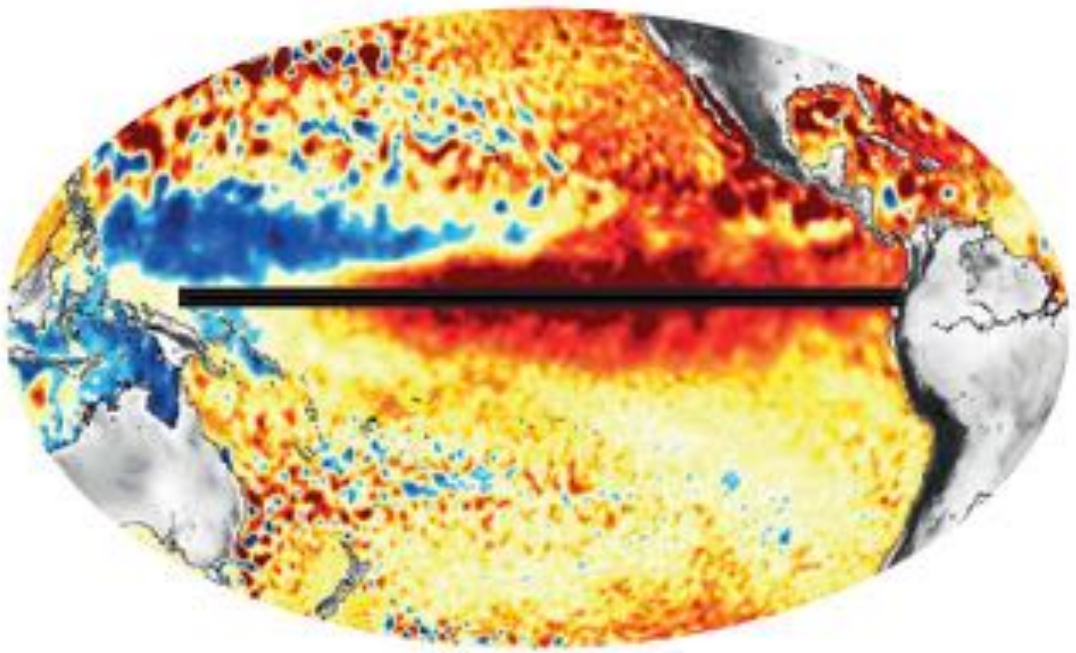


Importance of Data Quality

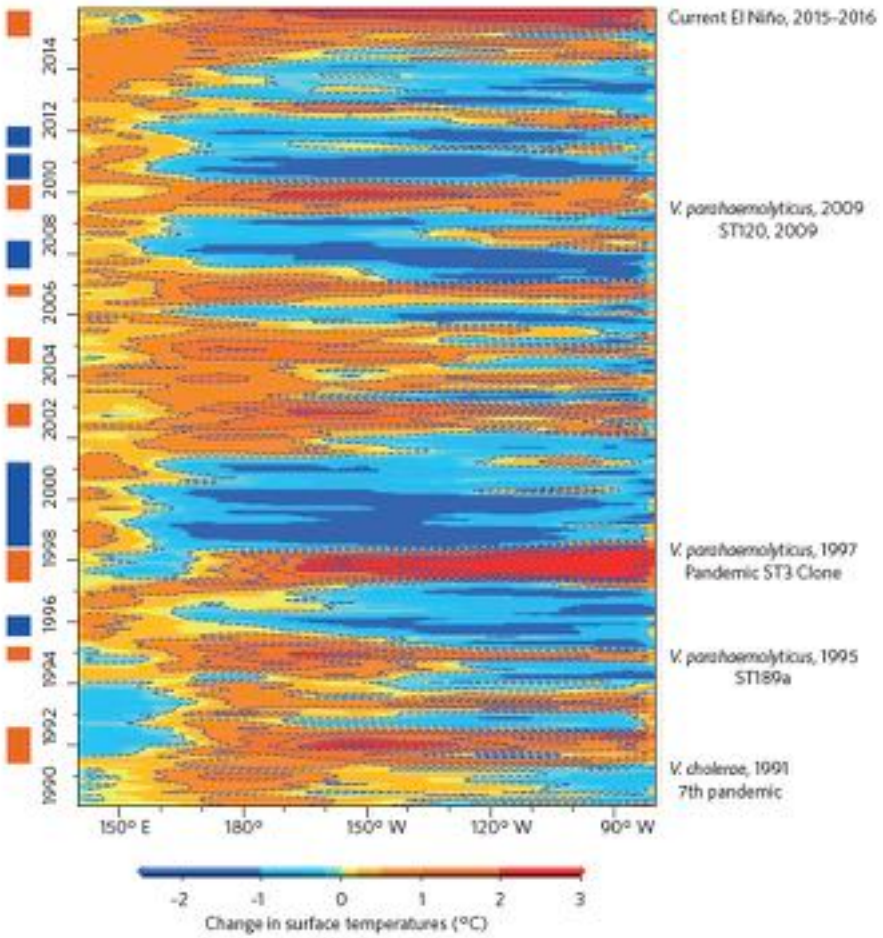
- Quality of any analysis will depend on the quality of the data.
- The COVID-19 is a well studied example of problems associated with under-sampling.
- More than 4.7 million people in India – nearly 10 times higher than official records suggest – are thought to have died because of Covid-19, according to a World Health Organization report.
- Problems with data quality tend to be higher for other infectious diseases
- Data quality issues tend to worse in low-income income countries, and the burden of water-borne diseases is higher in tropical, low-income countries
- Within country differences important for big countries: high spatial and temporal resolution needed



