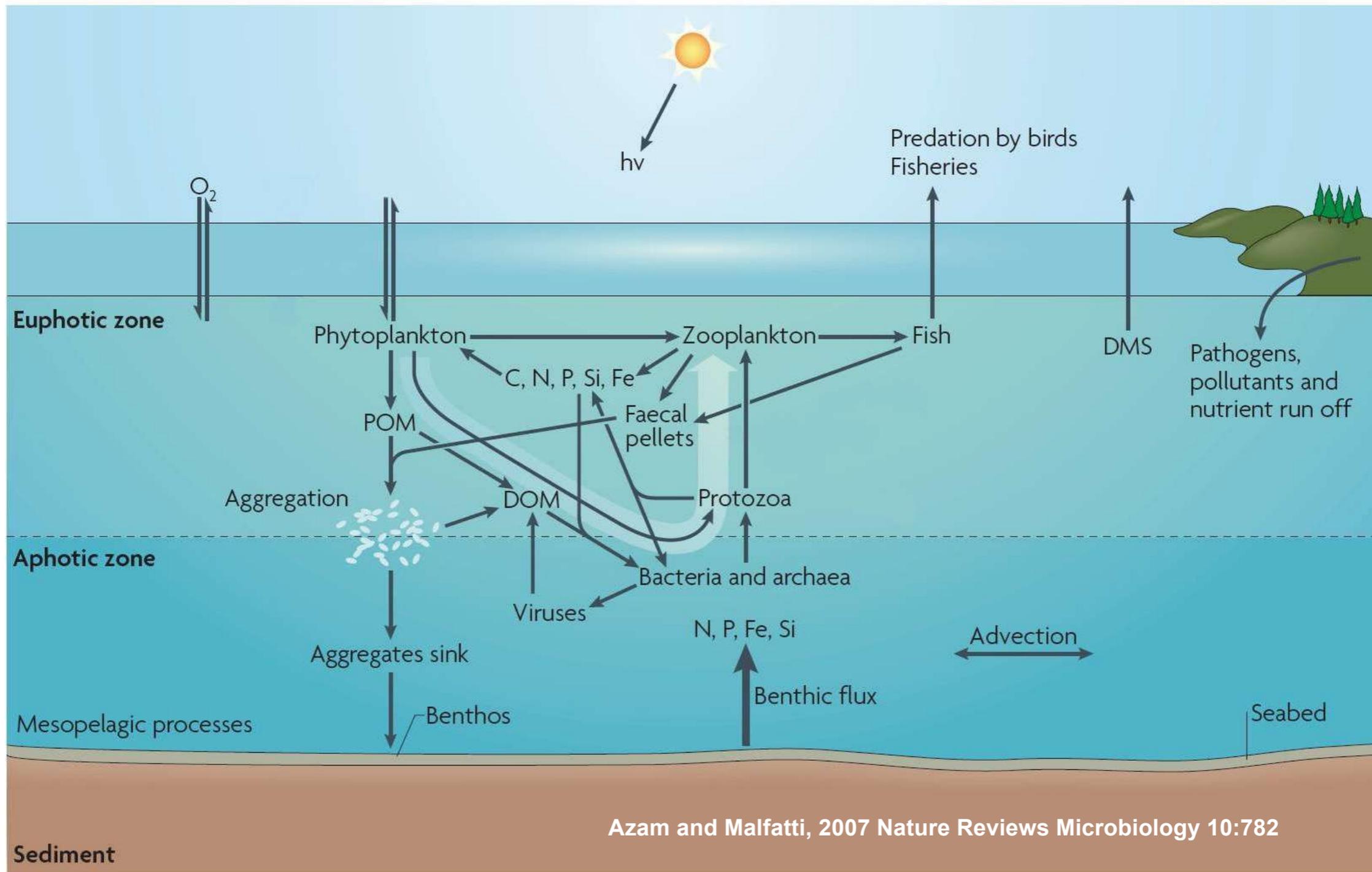


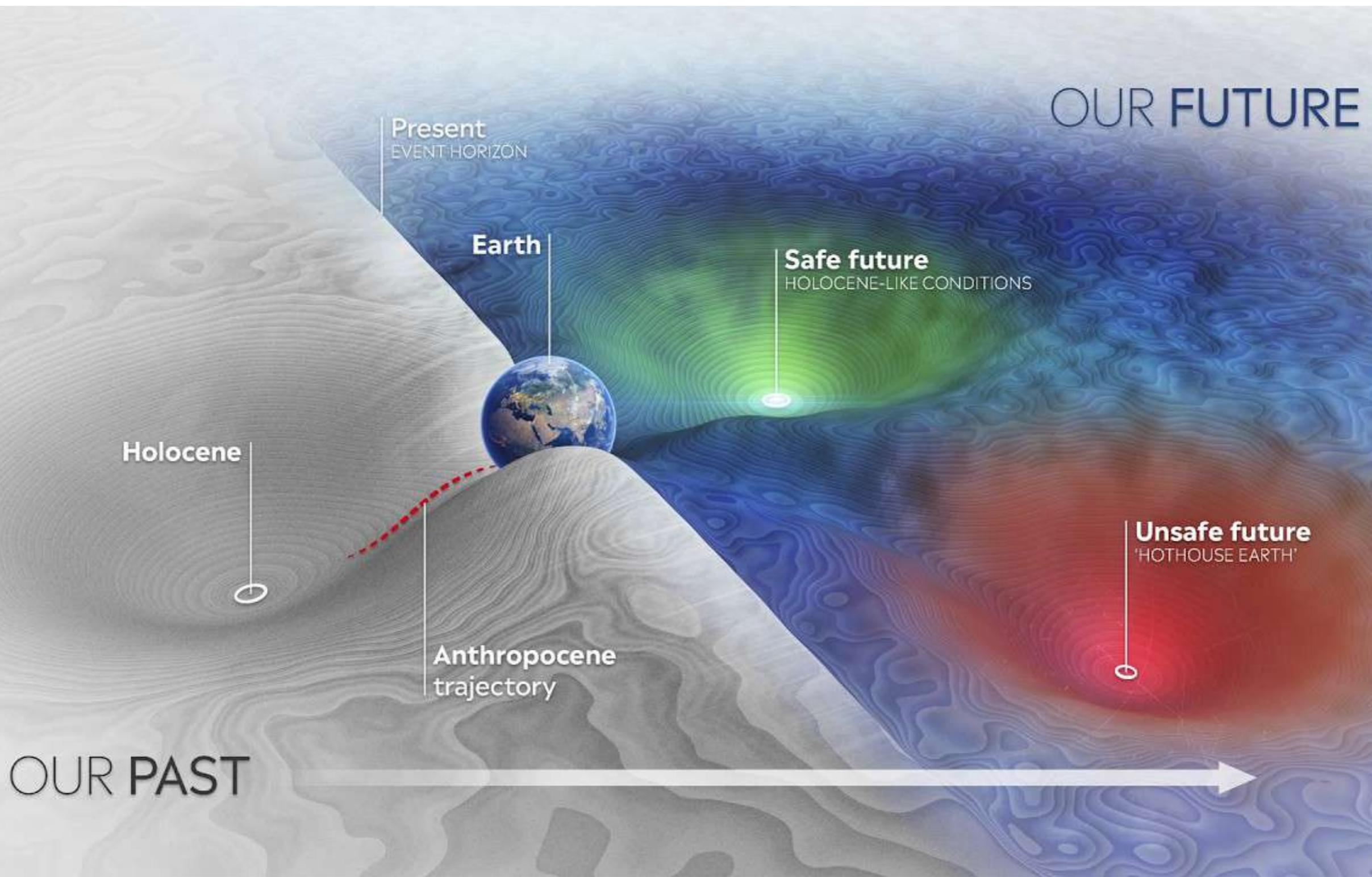
L06a:

Marine Microbes and Society

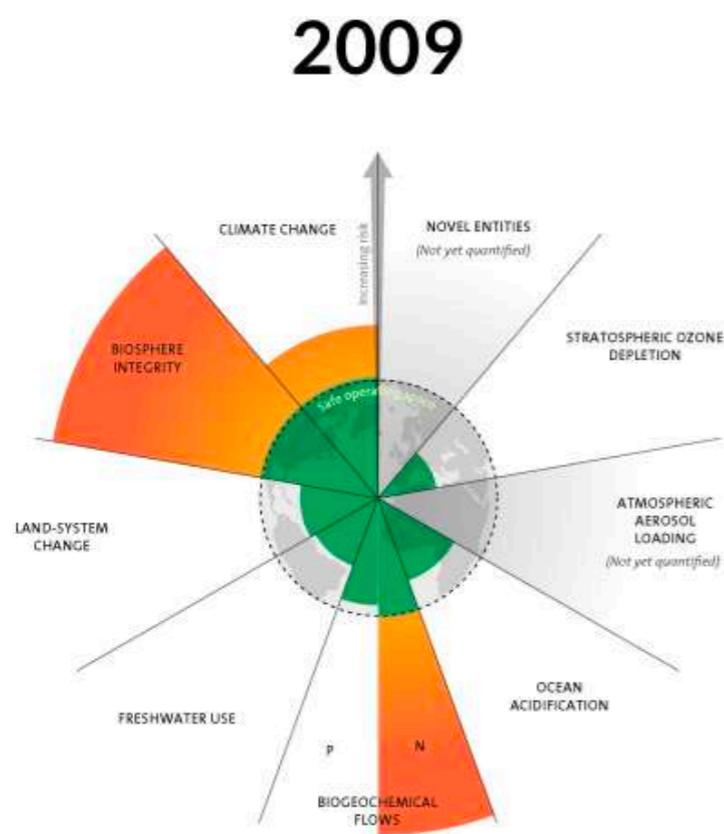
Microbial fingerprint on planet Earth and Human Society



