Piggybacking-the-Winner
- how phage kill a coral reef -

photo
by BZ

Forest Rohwer - San Diego State University

Coral reefs are declining worldwide

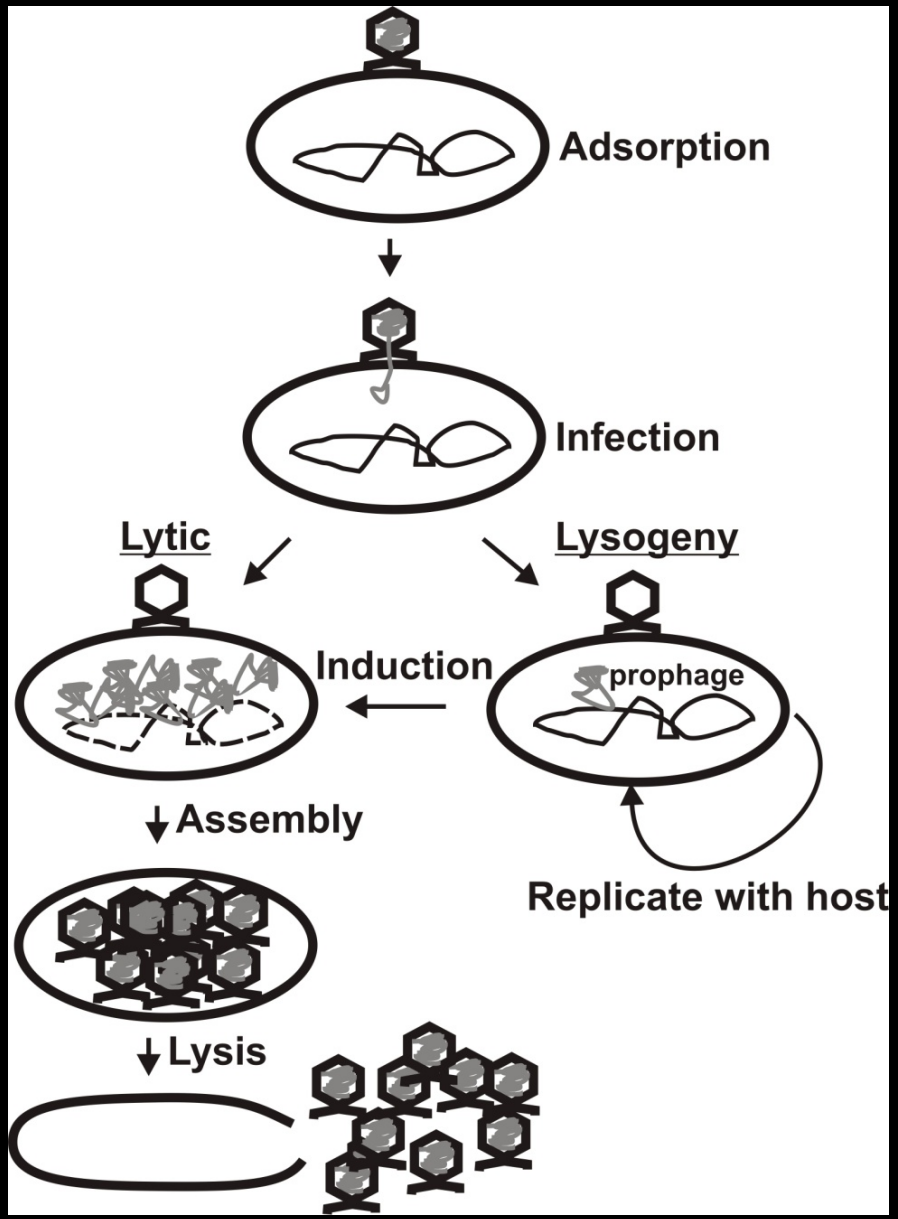
Local - Human habitation results in coral diseases

- fishing (organic matter) & nutrient additions-

Global - Increasing CO_2

-temperature change and decreasing pH-

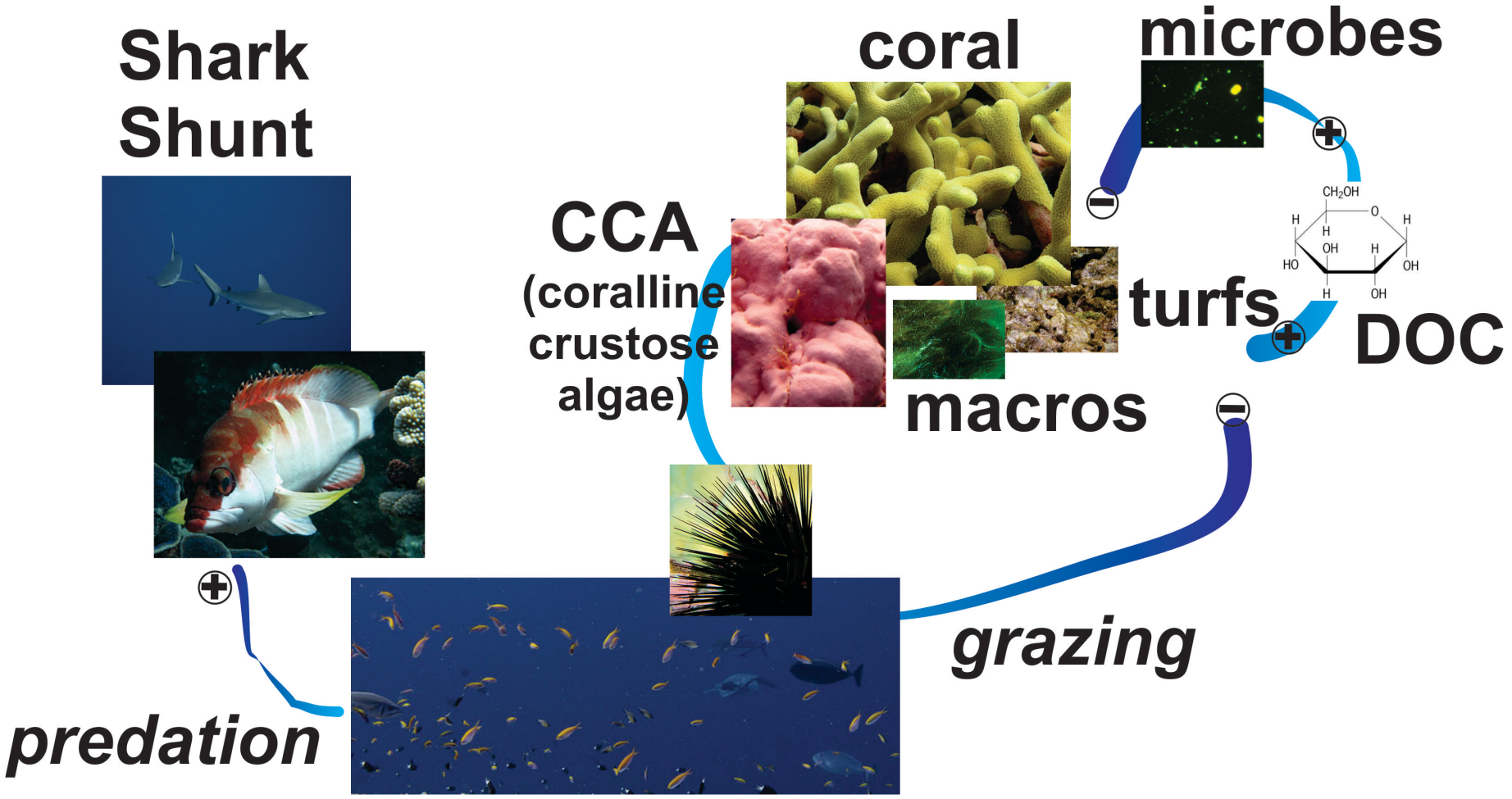
Temperate phage must protect bacterial host against other phage & protists (or they will be killed with their host cell)



dense cellular systems necessitate strong anti-predator systems for lysogens

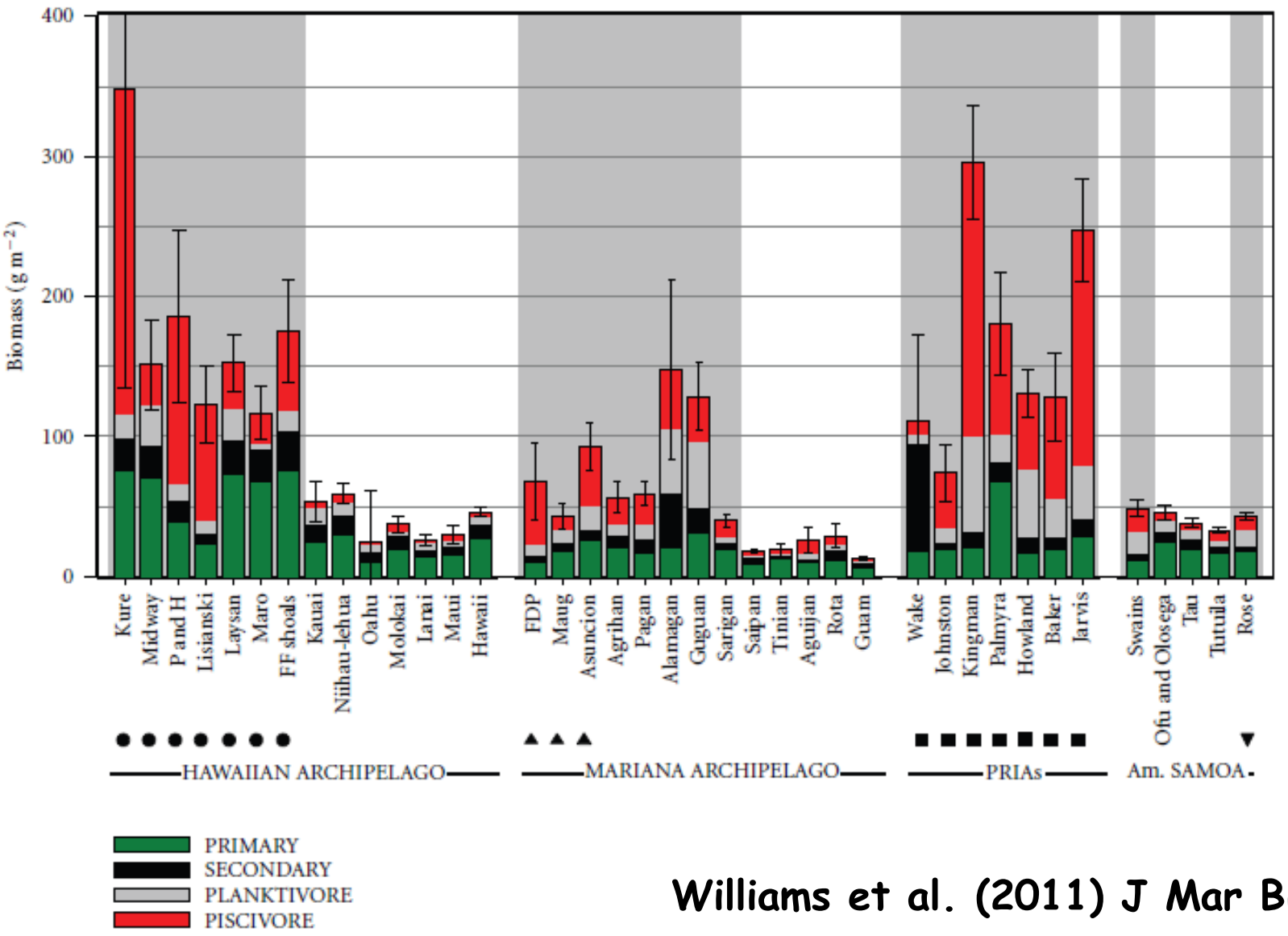
Piggyback-the-Winner is the ecological dynamic of increasing lysogeny with higher host densities