Is *El Niño* a long-distance corridor for waterborne disease?



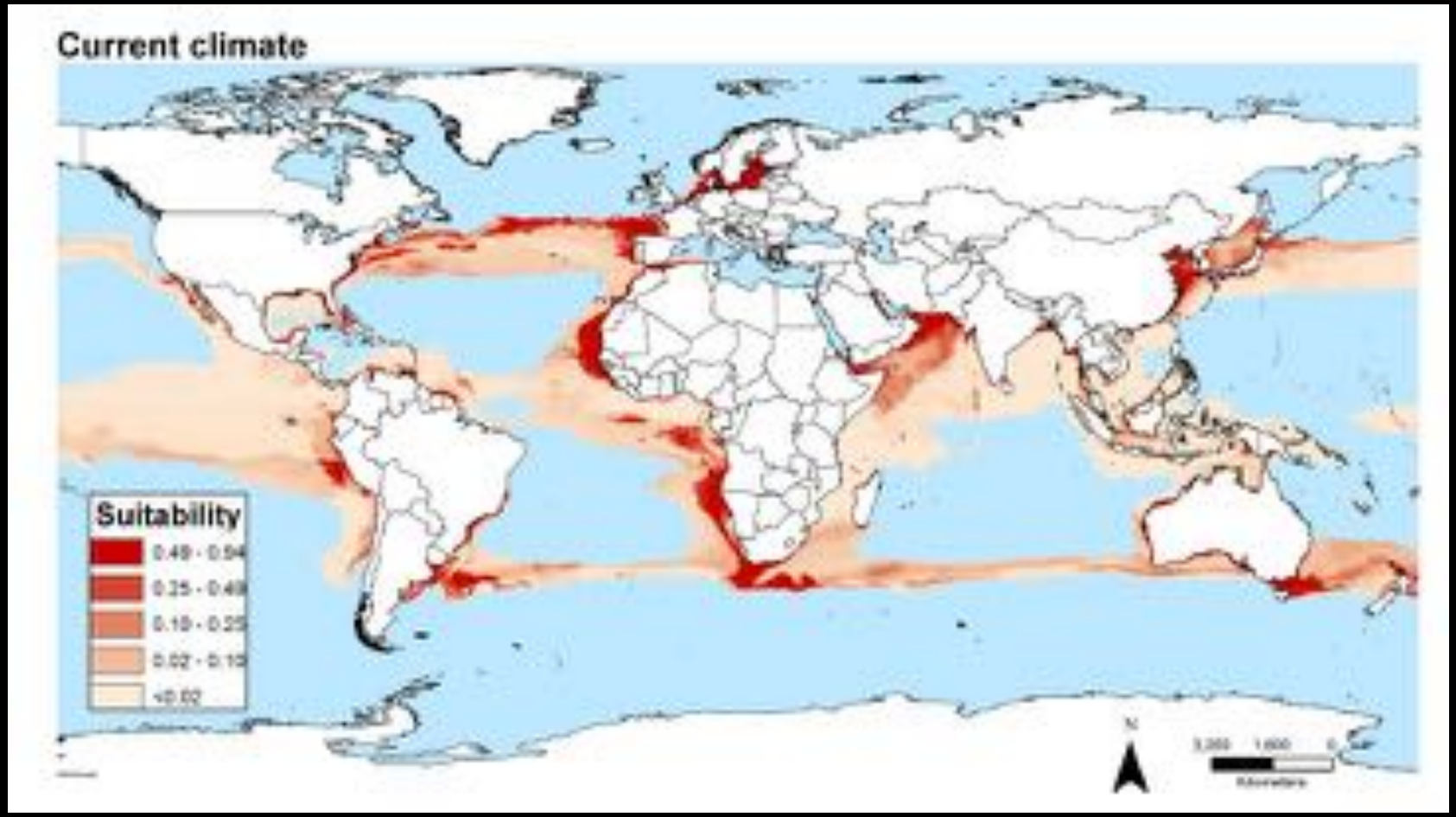
El Niño event of 2017 establishes an ocean corridor between Asia and South America, suitable for transport of bacteria from Asia to South America