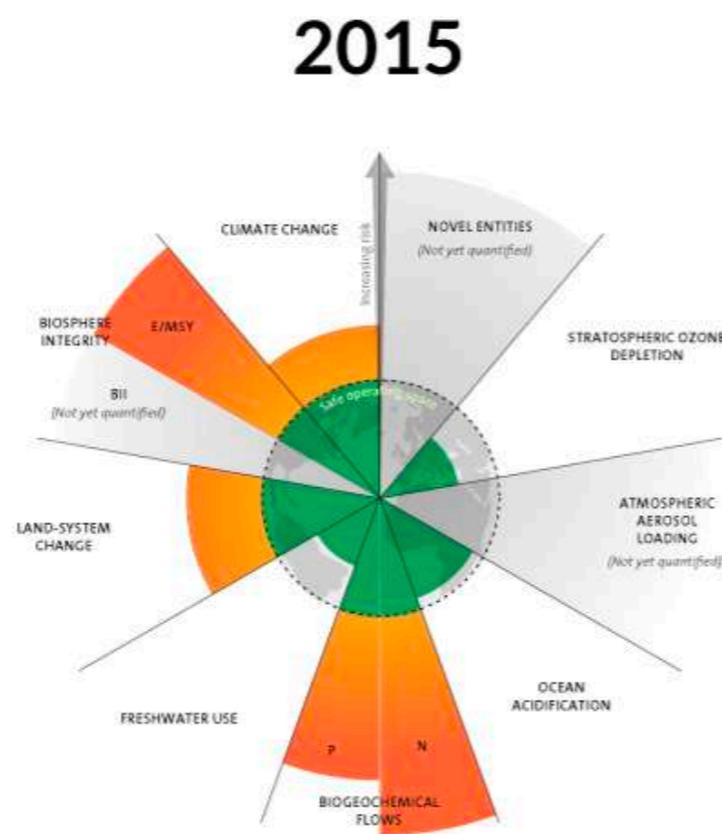
Azam and Malfatti, 2007 Nature Reviews Microbiology 10:782



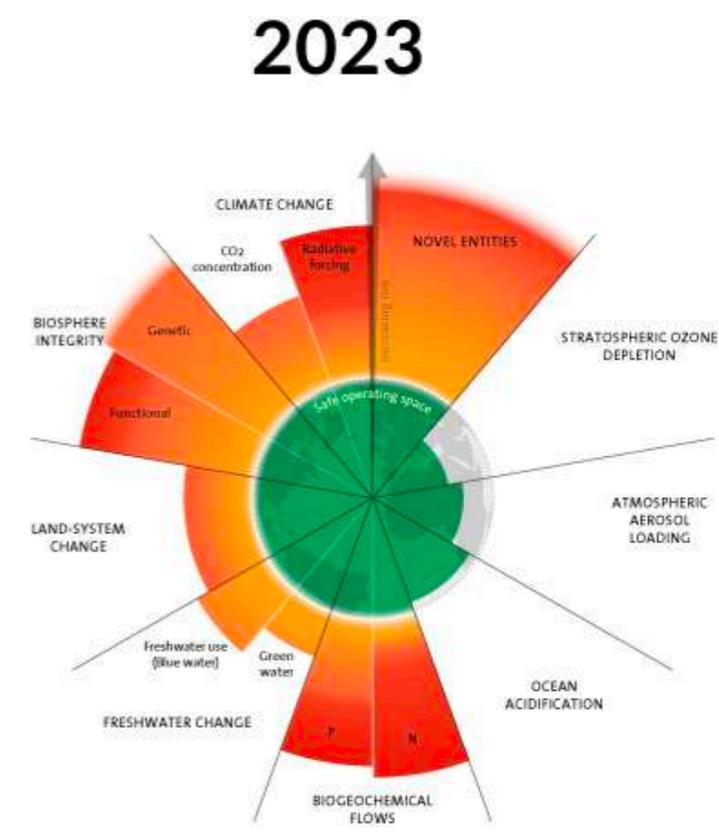
Planetary boundaries



3 boundaries crossed



4 boundaries crossed



6 boundaries crossed

The planetary boundaries concept presents a set of nine planetary boundaries within which humanity can continue to develop and thrive for generations to come

In September 2023, a team of scientists quantified, for the first time, all nine processes that regulate the stability and resilience of the Earth system

Novel entities

Microbes and Pollution

Pollution

Before 1972, humans around the world spewed trash, sewage sludge, and chemical, industrial, and radioactive wastes into the ocean with impunity

The London Convention, ratified in 1975 by the United States, was the first international agreement to spell out better protection for the marine environment

The agreement implemented regulatory programs and **prohibited the disposal of hazardous materials at sea**

An updated agreement, the **London Protocol**, went into effect in **2006**, more specifically banning all wastes and materials except for a short list of items, like leftover materials from dredging. It can change the physical, chemical, and biological state of the ocean and coastal areas, posing a threat to marine wildlife and ecosystems, and the industries and livelihoods dependent on them, such as fisheries and tourism. Toxic chemicals also become concentrated in the food chain and can impact human health.

There are three significant forms of oceanic and coastal pollution:

- **Nitrogen-phosphorous pollution** from agriculture, sewage, and urban and industrial run-off;
- **Chemical pollution** that comprises, but is not limited to, pesticides, petroleum, pharmaceuticals and personal care products, heavy metals and industrial discharge;
- **Plastic-debris pollution.**

Human pollution Chemical pollution Radioactive pollution

The screenshot displays the EMODnet Map Viewer interface. On the left, a control panel is visible with the following sections:

- Layers**:
 - Pipelines
 - Route Density** >
 - Vessel Density** >
 - Waste Disposal** ▾
 - Discharge Points
 - Treatment Plants
 - Waste at ports
 - Dumped Munitions (Polygons)
 - Dumped Munitions (Points)
 - Dredge Spoil Dumping (Polygons)
 - Dredge Spoil Dumping (Points)
 - EMODnet Physics** ▾
 - .In situ data** >
 - + Add external layers**
- Marine regions**: Search for a region ... ▾
- Change basemap**: EMODNET World Base Layer ▾

The main map area shows a 3D topographic view of the Mediterranean region, with numerous red and purple icons representing data points. A scale bar at the bottom left indicates 10 km, and the coordinates 13.16541, 45.41895 are displayed. The EMODnet logo and 'European Marine Observation and Data Network' text are located in the bottom right corner of the map area.

Ocean pollution:

- **Microbial contamination**
- **Mercury cycle**
- **Oil Spill/Crude oil seepage**

OCEAN POLLUTION

Pollution of the oceans is widespread, worsening, and in most countries poorly controlled. Human activities result in a complex mixture of substances entering the aquatic environment

More than 80% arises from land-based sources

It reaches the oceans through rivers, runoff, atmospheric deposition and direct discharges. Ocean pollution has multiple negative impacts on ecosystems and human health, particularly in vulnerable populations

PLASTIC WASTE

1 An estimated 10 million metric tons of plastic enter the seas each year. Plastic pollution threatens marine mammals, fish and seabirds. It breaks down into microplastic and nanoplastic particles that can enter the human food chain

OIL SPILLS

2 Oil spills kill beneficial marine microorganisms that produce oxygen. They lead also to adisruption of food sources and destruction of fragile habitats such as estuaries and coral reefs

MERCURY

3 Mercury is released from two main sources - coal combustion and small-scale gold mining. Exposures of infants in utero when pregnant mothers eat contaminated seafood can cause IQ loss and serious developmental disorders. In adults, mercury increases risks for dementia and cardiovascular disease

MANUFACTURED CHEMICALS

4 Manufactured chemicals such as phthalates, bisphenol A, flame retardants, perfluorinated chemicals, and pharmaceutical waste cause multiple diseases. They can also reduce human fertility and damage coral reefs

PESTICIDES

5 Pesticides sprayed on crops often end up in the ocean via rivers and watercourses. They contribute to global declines in fish stocks, and can also reduce human fertility

NUTRIENTS

6 Agricultural fertilizers, animal feedlot waste, and human sewage increase the frequency of harmful algal blooms, accelerate the spread of life-threatening bacteria, and increase anti-microbial resistance

Ladrikan et al., 2020

WILL DESIGNED IN 2020 BY WILL STAHL-TIMMINS

Figure 1: Ocean Pollution – A Complex Mixture.

Microbial /contamination pollution

Via wastewater discharge

Human & Animal waste

Pathogenic bacteria, viruses and fungi

Gammaproteobacteria

Aeromonas hydrophila

Vibrio cholerae

Vibrio vulnificus

Vibrio parahaemolyticus

Vibrio mimicus

Vibrio alginolyticus

Salmonella spp.

Shigella spp.

Escherichia coli

Plesiomonas shigelloides

Epsilonproteobacteria

Campylobacter spp

(*C. lari*, *C. coli*, *C. jejuni*)

Helicobacter pylori

Arcobacter butzleri

Arcobacter skirrowii

Arcobacter cryaerophilus

Firmicutes

Clostridium perfringens

Erysipelothrix rhusiopathiae

Actinobacteria

Mycobacterium avium paratub.