Healthy reef



~ 90% energy is loss at each trophic step

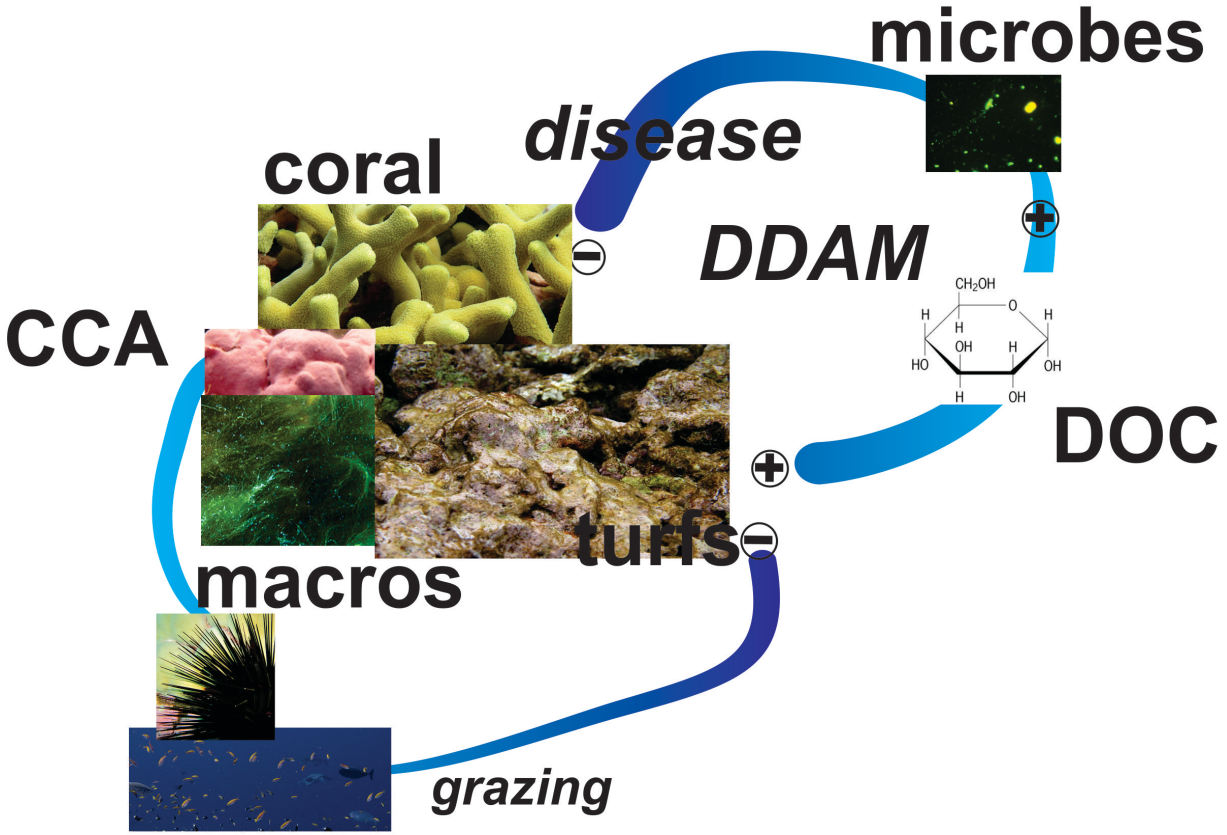
Humans kill the sharks & groupers



Williams et al. (2011) J Mar Biol

- fishing increased dramatically after WWII -

Fished reef



1) microbialization: shunting of energy away from macrobes to feed microbes

2) more potential pathogens because of prophage

DDAM

- DOC, disease, algae, microbes
- positive feedback that increases space for algae

Global survey of microbial dynamics on coral reefs

diver-deployable Niskins

↓

count microbes & measure DOC

quibits for metagenomes

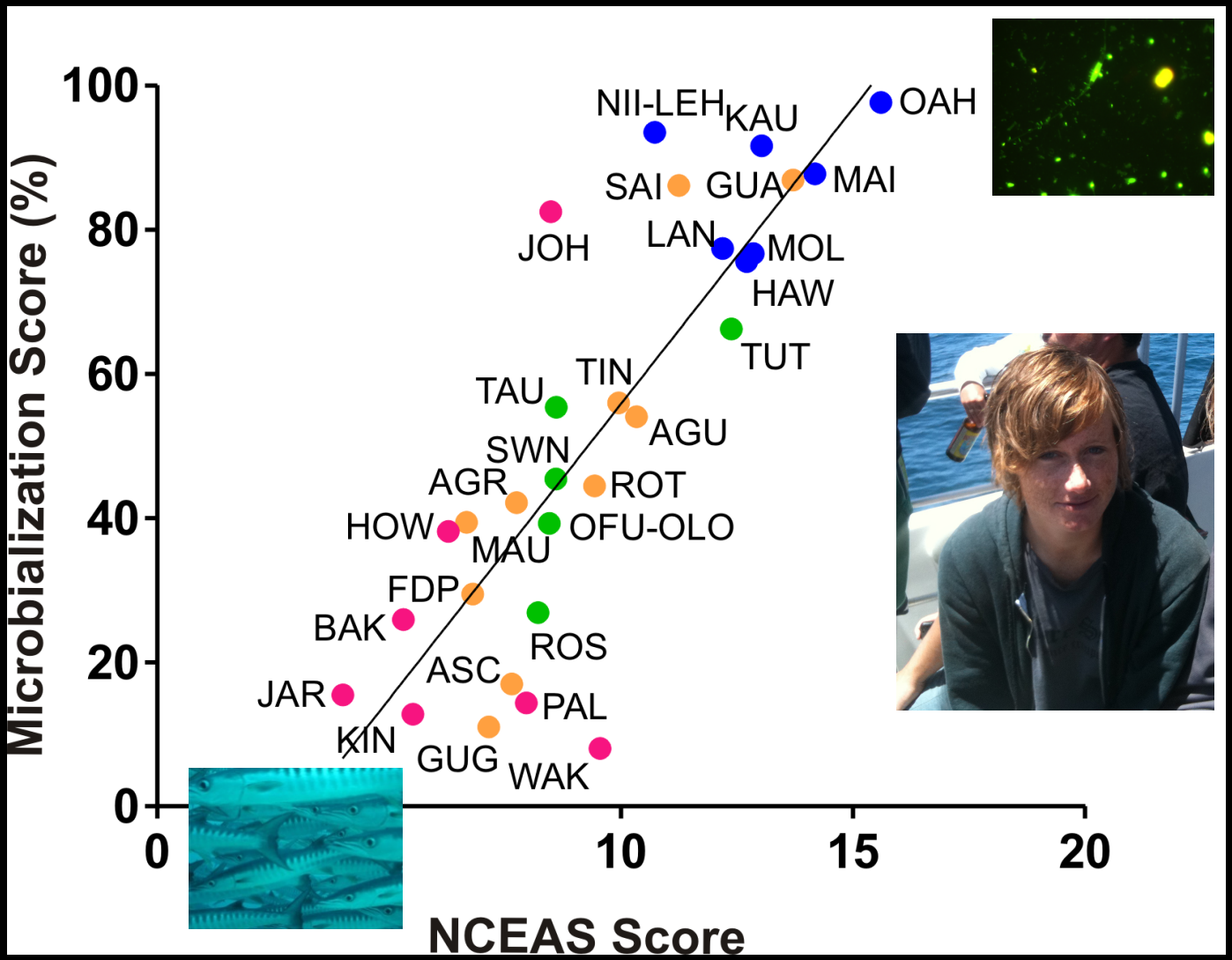
↓

sequencing

benthic surveys & fish counts

Over 200 sites from central Pacific (Line Islands & USA protectorates), Sri Lanka & Caribbean

Microbialization is a global phenomenon & strongly correlated with human activity



MFM Fairoz

Tracy McDole

Andi Haas

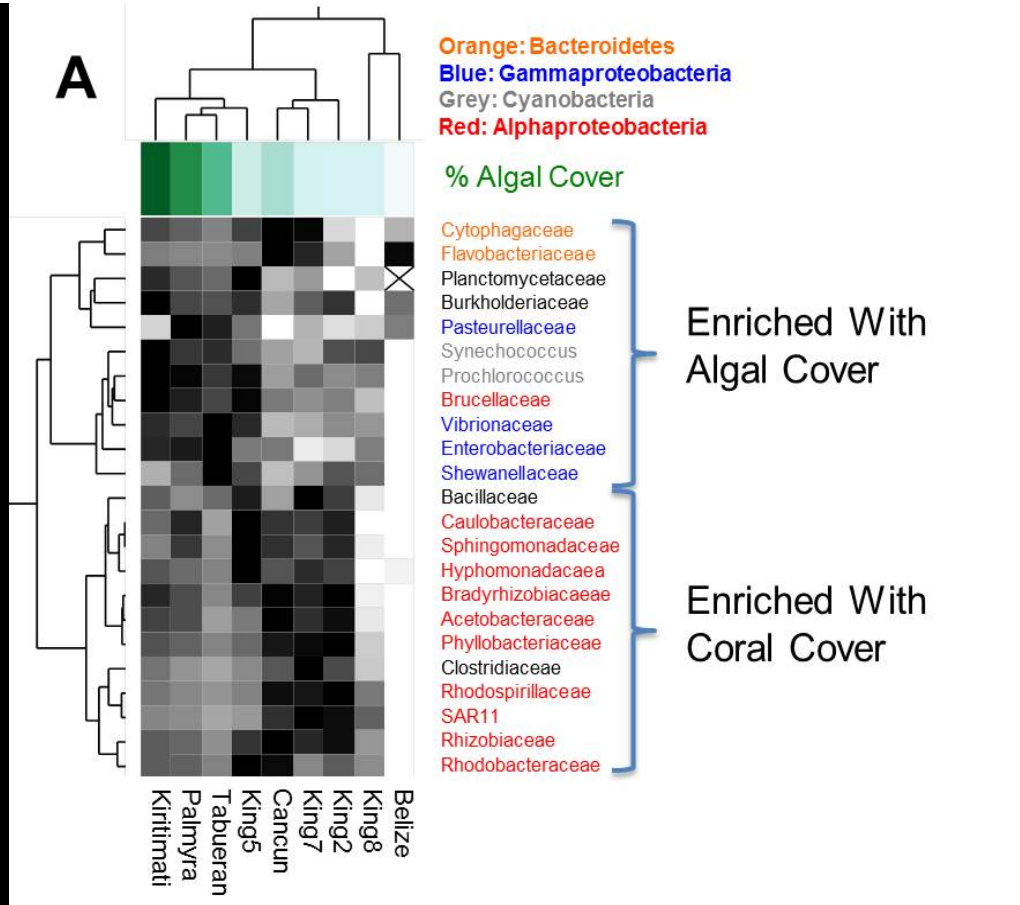
Increased Gammas/potential pathogens on degraded reefs

