# Investigating nitrogen remineralization in the mesopelagic with molecular and geochemical approaches

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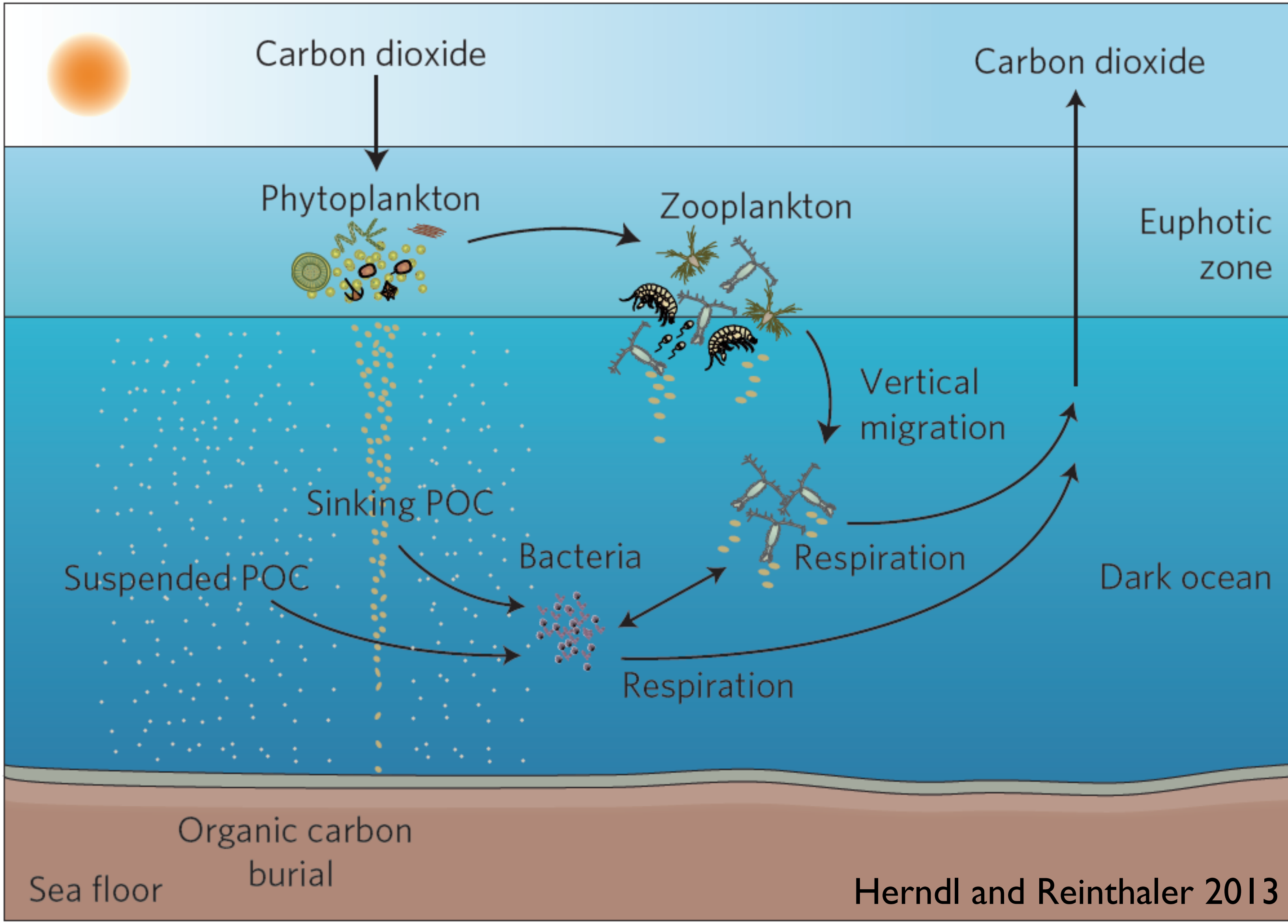
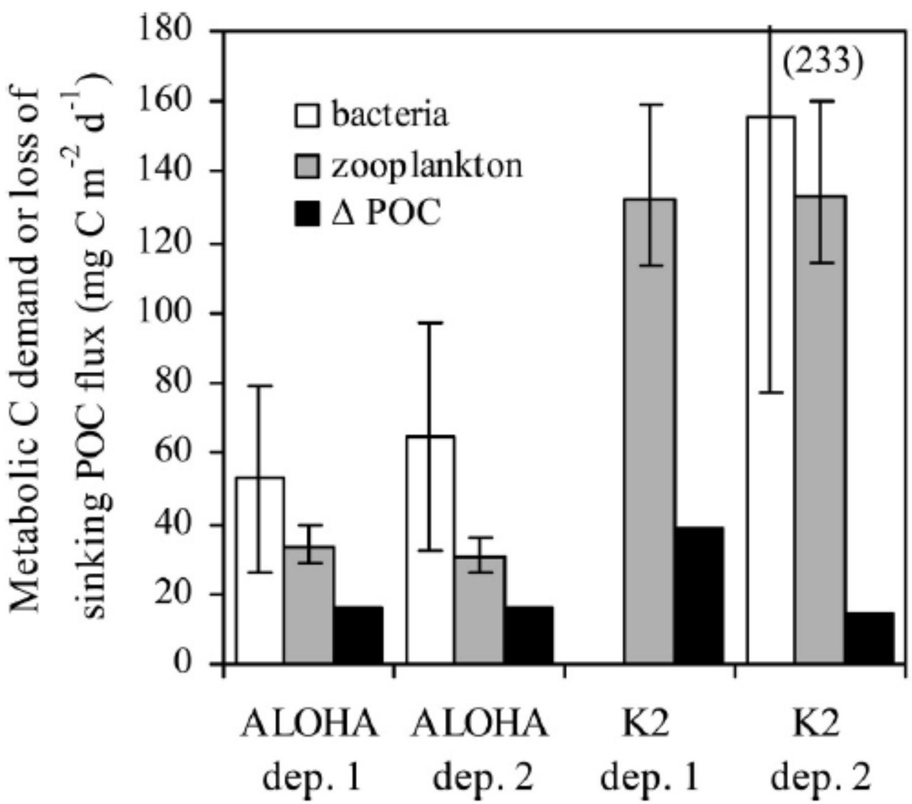
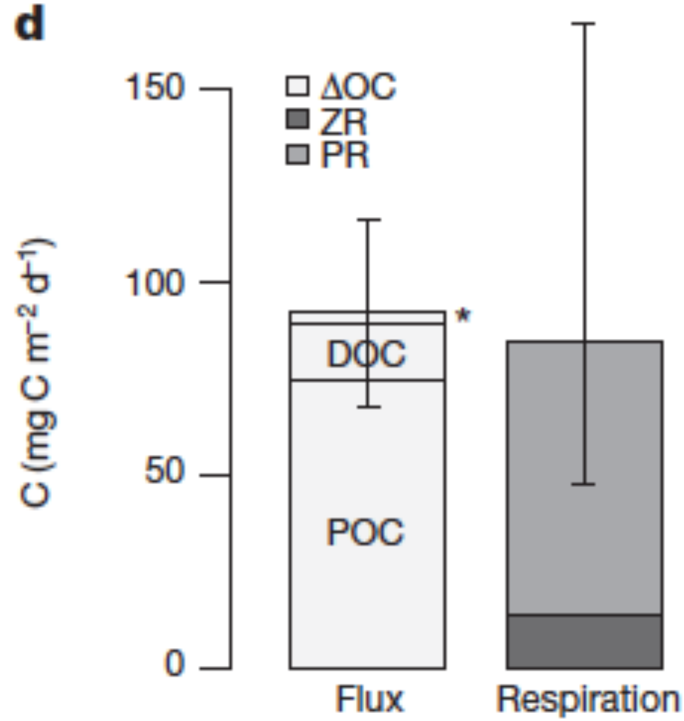