Mycobacterium marinum

Adenoviridae
(ds DNA) Adenoviruses

Caliciviridae
(ss RNA) Norwalk virus

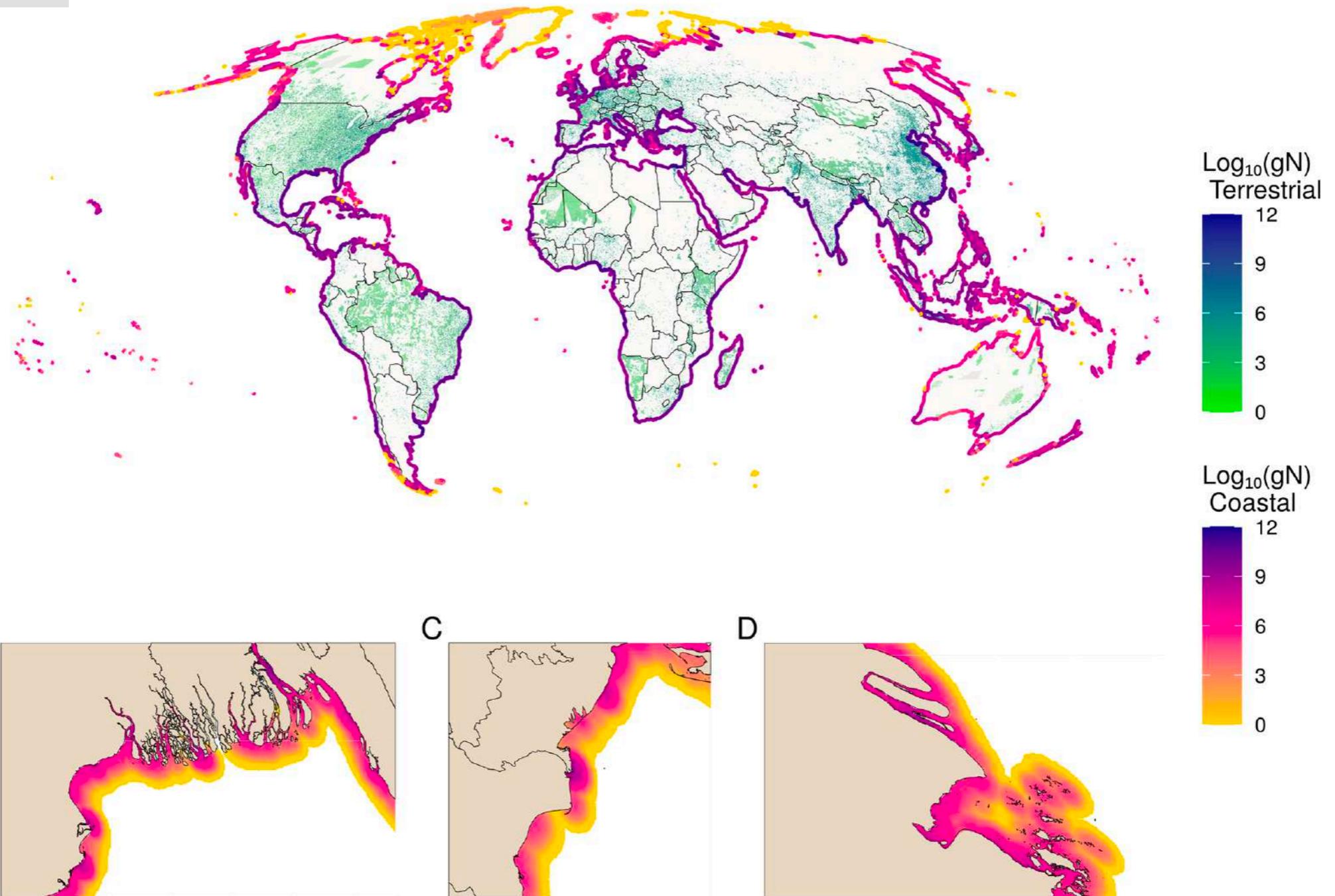
Astroviruses
Caliciviruses
Snow Mountain agent
Small round structured viruses

Picornaviridae
(ss RNA) Poliovirus
Coxsackievirus
Echoviruses
Enteroviruses

Hepatitis A

Reoviridae
(ds RNA) Reoviruses
Rotaviruses

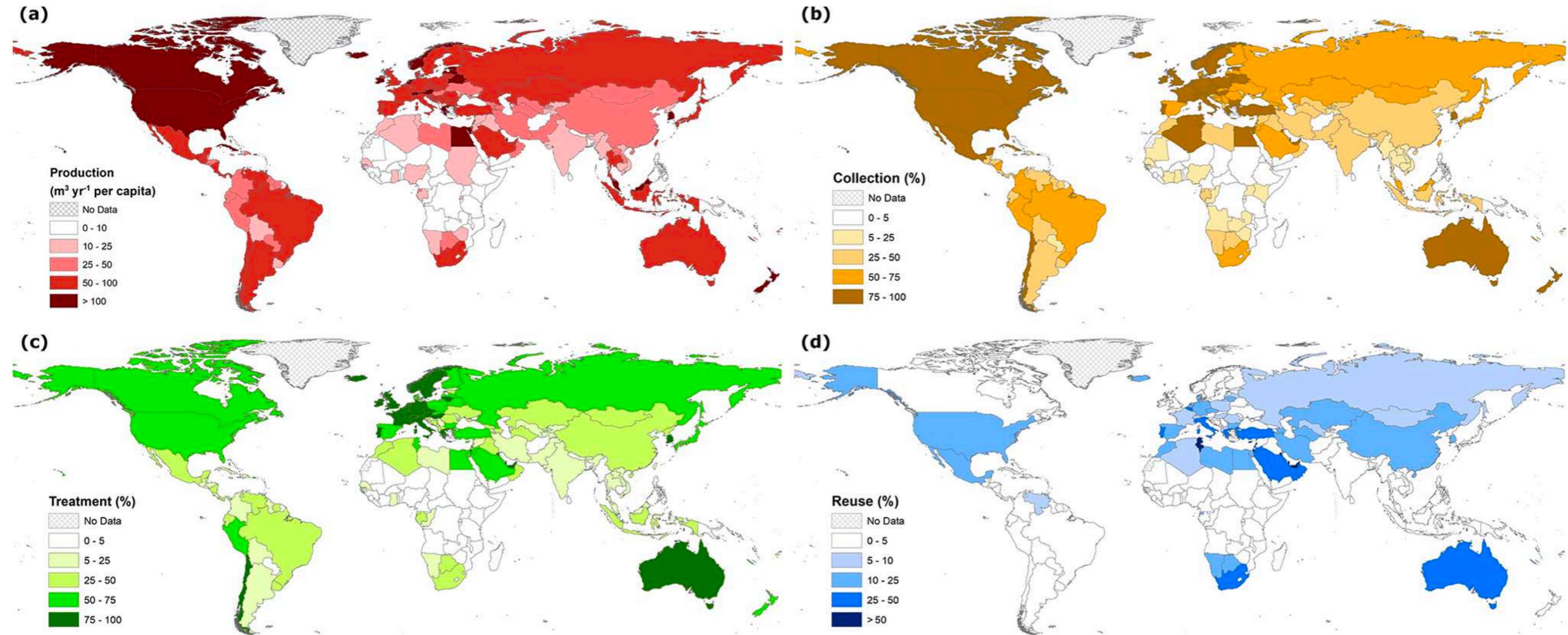
Global map of the terrestrial sources (green to blue) and coastal diffusion of inputs (yellow to purple) of total wastewater



Tuholske et al., 2021

Fecal indicator Organisms: *E. coli* and enterococci concentrations from waste water system

Wastewater production (m^3yr^{-1} per capita)



(a), collection (%) **(b)**, treatment (%) **(c)** and reuse (% , irrigation, desalination) **(d)** at the country scale

Chemical pollution

There are several major groups of chemicals such as:

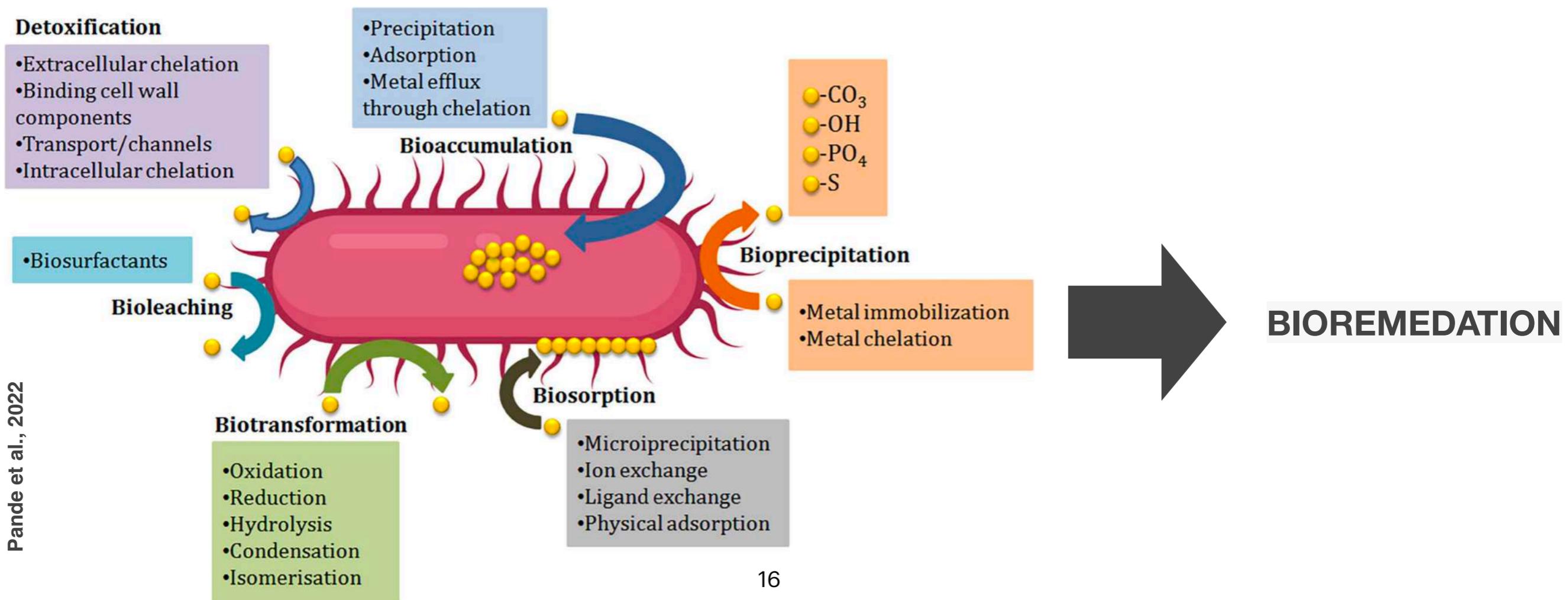
- **Pesticides and biocides;**
- **Pharmaceuticals;**
- **Industrial chemicals** such as solvents, flame retardants and plastic softeners;
- **Unwanted by-products** such as polychlorinated dibenzodioxins and furans
- **Oil from spills, discharge and shipping** persistent, bioaccumulative, and toxic substances
- **Chemicals banned decades ago**, like polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs)
- **Pollutants recognised as endocrine disruptors and teratogens**, which impact the ability of marine species to reproduce or reduce offspring survival rates, present a growing concern

Microbes-Heavy Metals interactions

Heavy metals = Potentially toxic metals

Biological molecules like lipids, nucleic acids, proteins, and enzymes get damaged due to the production of free radicals by the HMs thus increasing intracellularly the reactive oxygen species (ROS) levels thereby leading to oxidative stress

The failure in all of these biological substances creates several physiological issues, including, cell damage, DNA damage, and enzyme inhibition