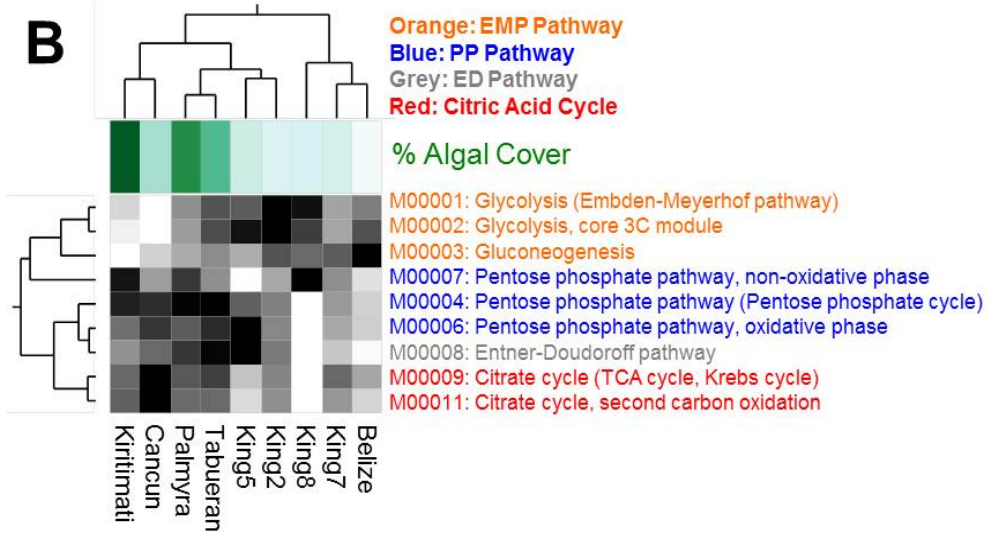
microbial metagenomes

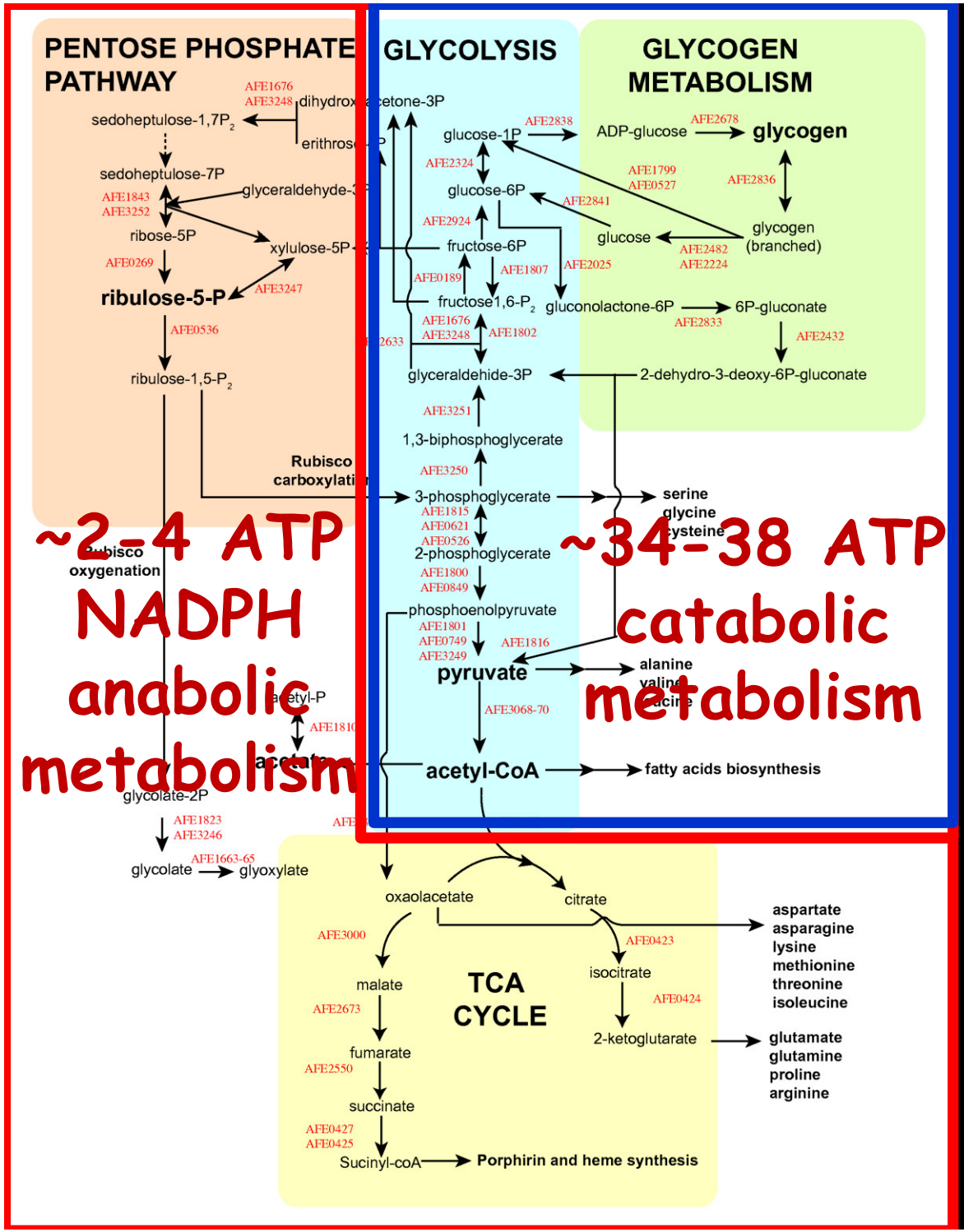
↓

MG-RAST annotations

Glycolysis is replaced by the Pentose Phosphate Pathway (PPP) on degraded reefs







Glycolysis (healthy reefs) is energy efficient versus Pentose Phosphate Pathway (PPP; degraded reefs)

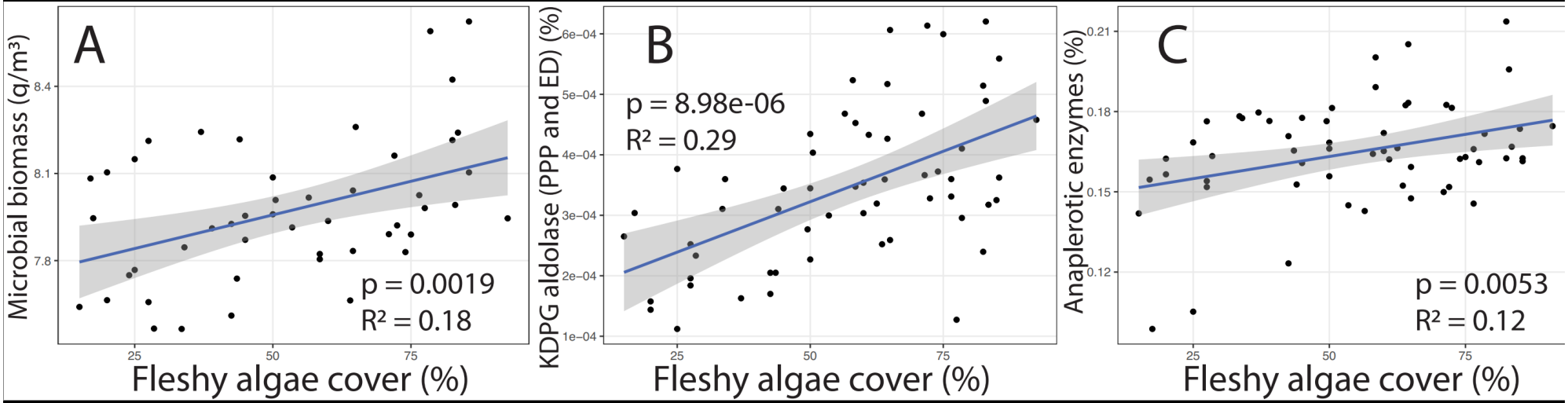
microbial metagenomes

↓

MG-RAST annotations

Maximum Yield versus Power

Power to Yield Switch is Global
(i.e., rise of the PPP & ED pathways)



50+ coral reef in central Pacific

↓

microbial metagenomes

↓

MG-RAST annotations

We think it is decoupling between oxygen & sugar...the bubble hypothesis:)