Major *Vibrio* outbreaks in South America coincide with El *Niño* events

Martinez-Urtaza et al. 2018

Marine Environments Suitable for Cholera Bacteria

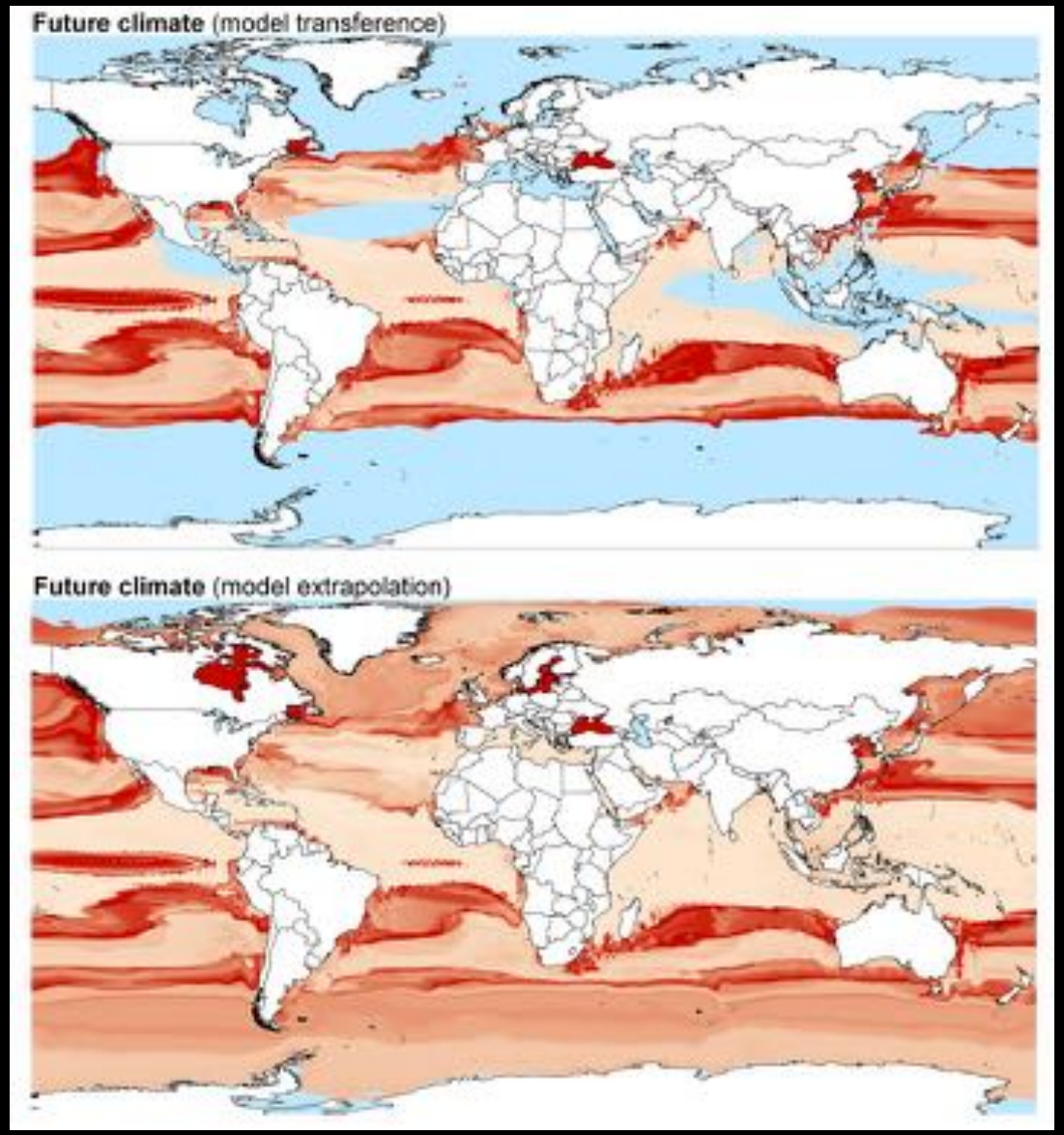


Satellite-based variables used in the ecological niche model:

- SST (minimum, mean, and maximum)
- PAR (maximum)
- Salinity (mean)
- Chlorophyll-a (maximum) – most important explanatory variable

Escobar et al. 2015

Climate Projections



Escobar et al. 2015

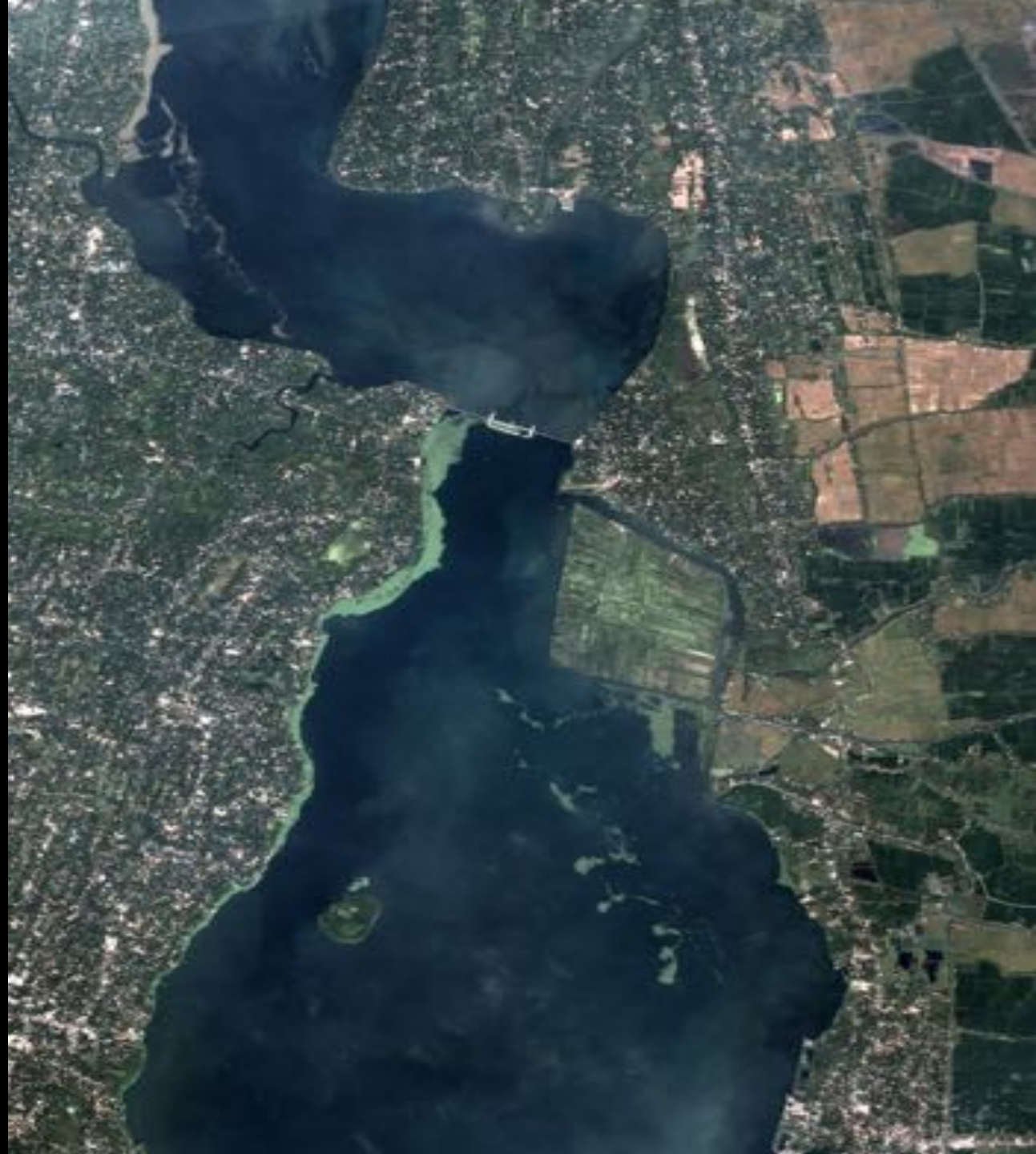
Remote Sensing for UN Sustainable Development Goals