Microbial Biotransformations

Microbial group	HM contamination	Microorganism	Microbial/Resistance mechanism	References
Bacteria	Cadmium	<i>Pseudomonas aeruginosa</i>	Biosorption	Chellaiah, 2018
	Lead	<i>Bacillus subtilis</i> X3	Bioimmobilization	Qiao et al., 2019
	Cadmium and lead	<i>Pseudomonas aeruginosa</i> and <i>Bacillus cereus</i>	Bioaugmentation	Nath et al., 2018
	Cadmium	<i>Cupriavidus</i> sp. strain Cd ⁺²	Bioprecipitation	Li et al., 2019
	Nickel	<i>Bacillus</i> sp. KL1	Biosorption	Taran et al., 2019
	Copper, cadmium, and zinc	<i>Desulfovibrio desulfuricans</i>	Extracellular sequestration	Yue et al., 2015
	Copper, palladium, and zinc	<i>Pseudomonas aeruginosa</i>		Teitzel and Parsek, 2003
	Cadmium and zinc	<i>Synechococcus</i> sp.	Intracellular sequestration	Blindauer et al., 2008
	Mercury, cadmium, and zinc	<i>Escherichia coli</i>	Active export	Lerebours et al., 2016
	Mercury	<i>Bacillus firmus</i>	Enzymatic detoxification	Noroozi et al., 2017
Algae	Cadmium, zinc, lead, and nickel	<i>Asparagopsis armata</i>	Biosorption	Romera et al., 2007
	Ar(V)	<i>Lessonia nigrescens</i>		Hansen et al., 2006
	Lead, nickel, and cadmium	<i>Cystoseira barbata</i>		Yalçın et al., 2012
	Lead, nickel, cadmium, and zinc	<i>Codium vermilara</i>		Romera et al., 2007
Fungi	Copper, lead, and Cr(VI)	<i>Aspergillus niger</i>		Dursun et al., 2003
	Lead	<i>Botrytis cinerea</i>		Akar et al., 2005
	Copper	<i>Rhizopus oryzae</i>		Fu et al., 2012
	Silver	<i>Pleurotus platypus</i>		Das et al., 2010

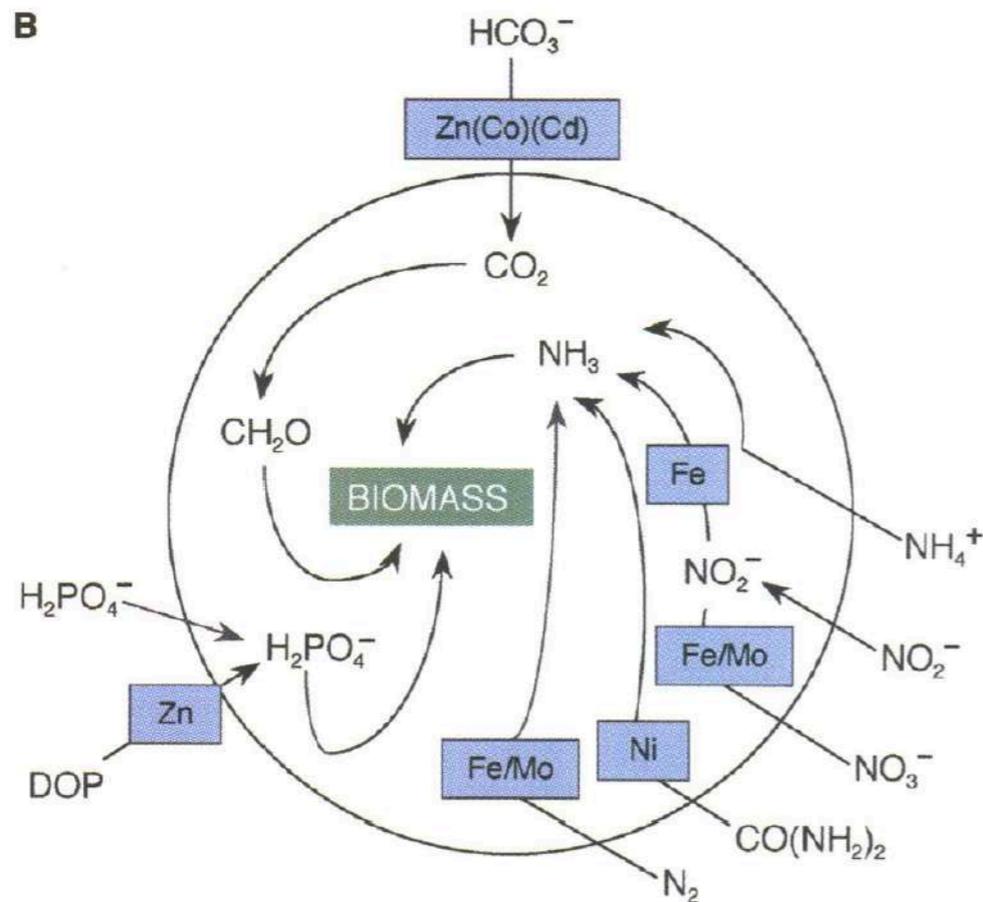
Microbes-Heavy Metals source in the environment

Many of the trace elements contained in **coal** (Ag, As, Ba, Bi, Br, Cd, Cl, Co, Cr, Cs, Cu, F, Ga, Ge, Hf, Hg, I, In, Mo, Ni, Pb, Rb, Re, Sb, Sc, Sn, Sr, Th, Tl, U, V, Y, Zn) in gaseous emissions or fly ash are emitted into the atmosphere during the coal combustion process

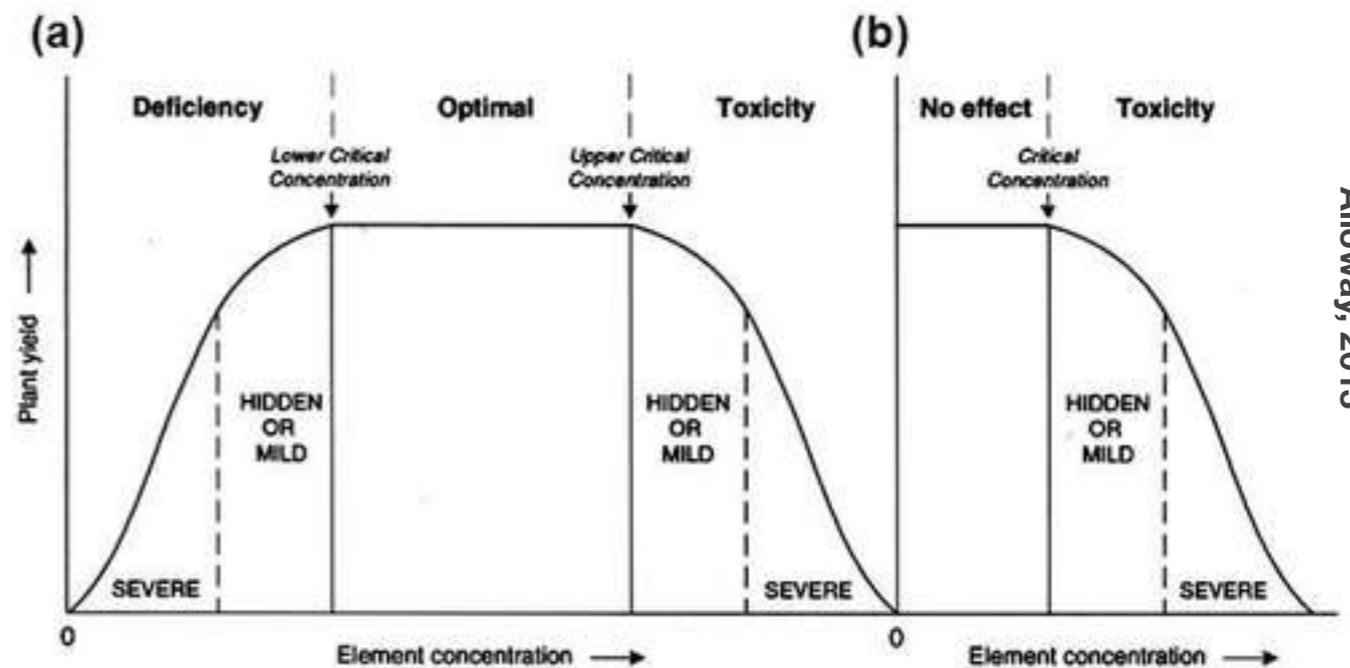
hydrogen 1 H 1.0079																	helium 2 He 4.0026										
lithium 3 Li 6.941	beryllium 4 Be 9.0122											boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180										
sodium 11 Na 22.990	magnesium 12 Mg 24.305											aluminum 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948										
potassium 19 K 39.098	calcium 20 Ca 40.078	scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.38	gallium 31 Ga 69.723	germanium 32 Ge 72.64	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.798										
rubidium 37 Rb 85.468	strontium 38 Sr 87.62	yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29										
caesium 55 Cs 132.91	barium 56 Ba 137.33											hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]	
francium 87 Fr [223]	radium 88 Ra [226]											rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [277]	meitnerium 109 Mt [268]	darmstadtium 110 Ds [271]	roentgenium 111 Rg [272]								

lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.05	lutetium 71 Lu 174.97
actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]	lawrencium 103 Lr [262]