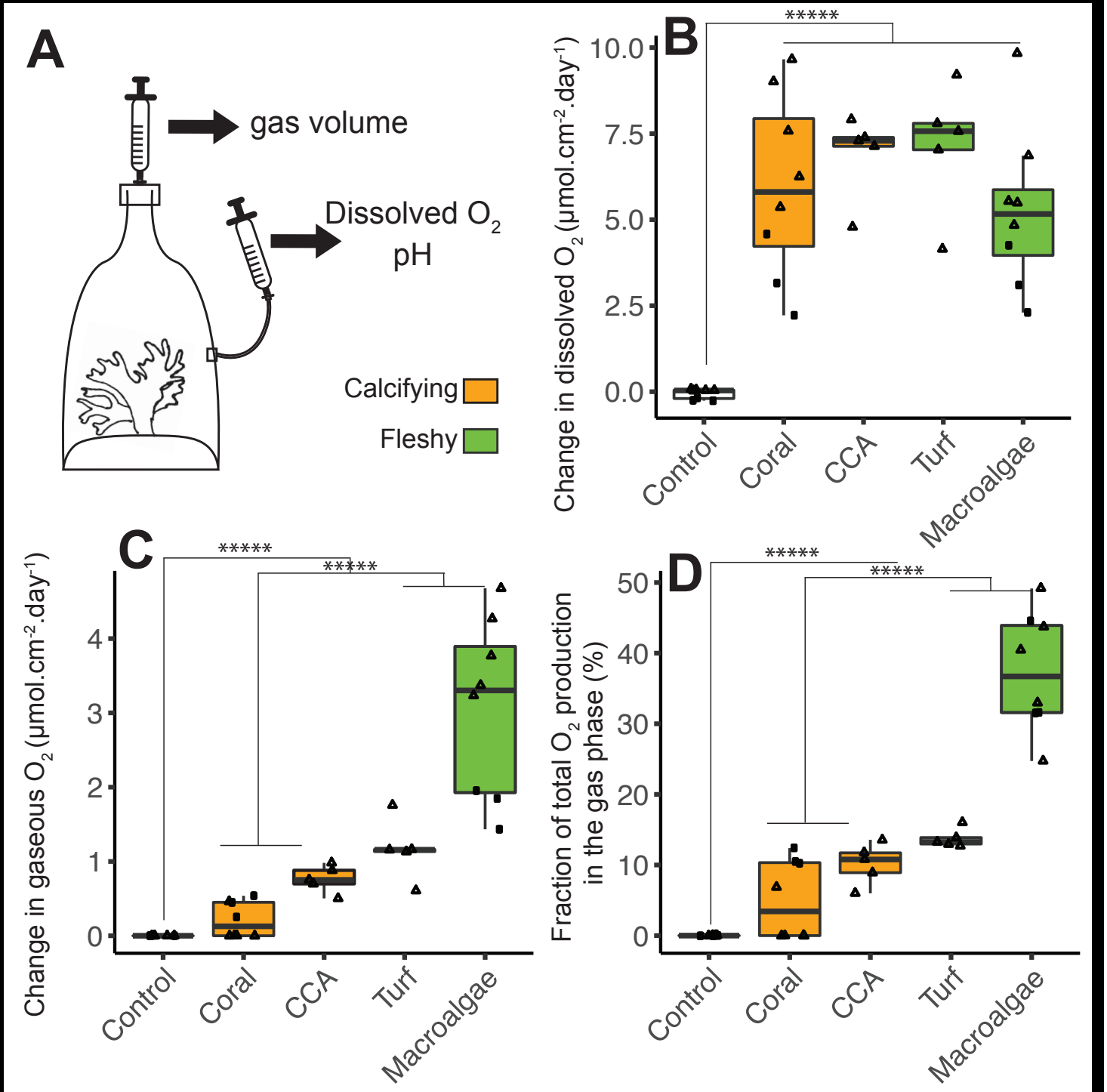
POP experiments

coral & algae into incubation chambers

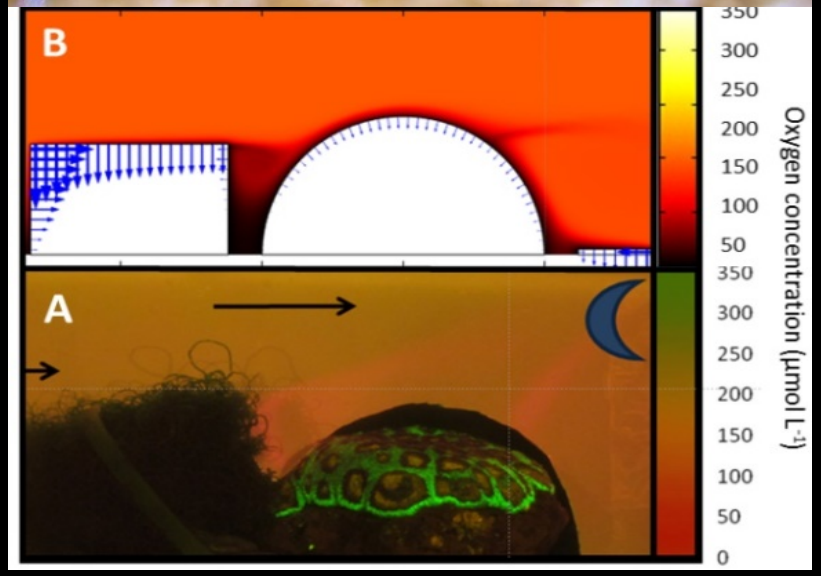
↓

measure oxygen in gas & water

Macroalgae lose ~35% of oxygen as bubbles



Glucose-Oxygen Decoupling via bubbles favors anabolic metabolisms



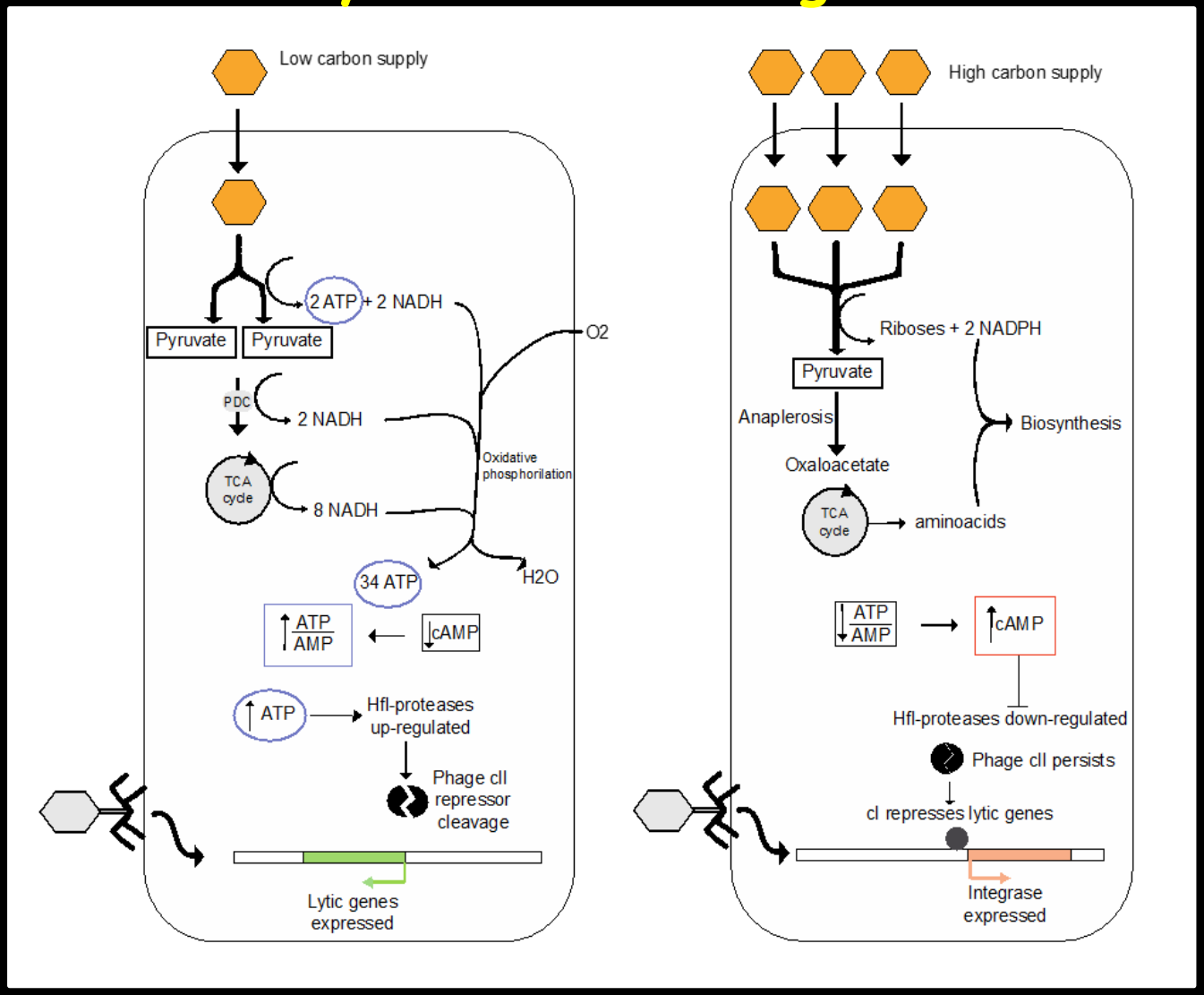
Algae release oxygen

Coral holobionts hold onto their oxygen

The Lambda Switch

Heathy Reef

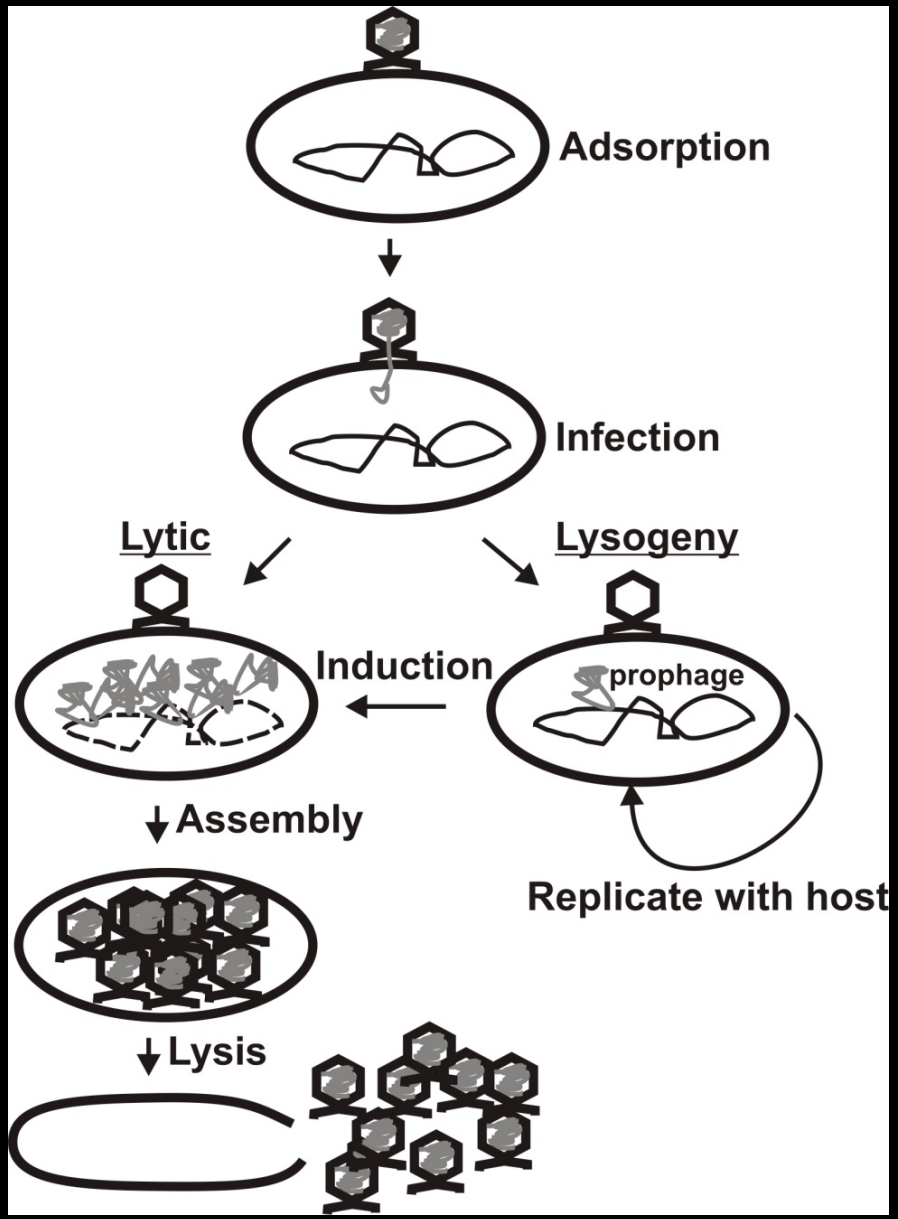
Degraded Reef



Cynthia Silveira

Temperate life cycle should be favored under anabolic/decoupled conditions

Temperate phage must protect bacterial host against other phage & protists (or they will be killed with their host cell)



dense microbial systems necessitate strong anti-predator systems for lysogens

Piggyback-the-Winner is the ecological dynamic of increased lysogeny with higher host densities

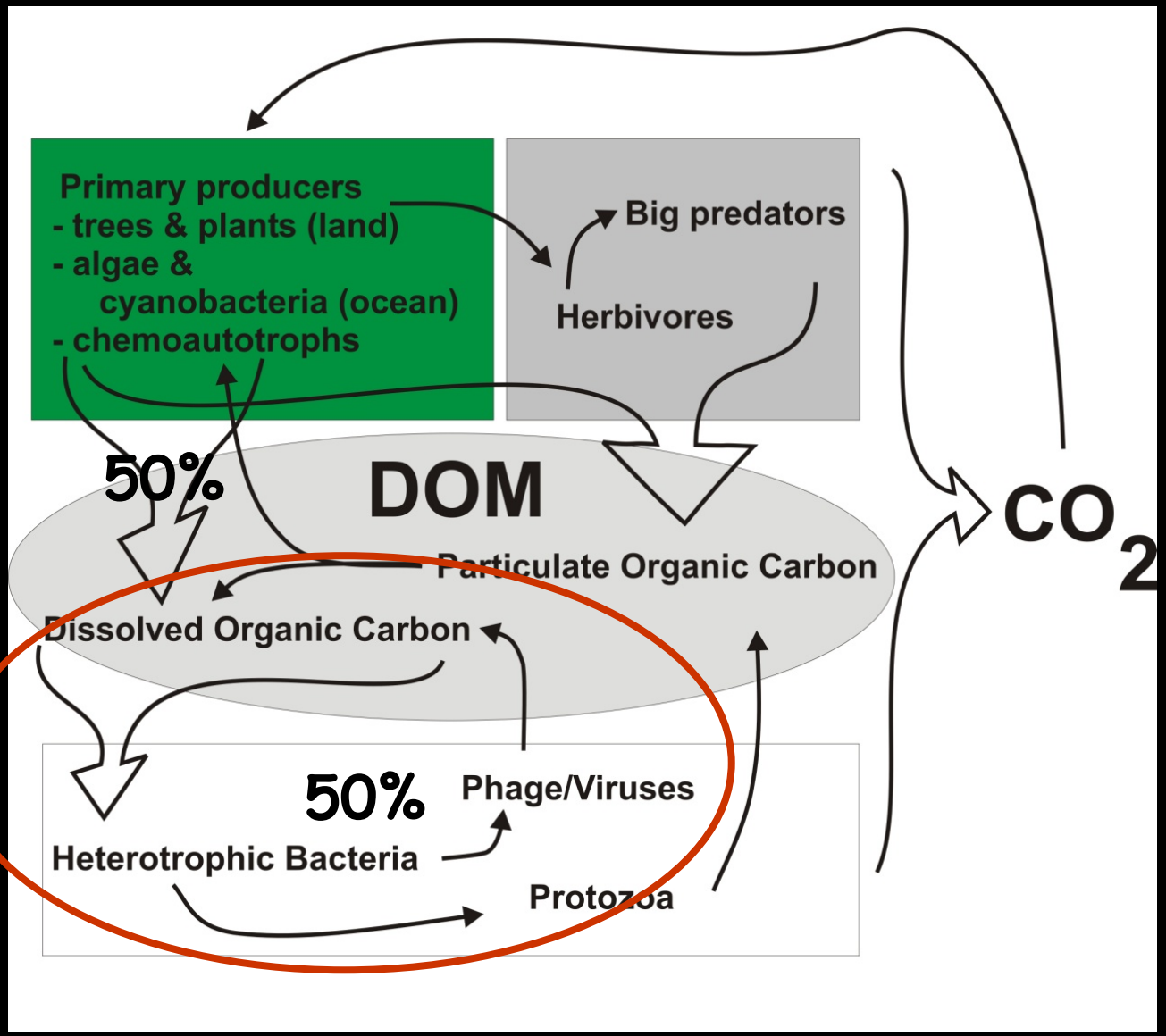
Phage & plasmid encoded exotoxins

	Anthrax	*Bacillus anthracis*	Plasmid
	Botulism	*Clostridium botulinum*	Phage and Plasmid
CTX	Cholera	*Vibrio cholerae*	Phage and Plasmid
DTX	Diphtheria	*Corynebacterium diphtheriae*	Phage
STX	Diarrheagenic *E. coli*	*Escherichia coli* (EHEC strains)	Phage
	Tetanus	*Clostridium tetani*	Plasmid
	Toxic shock	*Staphylococcus aureus*	Phage
SEA	Staph Food Poisoning	*Staphylococcus aureus*	Phage and Plasmid
	Scalded Skin Syndrome	*Staphylococcus aureus*	Phage and Plasmid
	Scarlet fever	*Streptococcus pyogenes*	Phage