The 16 SDGs are an expression of intergovernmental aspirations to make a better global society. Earth observation is useful, and is being used, to help meet the goals and the associated targets.

Relevant SDG	What can ocean colour do?
SDG 2: Zero Hunger	Responsible fisheries and aquaculture
SDG 3: Good Health	Food quality, water-borne diseases
SDG 6: Clean Water	Water quality
SDG 13: Climate Action	Essential Climate Variable, Biophysical dynamics, Carbon cycle
SDG 14: Life Below Water	Marine biodiversity, Marine food web

SDG 6: Water and Sanitation

- Ocean colour is just as useful in lakes as in the ocean
- SDG Target 6.6: “By 2030, protect and restore water-related ecosystems, including …., wetlands, rivers, aquifers and lakes”
- Bacteria responsible for diseases such as cholera contaminate water used for drinking and bathing, a reality aggravated by poor sanitation and by flooding
- Ocean colour (chlorophyll concentration) has been shown to be a good predictor of the abundance of the bacterium responsible for cholera
- Ocean colour being explored to develop geo-referenced risk maps for cholera outbreaks



Concluding Remarks

- Remote sensing offers several avenues to explore the dynamics of pathogenic organisms (bacteria or virus) that are associated with water-borne or vector-borne diseases.

- But the problem is complex, and calls for an integrated approach, with remote-sensing scientists, marine microbiologists, geneticists, modellers, health workers and social workers coming together to reduce the risks to humans from water-borne diseases.

- We are building a global network of interested scientists to learn from each other and to work towards a more general solution to the problem applicable in multiple locations and for diverse conditions.

“Kennt man die Eigenfarbe eines Sees, so kennt man auch seine übrigen Eigenschaften’’—if you know the color of a lake, you also know its other characteristics – A. Thienemann 1925

THIENEMANN, A. 1925. Inland waters of central Europe. E. Schweizbart’sche Verlagsbuchshandlung. Cited in Tranvik et al. (2009) Limnology and Oceanography

For More Information:

- For training opportunities: EUMETSAT Training Zone provides various training opportunities on satellite observations
  https://training.eumetsat.int/
- To learn more about ocean colour: IOCCG provides a lot of information on ocean colour. Their reports, which are free, are very useful resource material
  https://ioccg.org/