Transition from being essential to be toxic: metal gradients in biota



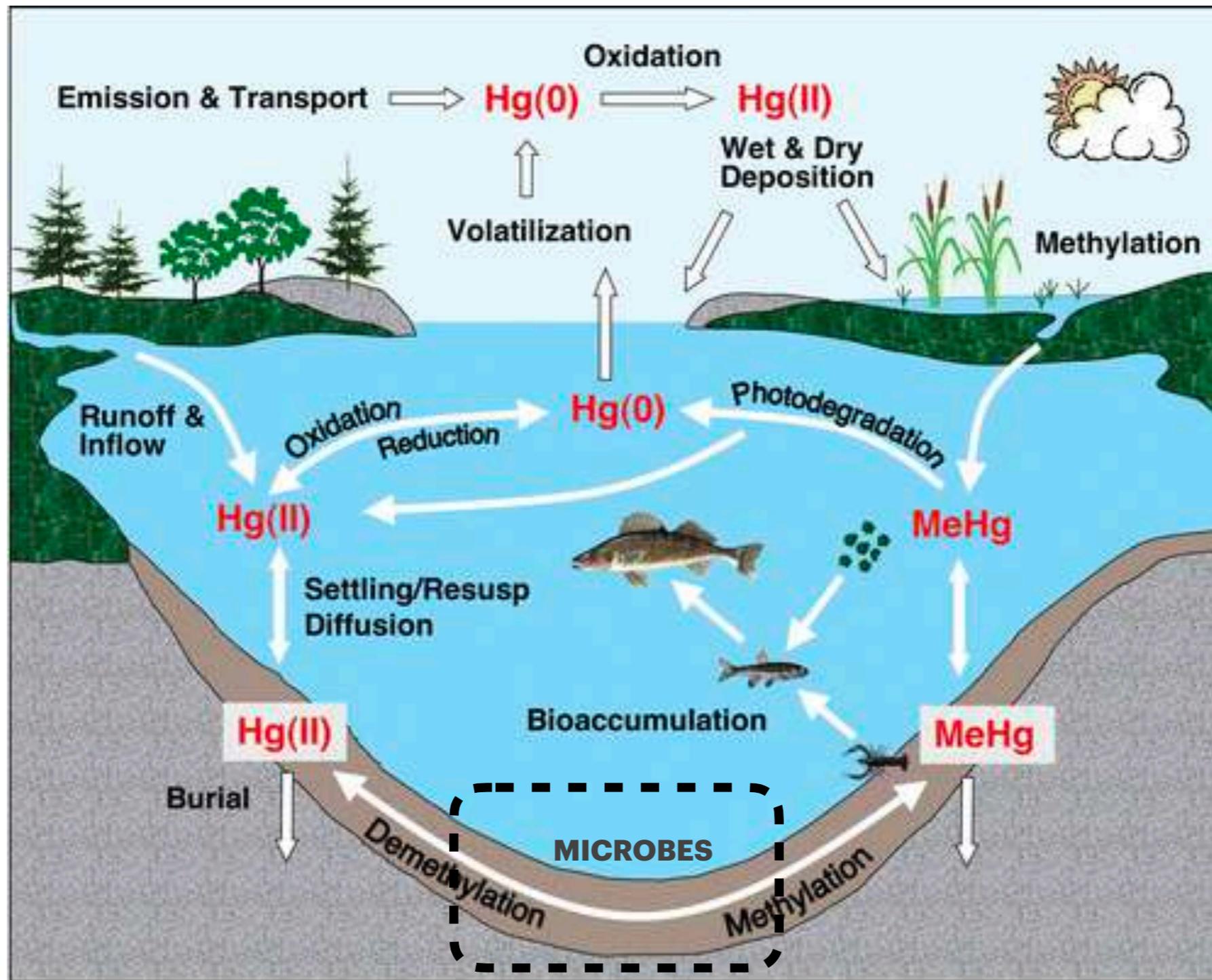
Typical does-response curve for (a) essential and (b) nonessential elements



Alloway, 2013

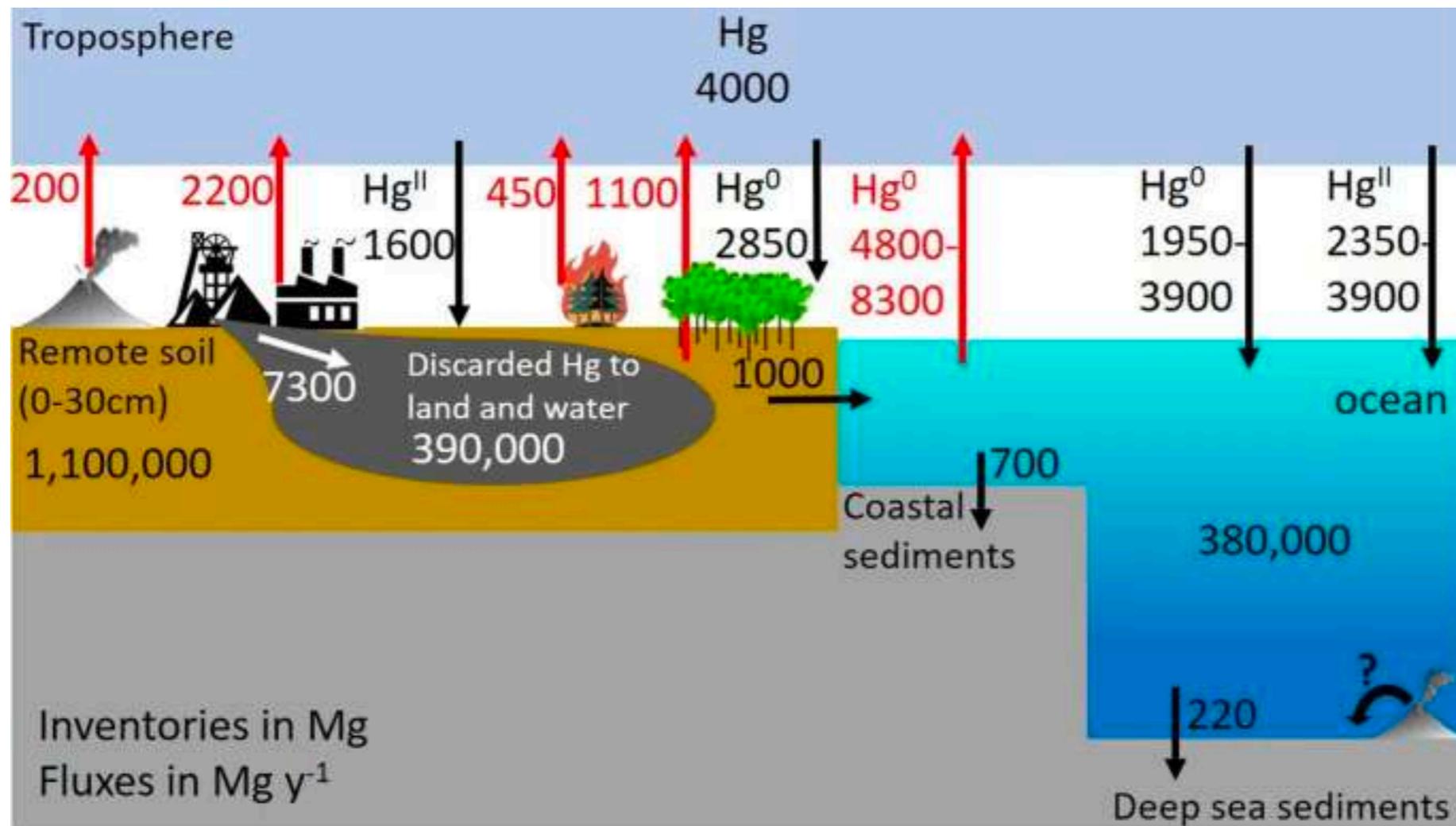
Example of metal requirement for a phytoplankton cell in the ocean

Study case: Mercury cycle

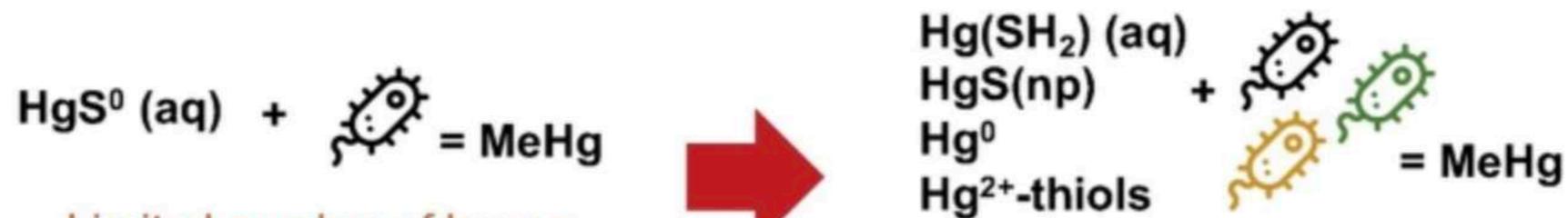


 Selin NE. 2009.
Annu. Rev. Environ. Resour. 34:43–63

Hg cycling budget



c) MeHg is produced in diverse environments across redox gradients

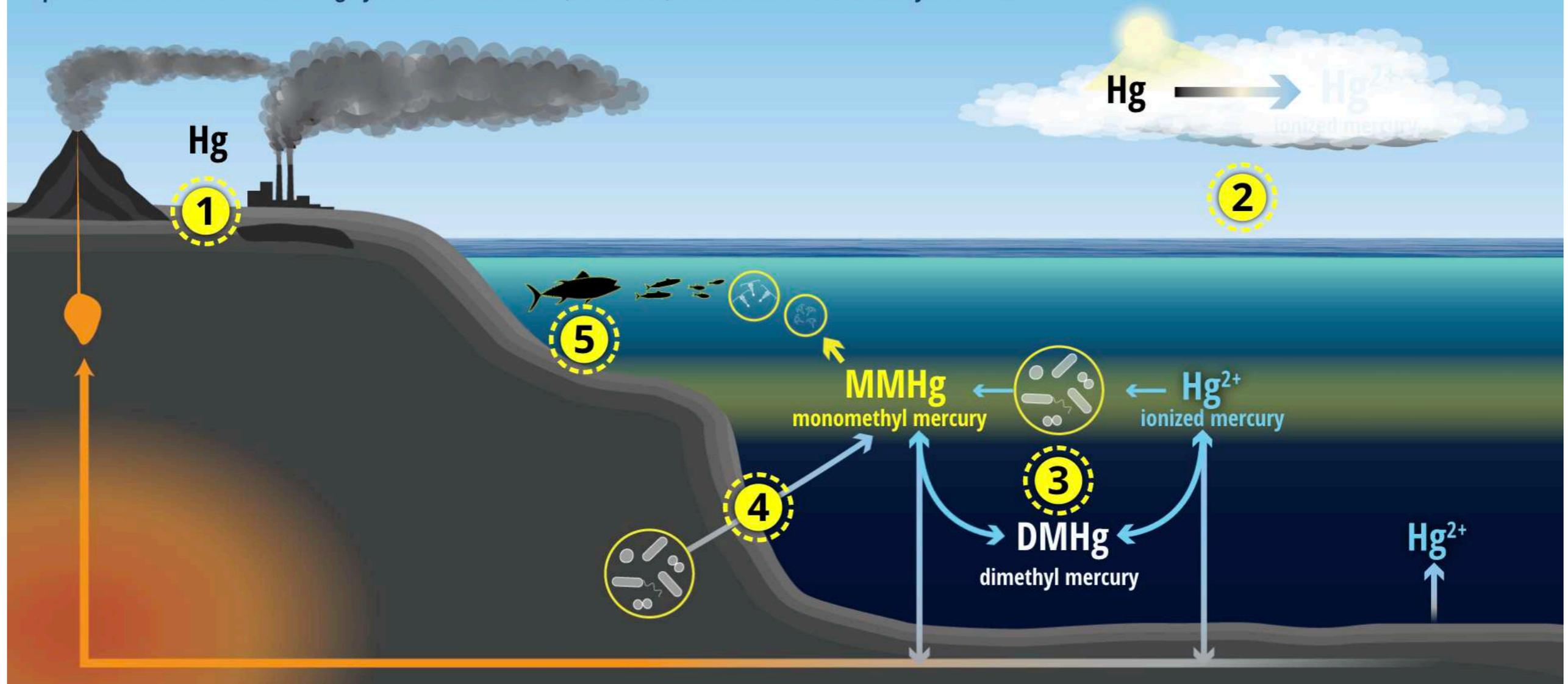


Limited number of known methylators and of Hg substrate available for methylation. Sulfate-, iron-reducing bacteria, and methanogenic archaea in anoxic sediments