- ask me ZOT toxin in CF & corals over beer -

Exotoxins kill eukaryotic cells, including protists

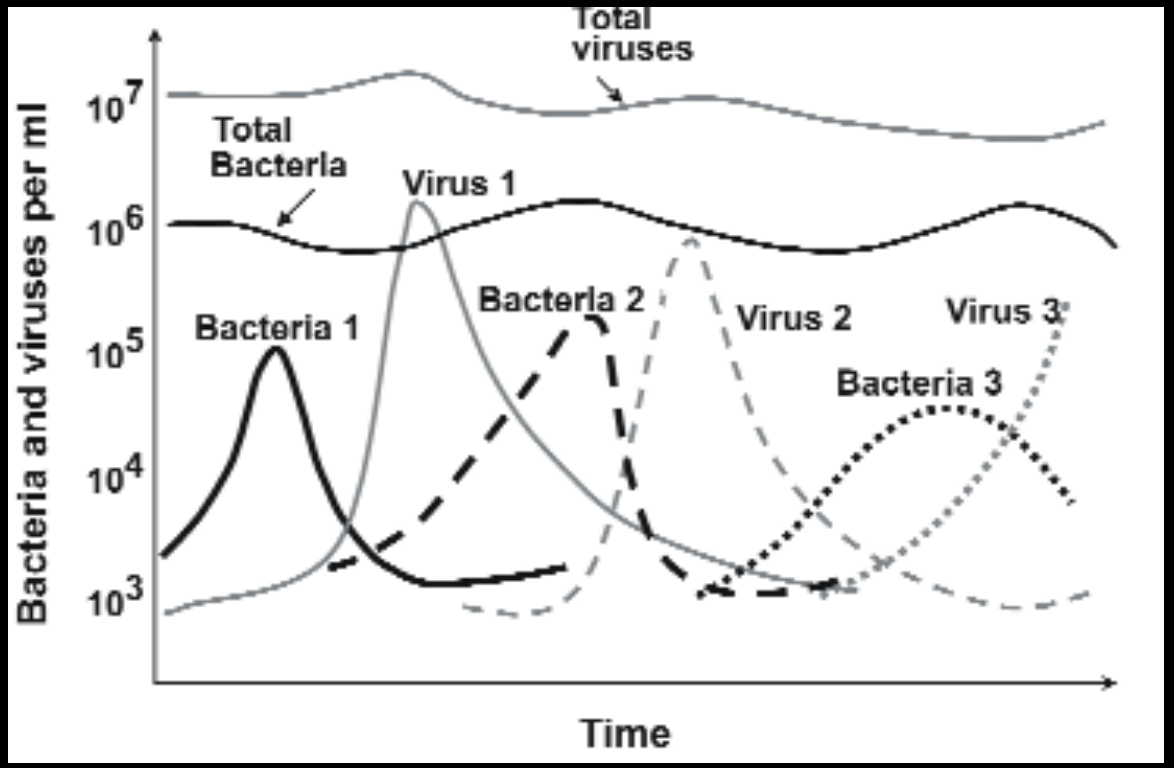
Phage & protist control marine microbial abundances



- typically about 10 phage:cell -

Kill-the-Winner/Lotka-Volterra dynamics

Kill-the-Winner
(Thingstad et al.)



These dynamics are mass action driven...

Viral & microbial abundances do not linearly scale on coral reefs (Nature 2016)

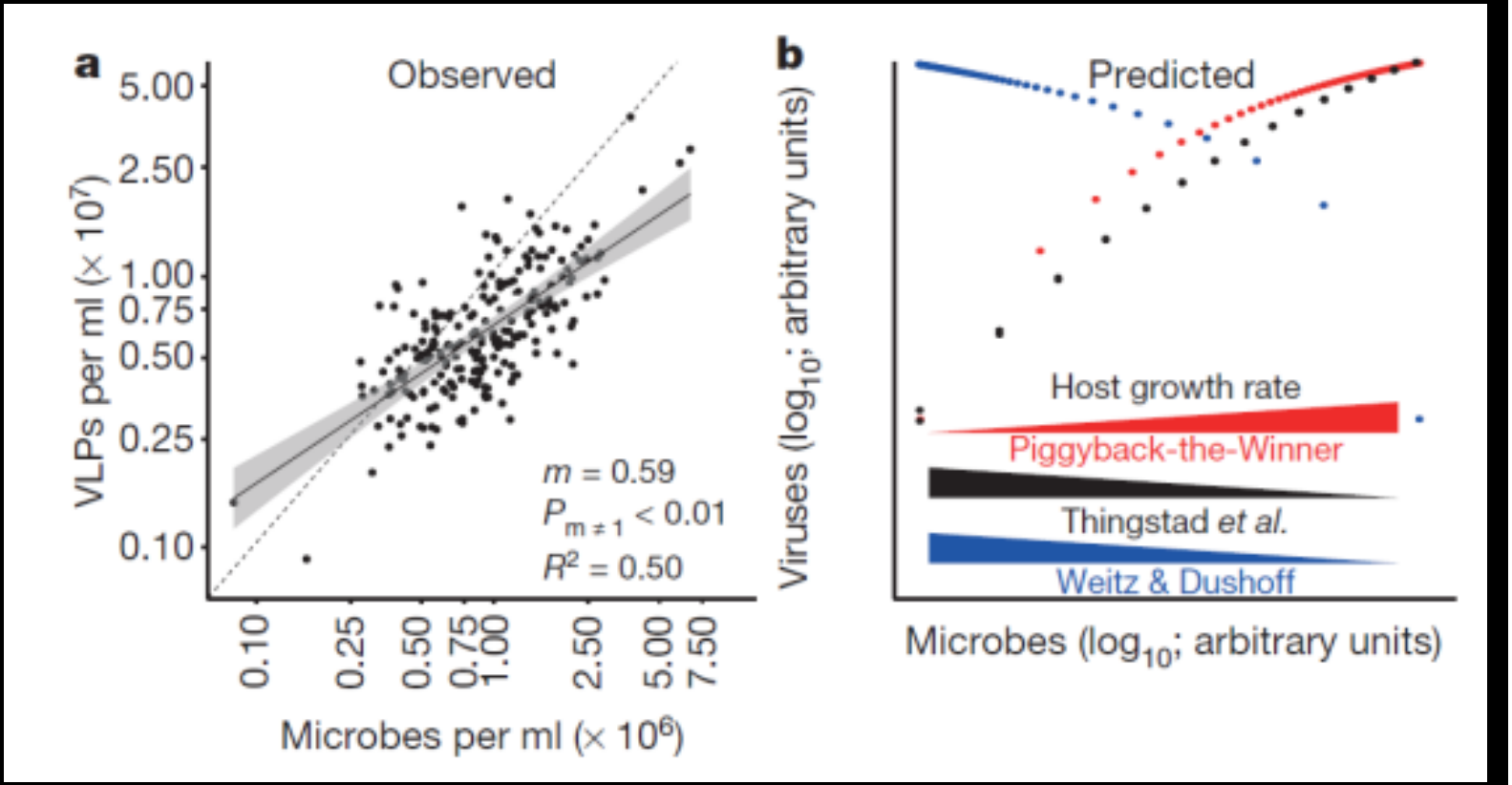
capture microbes and VLPs on 0.02 Anodisc

↓

stain with SYBR-Gold

↓

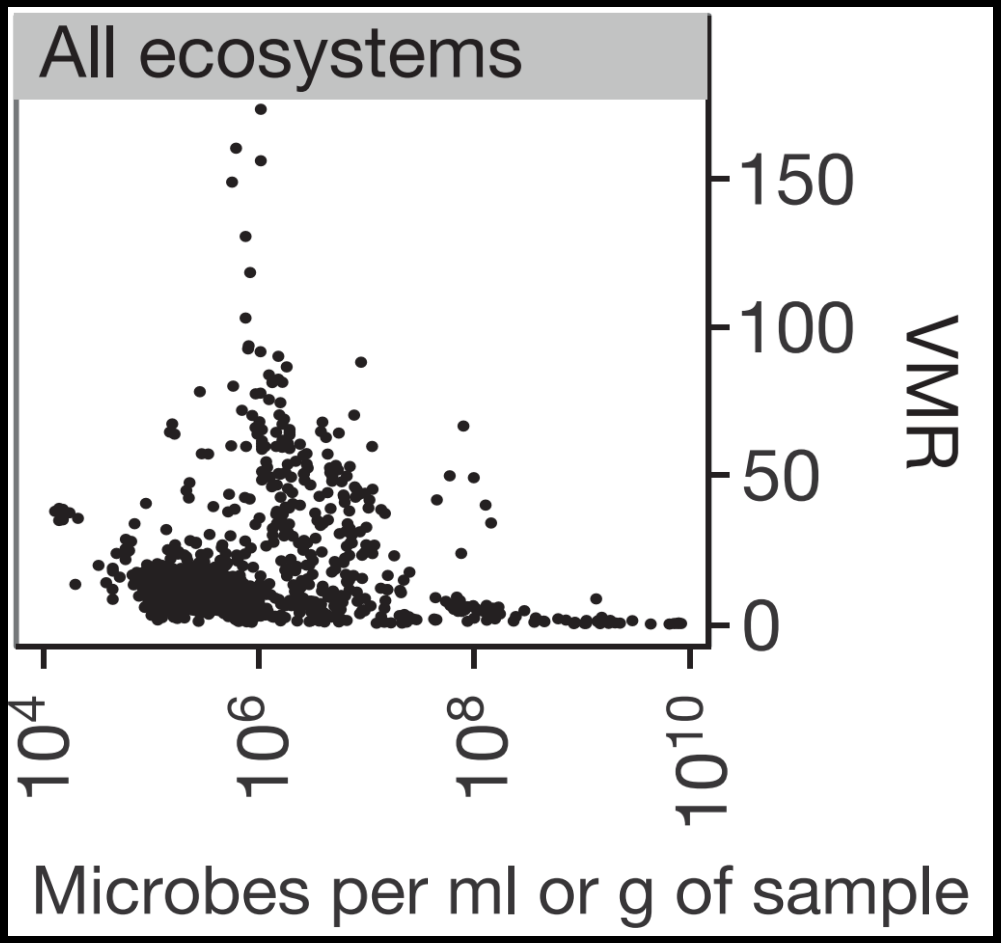
count with epifluorescent microscope



Viral predation pressure is decoupled from mass action driven interactions

Viral & microbial abundances do not linearly scale within & across ecosystems

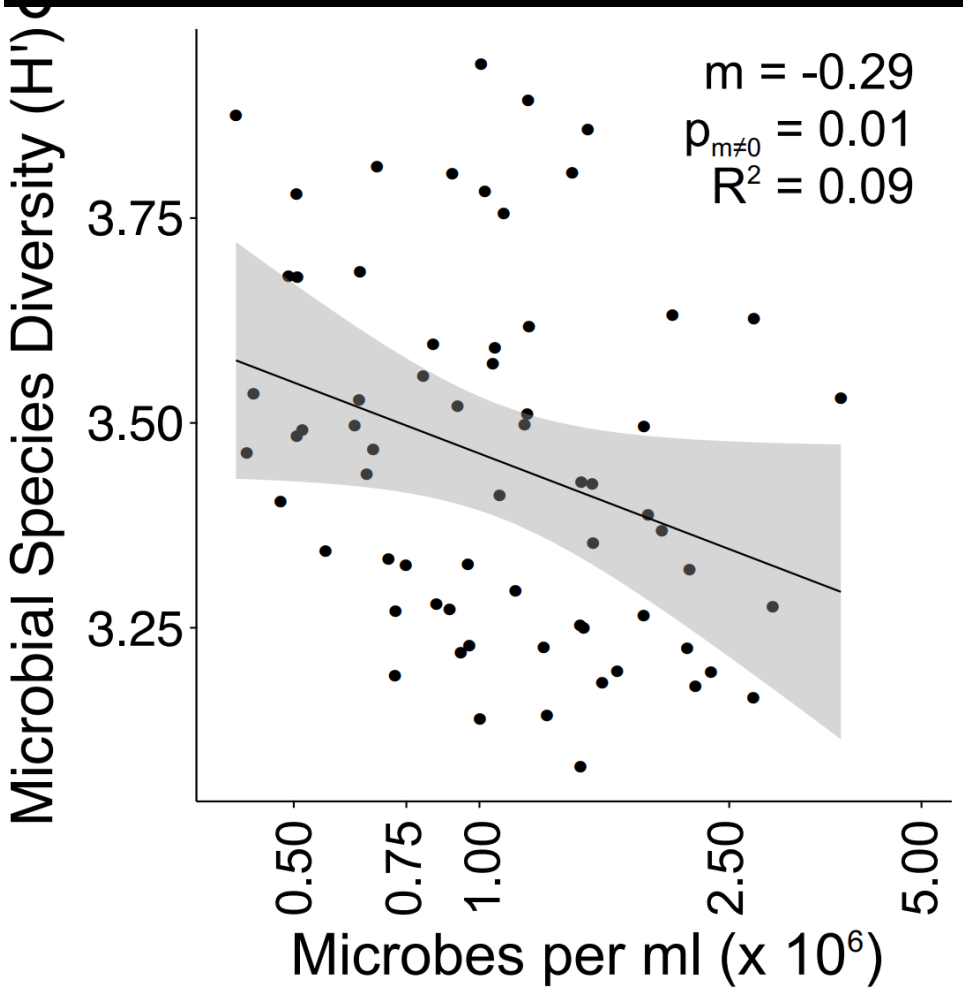
direct counts from ~20 ecosystems & 1,000s of samples

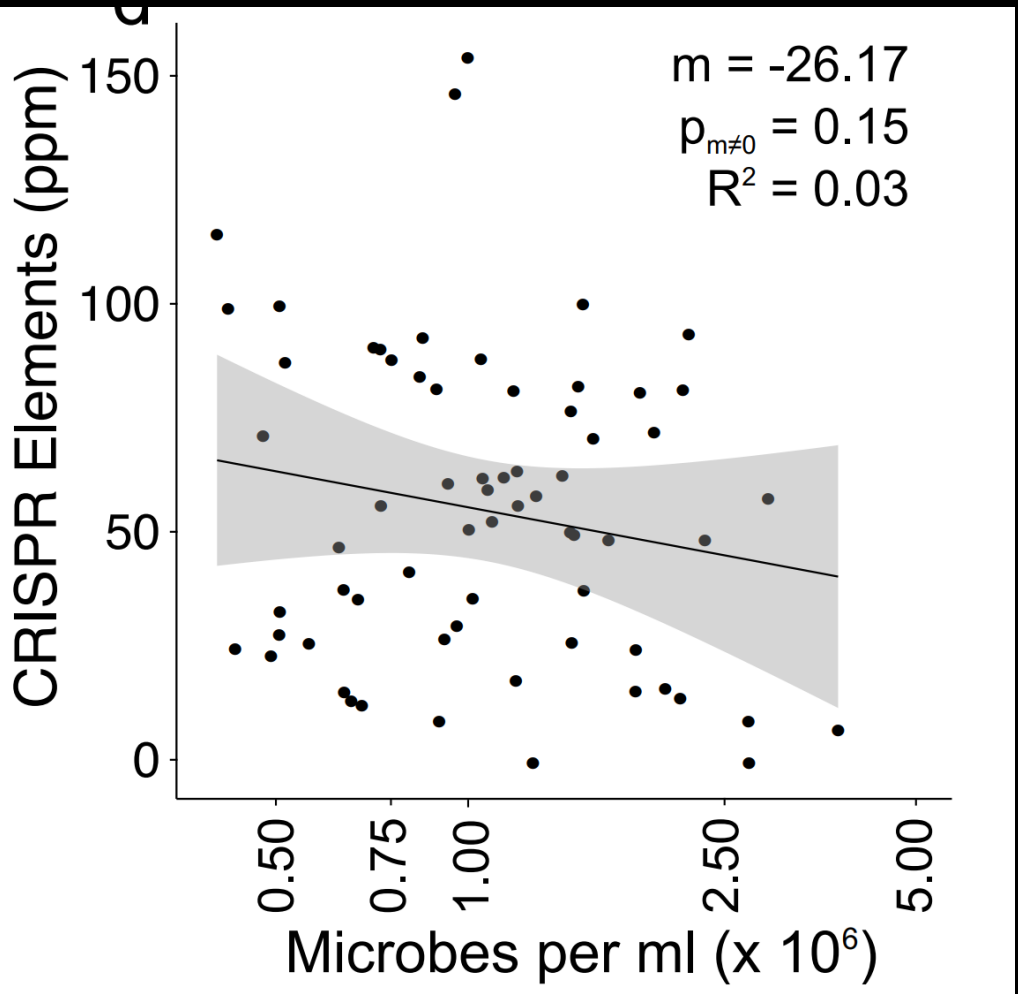


emphasis on marine microbial communities partially confused the issue because they are right at 10^6 microbes per ml

- low VMRs are indicative of lysogeny -

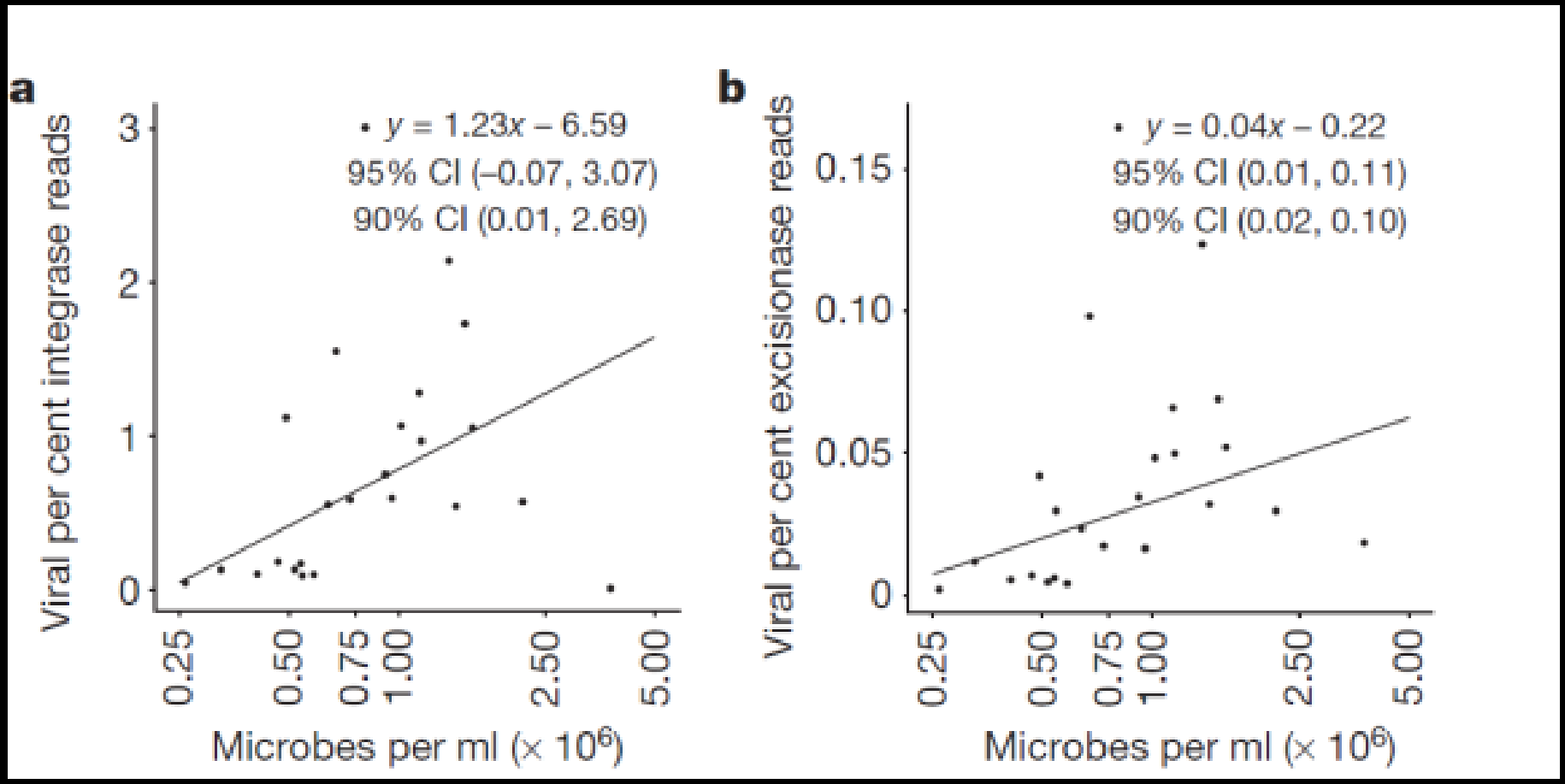
Microbial species diversity decreases with increasing abundance on coral reefs





Restriction enzymes, CRISPRs & other phage resistant mechanisms decrease with abundance

Viral communities are more temperate (carrying prophage) at higher cell abundances



collect water from coral reef boundary layer → viromes → quantify integrase sequences

Superinfection exclusion protect against other phage

Phage communities are more virulent at higher cell abundances found on degraded coral reefs