Methylation of diverse Hg substrates by metabolically and phylogenetically diverse microbes in anoxic sediments, biofilms, and microbial mats, as well as in oxic marine water column

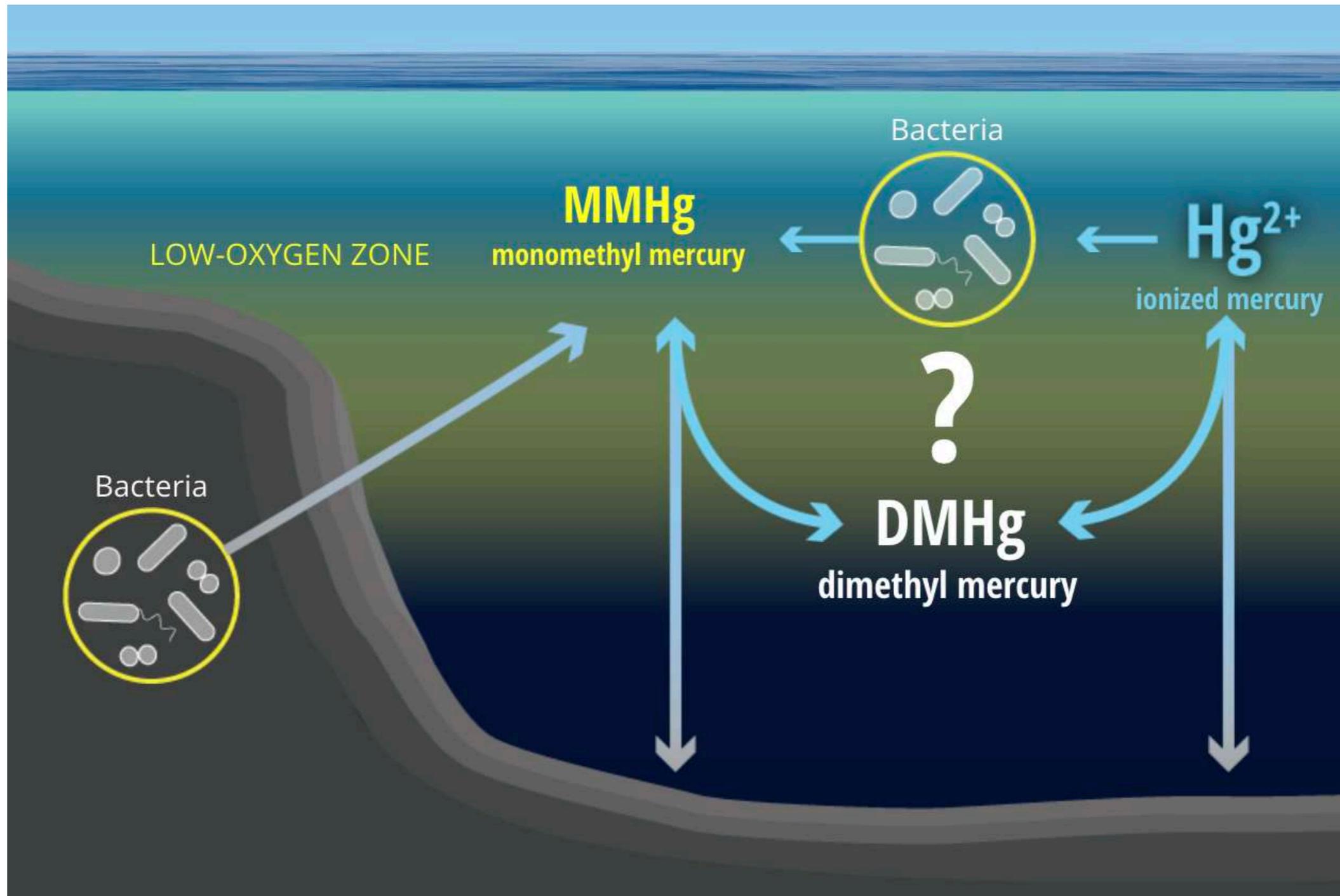
The Mercury Cycle

Mercury (Hg) cycles through the Earth's atmosphere, ocean and rock. In the ocean, mercury is converted to monomethyl mercury (MMHg), a neurotoxin that moves up the food chain and becomes highly concentrated in tuna, swordfish, and other seafood eaten by humans.



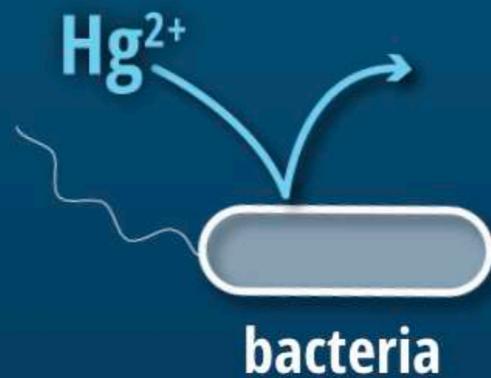
The microbial methylators

<https://www.whoi.edu/multimedia/mercury-cycle/>



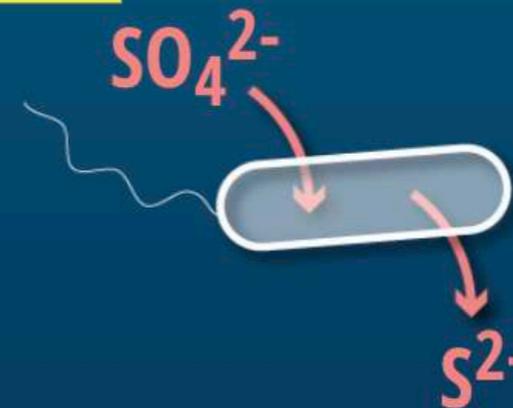
Microbial Hg methylation studies identified **sulfate and iron reducing bacteria, and methanogenic archaea** as key methylating species, leading to a paradigm where MeHg was mainly produced in anoxic sediments with dissolved Hg^{II}-sulfide species as substrate

1



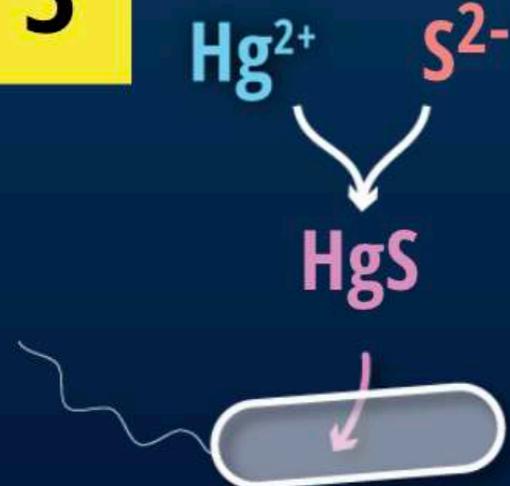
Ionized mercury (Hg^{2+}) in seawater and sediments cannot enter bacterial cells.

2



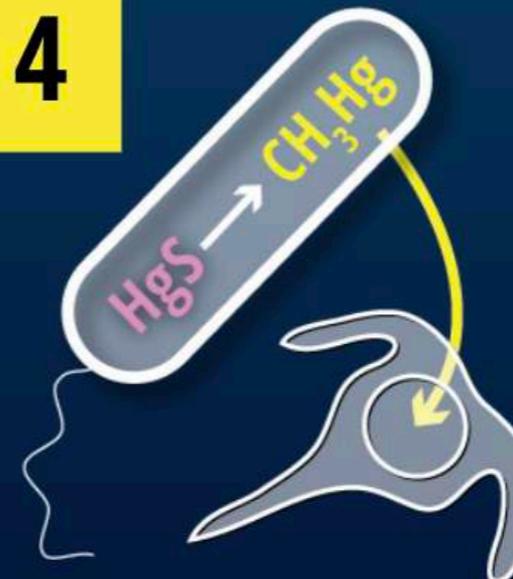
With little or no oxygen available, some bacteria use sulfate (SO_4^{2-}) for respiration, expelling sulfide (S^{2-}) as a waste product.

3



Sulfide combines with ionized mercury (Hg^{2+}) in seawater to form mercuric sulfide (HgS), which can diffuse into bacterial cells.

4



Inside bacterial cells, a methyl group (CH_3) replaces the sulfide to produce monomethyl mercury (CH_3Hg or MMHg), which diffuses into seawater and is taken up by phytoplankton.

Food Chain & Biomagnification



Dangerous levels of monomethyl mercury (MMHg) accumulate through biomagnification, the natural process that builds some substances to toxic levels as it travels up the food chain. Biomagnification starts with phytoplankton, which contain 10,000 times more MMHg than the seawater around them. Phytoplankton are eaten by zooplankton, which are eaten by small fish, which are eaten by larger fish and marine mammals. Instead of being expelled, MMHg accumulates in tissues resulting in an increase in concentration to 10 million times more MMHg than seawater – a level toxic to people.

Human Impacts

Eating large amounts of seafood, even over a long period, increases the risk of mercury poisoning. Children and fetuses are especially vulnerable. For that reason, the U.S. Environmental Protection Agency and Food and Drug Administration maintain up-to-date recommendations and guidelines for consumption of fish and shellfish by adults, children, and pregnant or nursing women.

<< BACK

REPLAY

NEXT >>

MMHg



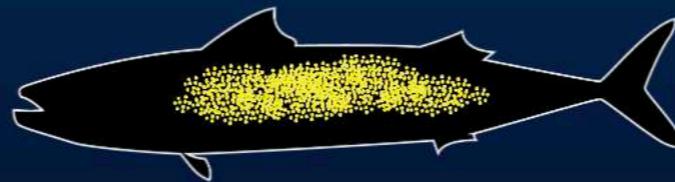
Phytoplankton



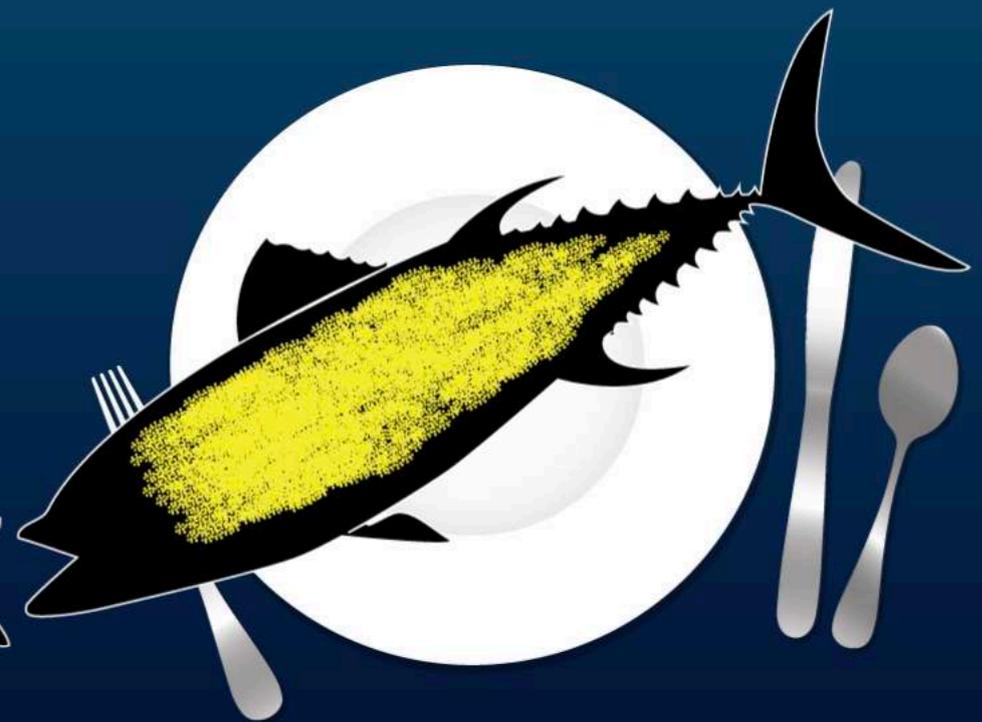
Zooplankton



Small fish



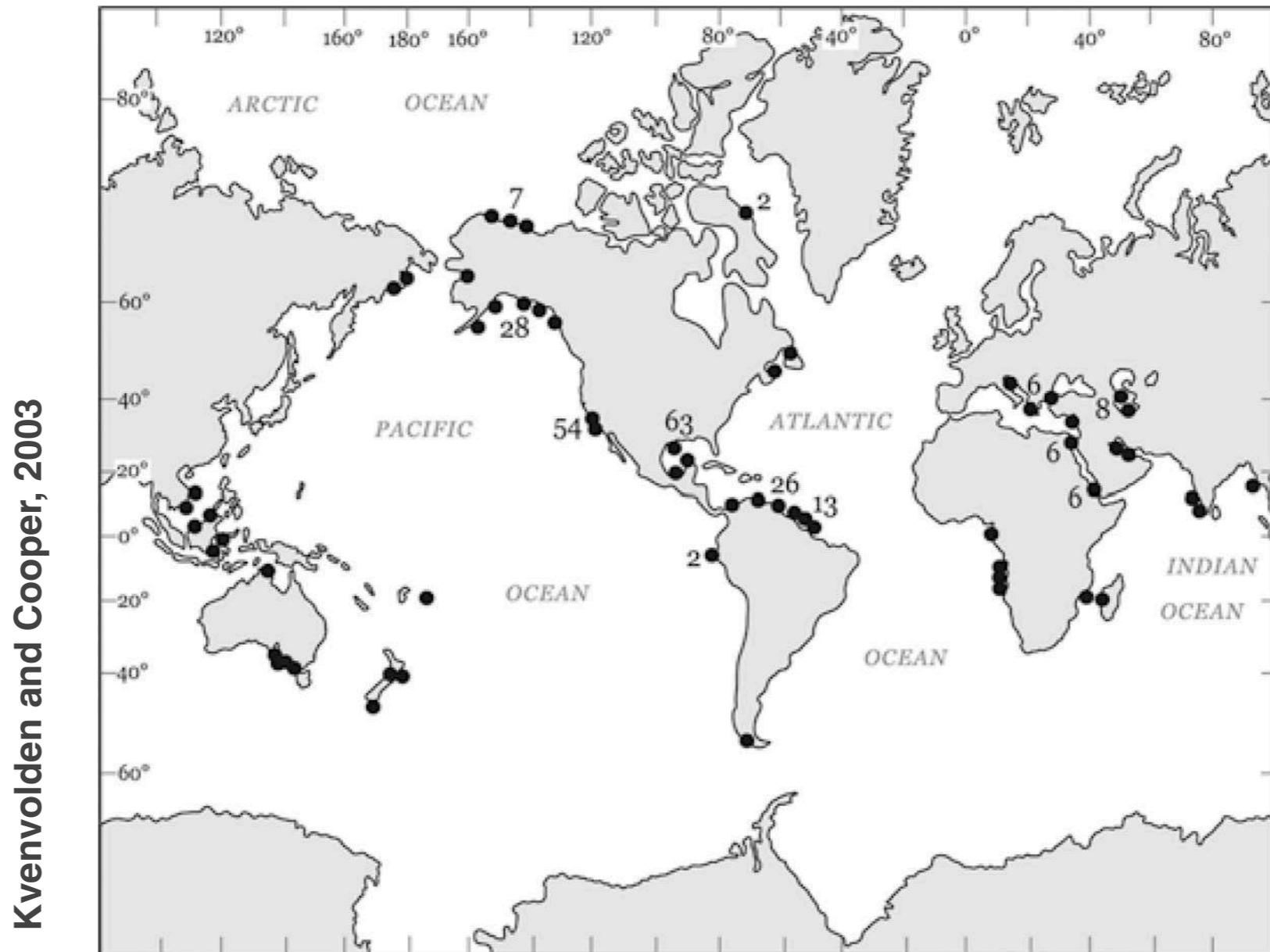
Bigger fish



Large fish

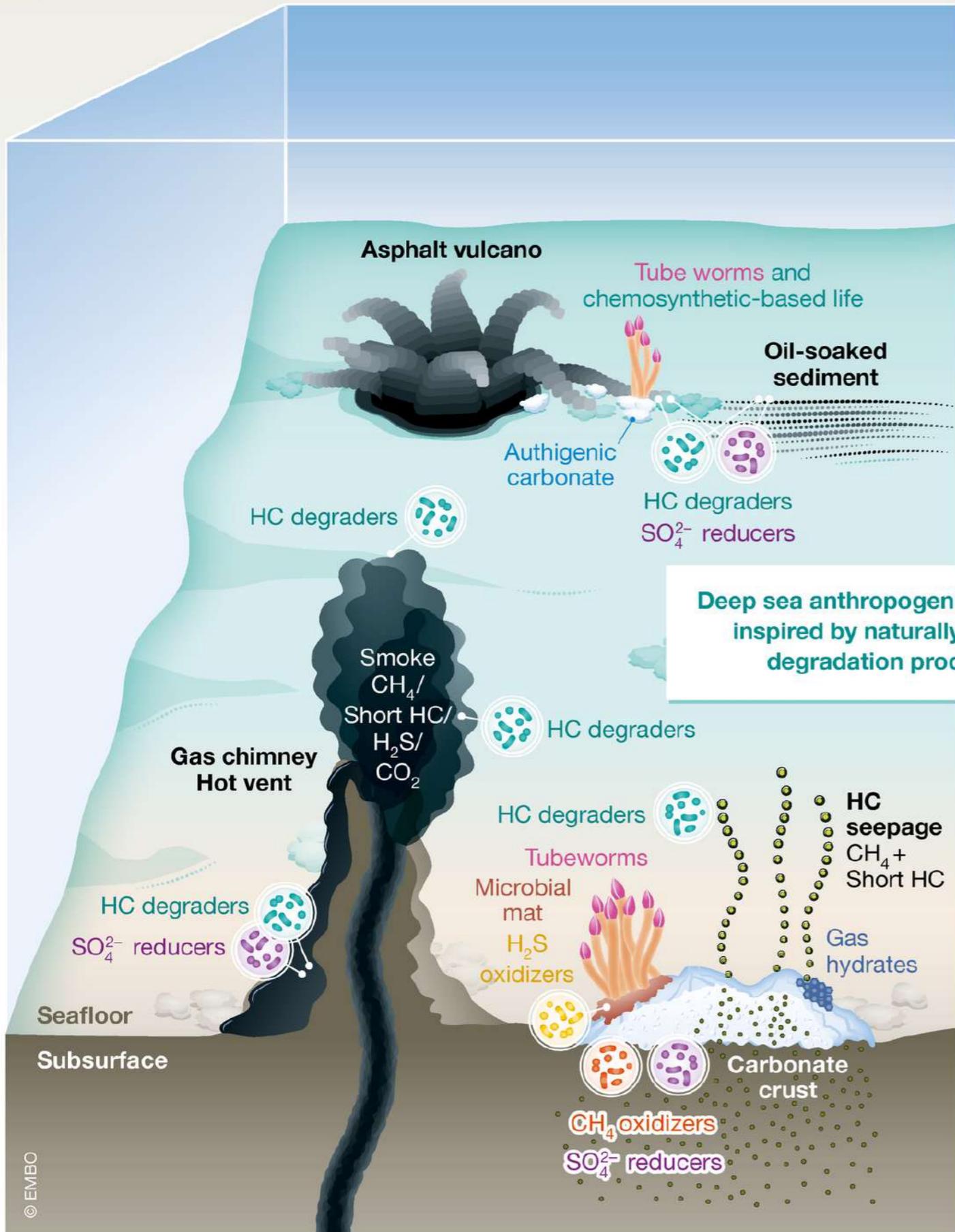
Oil Spill/Crude oil seepage

Natural seepage of crude oil into the marine environment



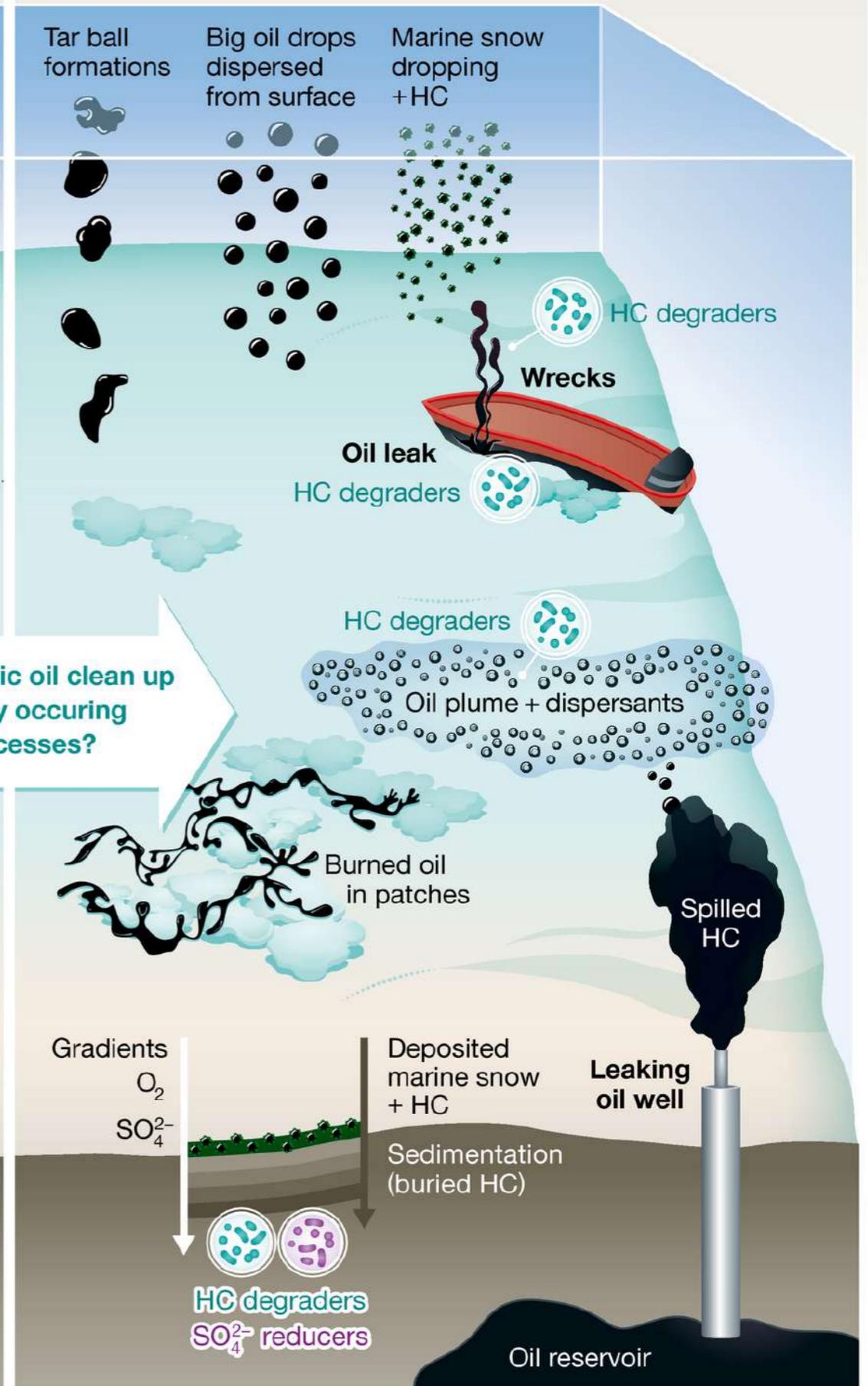
Locations of naturally occurring crude-oil seeps that impact the marine environment (adapted from Wilson et al. 1973). Numbers refer to number of seeps in a given region

A Natural sources of hydrocarbons (HCs) in the deep sea



700 million liters per year

B Anthropogenic sources of petroleum HCs in the deep sea



120 million liters per year

Scoma et al., 2017

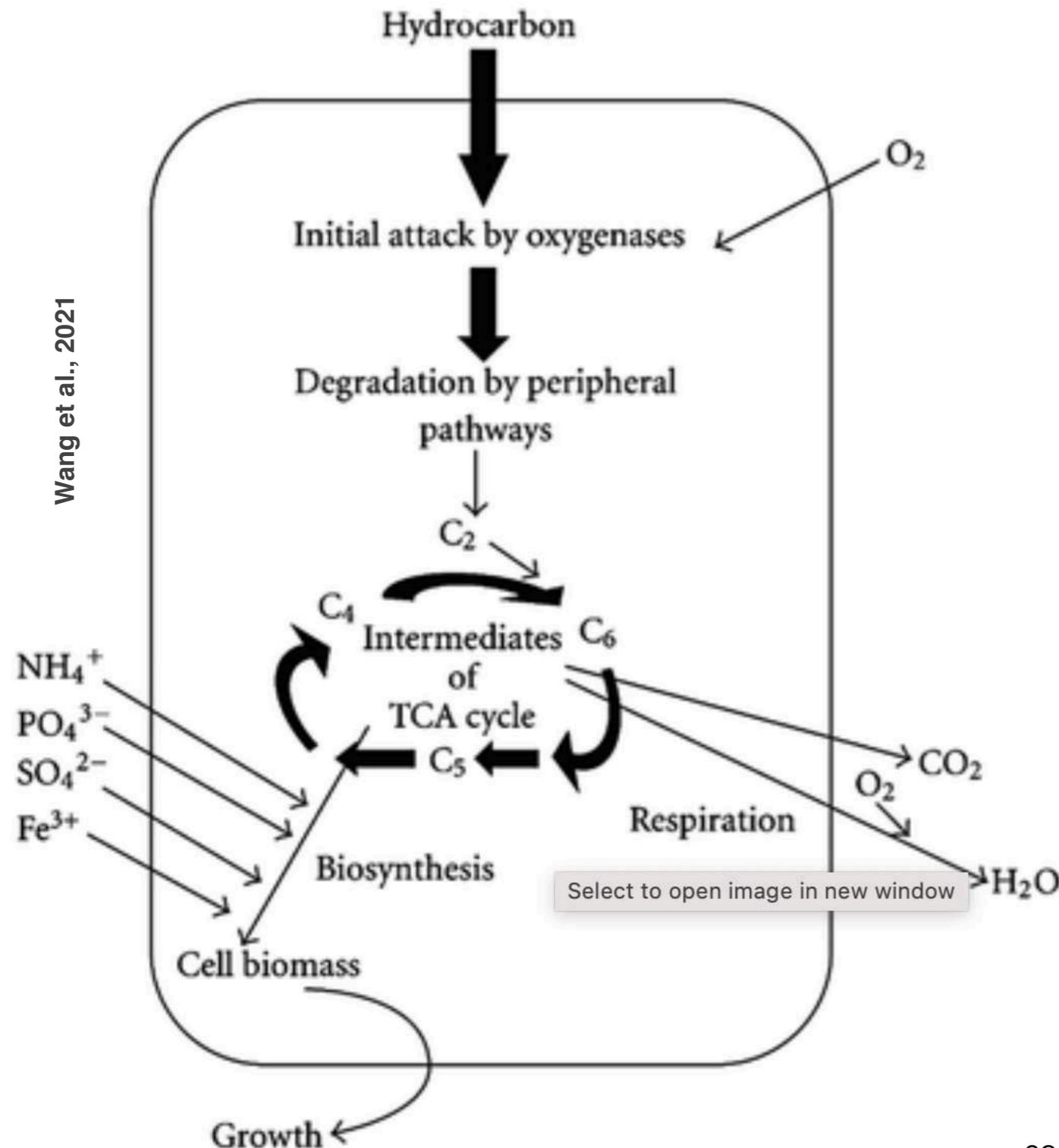
© EMBO

Petroleum-Microbes interaction

Petroleum is a complex **mixture of gaseous, liquid, and solid hydrocarbons**

Petroleum hydrocarbons (**HCs**) in the **environment** undergo **weathering**, which may involve **physical** (dispersion), **physiochemical** (evaporation, dissolution, sorption), **chemical** (photo-oxidation, auto-oxidation), and **biological** (plant and microbial catabolism of hydrocarbons) influences

HCs undergo enzymatic reactions under the catalysis of **oxygenase** and **catalase** in the presence of oxygen → HCs become **C2 molecules** and converted in the tricarboxylic acid cycle through the peripheral degradation pathway for microbial growth and HCs are oxidized to CO_2 and H_2O by respiration and generate energy