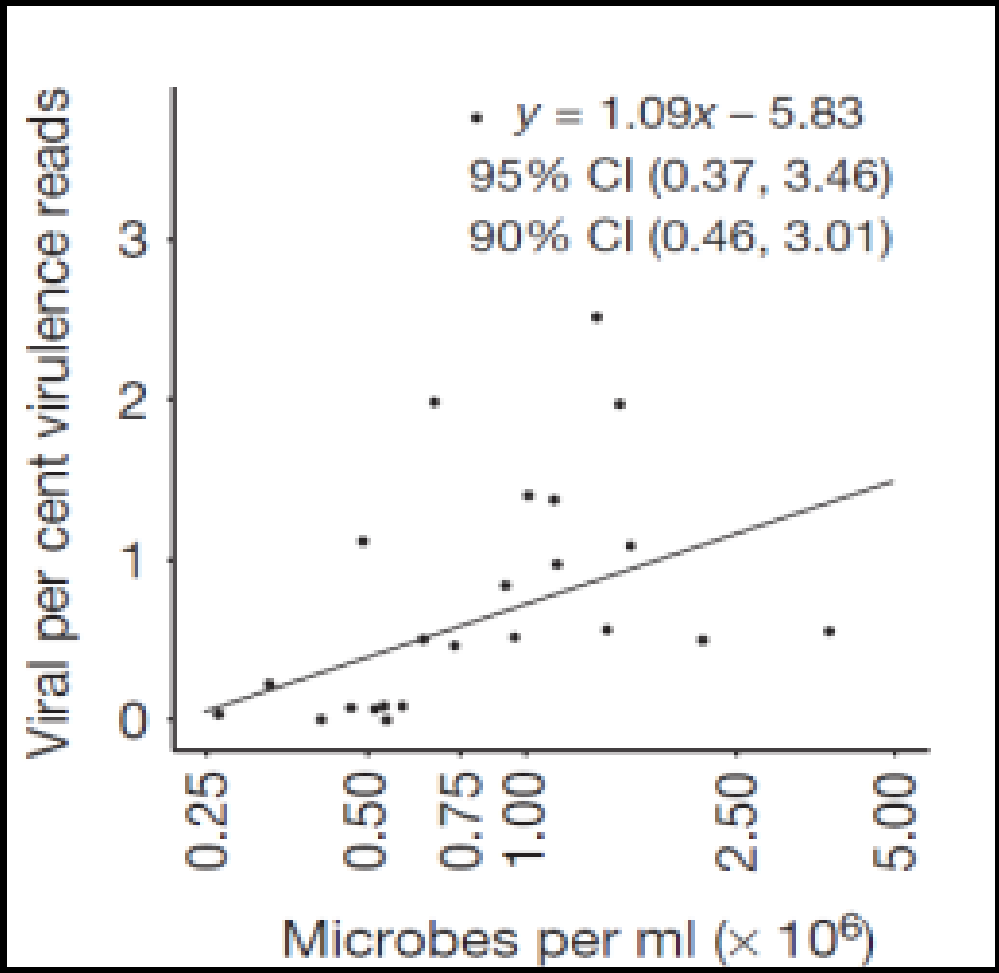
collect water from coral reef boundary layer

↓

viromes

↓

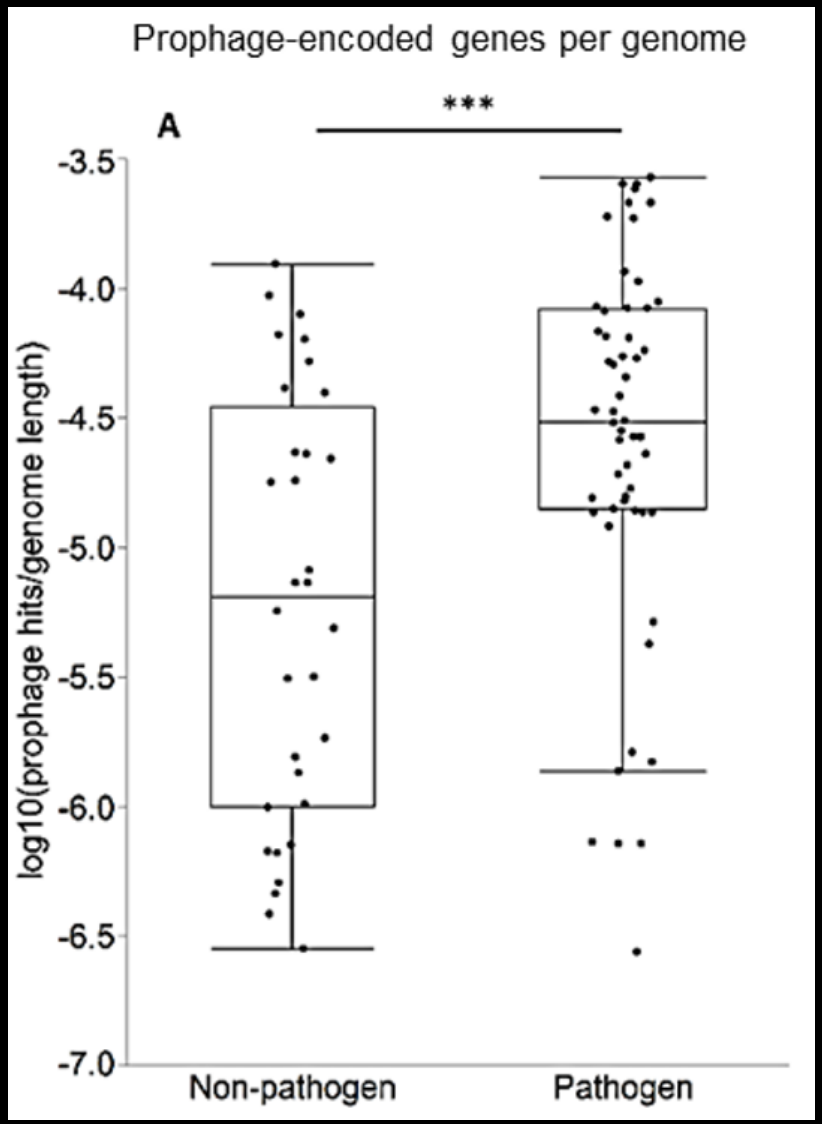
quantify virulence genes



Prophage are protecting lysogens from protists

Corollary: Coral disease is an emergent property

Cultured marine pathogens carry more prophage & virulence factors



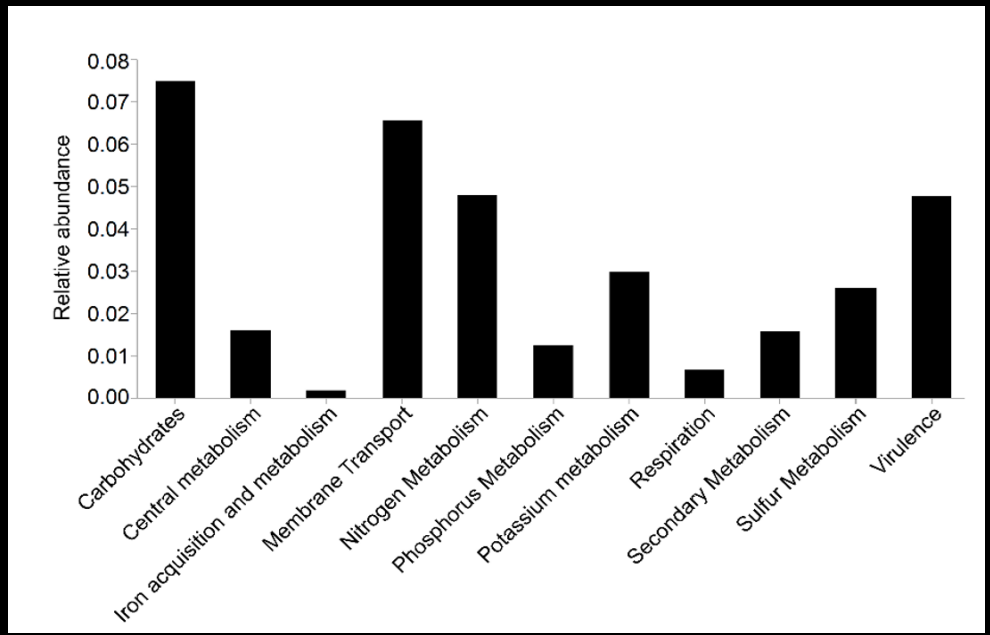
all known marine pathogens

↓

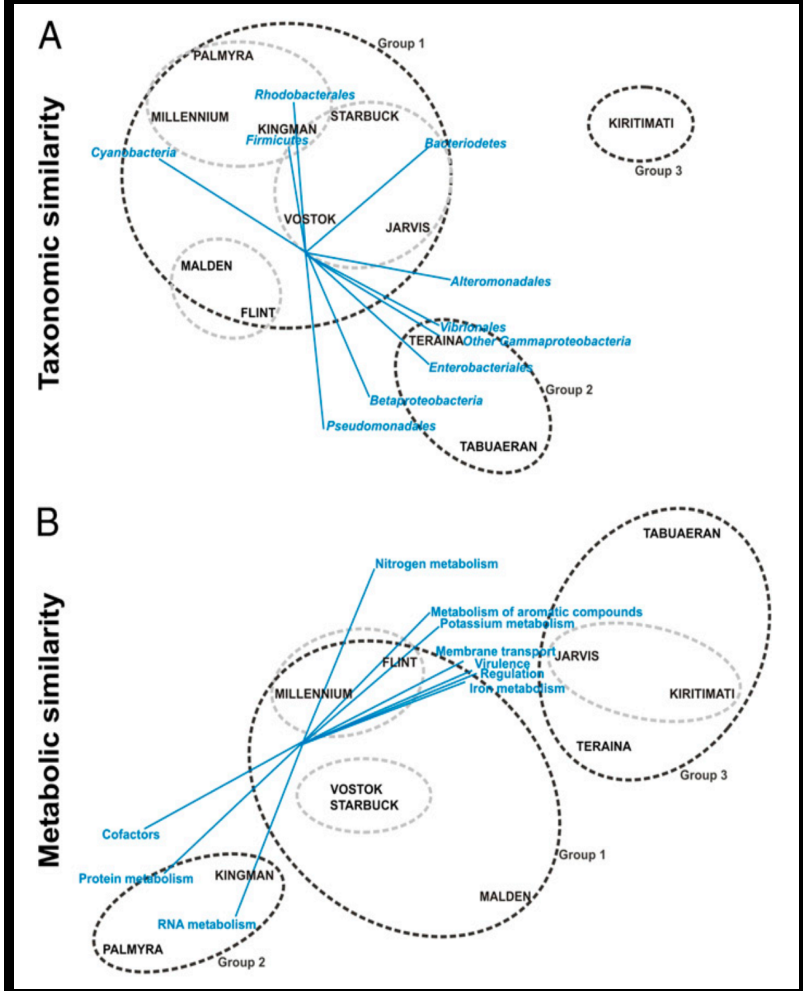
ID prophage

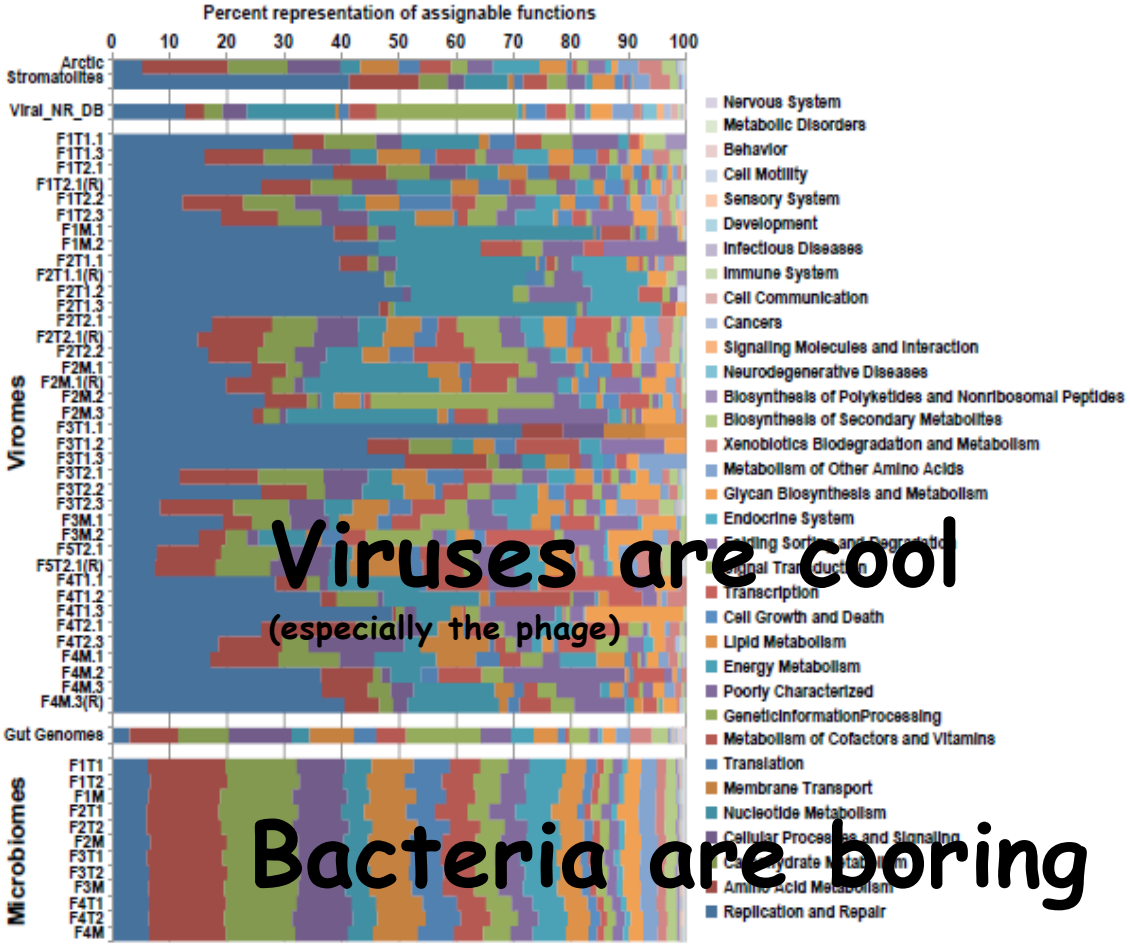
↓

classify gene categories



In general: Main energy pathways define taxonomy/core & local conditions define mobile elements





coral reefs

holobiont-associated

Main Take Home Points

Overfishing reduces grazing pressure, initiating trophic cascades that favors microbes.

Decoupling of electron-donors (e.g., glucose) and electron-acceptors (i.e., oxygen) leads to anabolic metabolisms on degraded coral reefs. This favors integration of phage.

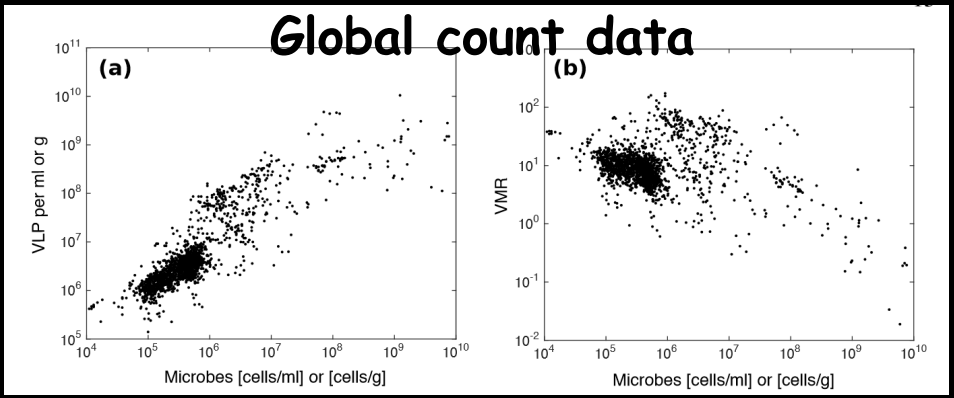
The fat & happy microbes on degraded reefs are more virulent because they carry prophage with exotoxins & other virulence factors to protect against protists.

Electron tranfer decoupling will favor proviruses in electron donor-heavy/high-cell abundance systems (e.g., multicellular organisms).

There are (at least) two ecological, metabolic steady states that the viruses are cueing onto...

Lysogenic versus lytic models of phage-host

Global count data

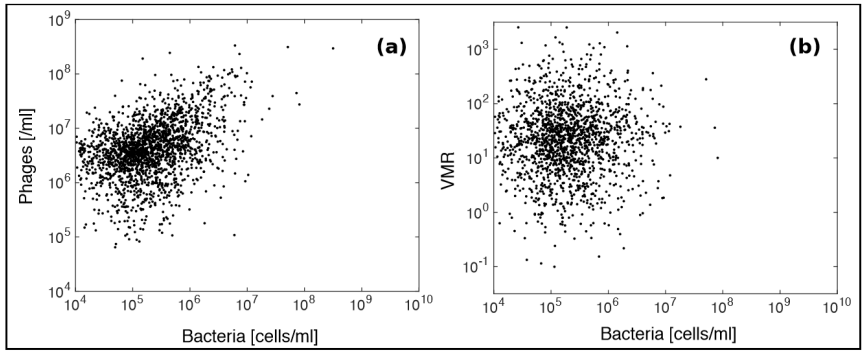


Lotka-Volterra like models for lytic & temperate communities

↓

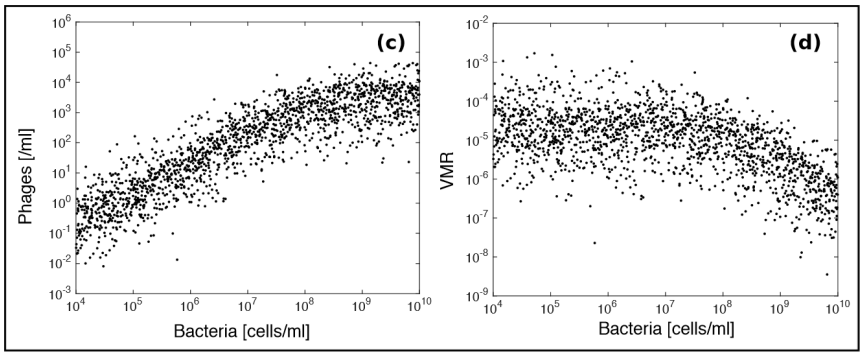
Latin Hypercube Sampling Scheme

Lytic World



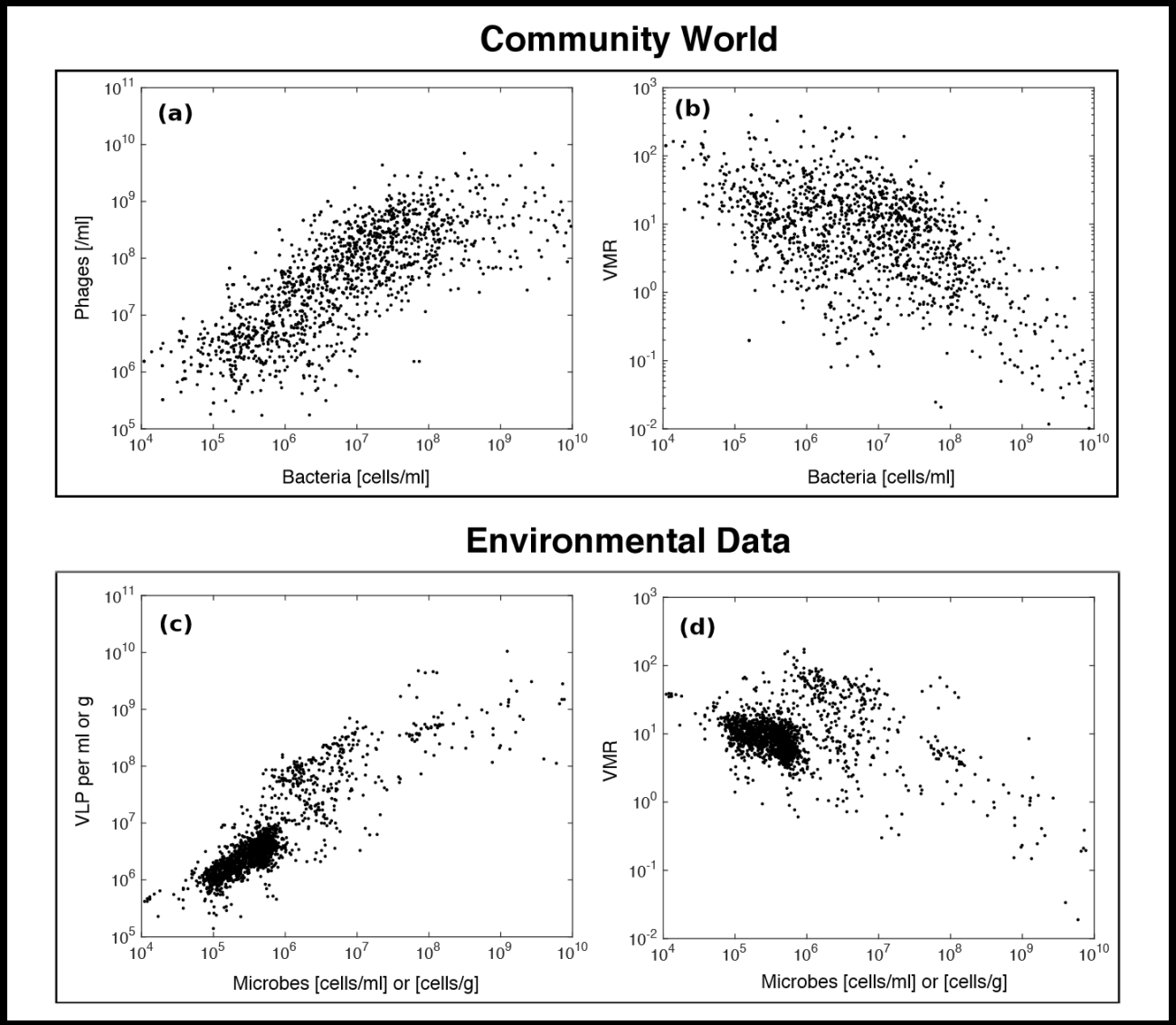
Parameter	Description
r	intrinsic growth rate of bacteria species
K	carrying capacity of bacteria community
d	infection rate of virulent phage species
c	burst size of virulent phage species
m	decay rate of virulent phage species
n	number of species in the community

Lysogenic World



Parameter	Description
r	intrinsic growth rate of lysogen species
K	carrying capacity of lysogen community
β	induction rate of prophage species
c	burst size of temperate phage species
m	decay rate of temperate phage species
d	infection rate of temperate phage species
χ	lysogen species immunity
n	number of species in the community

Lysogenic and lytic models together



Toni Luque

Emily Jasien

Don't forget the temperate viruses :)

Rohwer & Wegley-Kelly Lab (SDSU)

Barr, Jeremy
Benler, Sean
Boling, Lance
Calhoun, Sandi
Cobián, Ana
Fairoz, MFM
Furlan, Mike
Galtier d'Auriac, Ines
George, Emma
Grasis, Juris
Green, Kevin
Haas, Andi
Hartmann, Aaron
Hester, Eric
Lim, Yanwei
Little, Mark
Paul, Lauren
Nguyen, Sophie
Quinn, Robby (UCSD)
Quistad, Steve
Ransome, Emma (SI)
Reyes, Brandon
Roach, Ty
Robinett, Nate
Sanchez, Savannah
Silveira, Cynthia
Talago, Natasha
Janouškovec, Jan
Knowles, Benjamin
Rita Auro

Anca Segall (SDSU)

Luque Lab (SDSU)

Emily Jasien

BioMath (SDSU)

Barbara Bailey
Arlette Baljon
Ben Felts
Toni Luque
Jim Nulton
Peter Salamon

NOAA and SIO for
shiptime

The $$$:)


Gordon and Betty
MOORE
FOUNDATION


NSF


SAN DIEGO STATE
UNIVERSITY


NATIONAL INSTITUTES
OF HEALTH


CIFAR
CANADIAN INSTITUTE
for ADVANCED RESEARCH