Petroleum weathering, I

- **Weathering has diverse time scale and affect in a specific manner the complex petroleum complex mixture**
- Within few **hours**, HC spill phases: spreading, evaporation, dissolution, dispersion, and emulsification; (photo)oxidation, sinking
- **Biodegradation** starts after about 1 day, and can potentially last for years
- **Spreading and evaporation**, low-viscosity oil with a higher content of volatile compounds, are enhanced by the action of **wind, waves, and warm temperatures**
- **Waves and water turbulence induce dispersion** by breaking the oil slick on the sea surface into **droplets** —> have a greater surface-to-volume ratio than oil slick, which facilitates dissolution, sedimentation, and biodegradation

Petroleum weathering, II

- **Emulsification** occurs if **seawater droplets are suspended in oil** and creates the so-called **highly viscose chocolate mousse**, which binds a significant volume of water, **delays weathering** processes, and presents a **major challenge** for cleaning up owing to its stickiness
- **Dissolution** affects the water-soluble fraction of **light HCs**
- **Oxidation**, favored by sunlight, is a slower process, with other chemical modifications, promotes **tar formation in thick layers of highly viscous oil**
- Weathered oil **sinks** to the ocean bottom via **adsorption to so-called marine snow**
- Most of the **weathered oil**, however, **continues to float** on the surface until it ends on shorelines.