Carbon dioxide
Carbon dioxide
Phytoplankton
Zooplankton
Euphotic zone
Vertical migration
Sinking POC
Bacteria
Respiration
Suspended POC
Dark ocean
Respiration
Organic carbon burial
Sea floor
Herndl and Reinthaler 2013

# Estimates of bacterial carbon demand apparently exceed POC supply




Steinberg et al. 2008; Giering et al. 2014

# What does the nitrogen budget in the upper mesopelagic tell us?

Respiration: $CH_2O + O_2 \longrightarrow CO_2 + H_2O$

Nitrification: $NH_3 + 2\ O_2 \longrightarrow NO_3^- + H^+ + H_2O$

Two advantages:

Unlike carbon respiration, we can measure N remineralization directly.

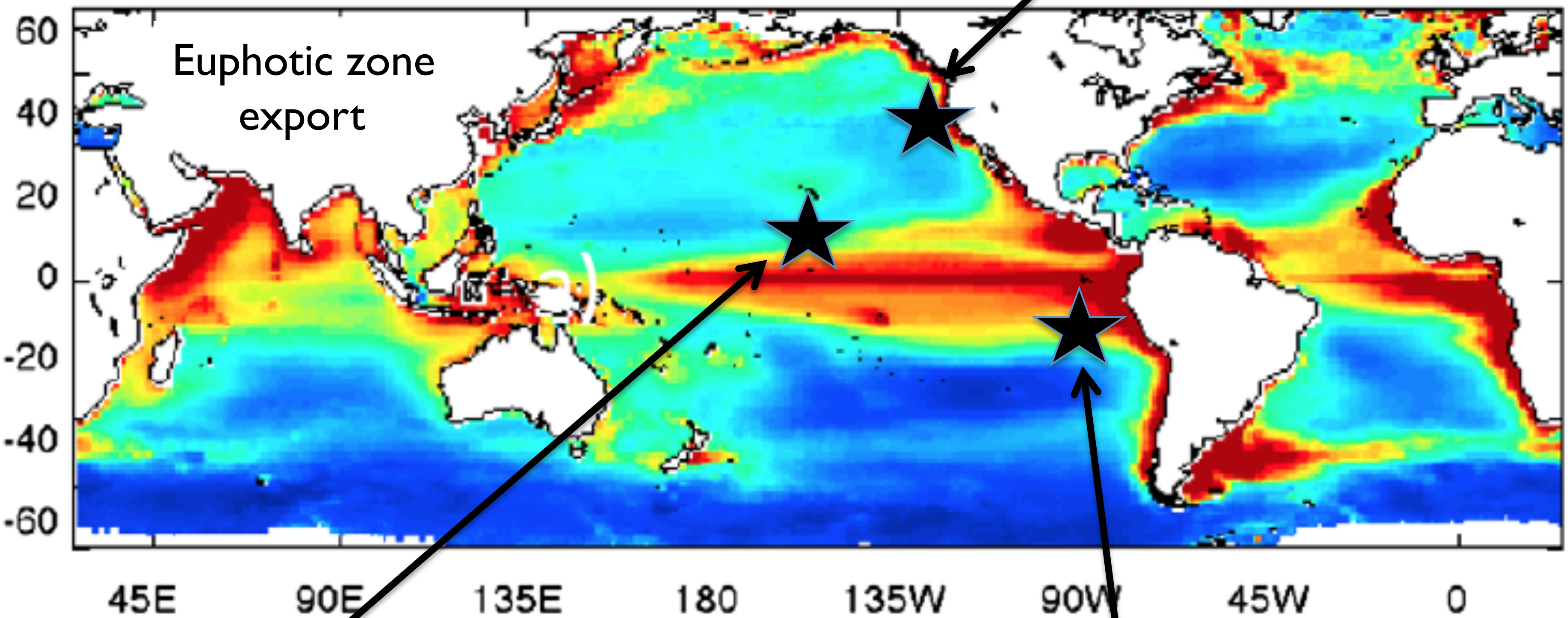
Less concern about excluding particle-associated processes.

Patterns in the distribution and activity of nitrifying organisms in the Pacific

Balancing PON export and N demand, and the fuel for autotrophy in the mesopelagic

Asking the microbes about the mesopelagic

Central California Current: 2007, 2009




Siegel et al. 2014, *GBC*

Equatorial Pacific: 2011
"METZYME"

Eastern Tropical South Pacific: 2009, 2010
"ETSP"

# THE EXPERIMENTAL DECOMPOSITION AND REGENERATION OF NITROGENOUS ORGANIC MATTER IN SEA WATER[1]

THEODOR VON BRAND, NORRIS W. RAKESTRAW AND CHARLES E. RENN

3. The main stages in the decomposition are: dead body—ammonia —nitrite—nitrate.

Von Brand et al. 1937

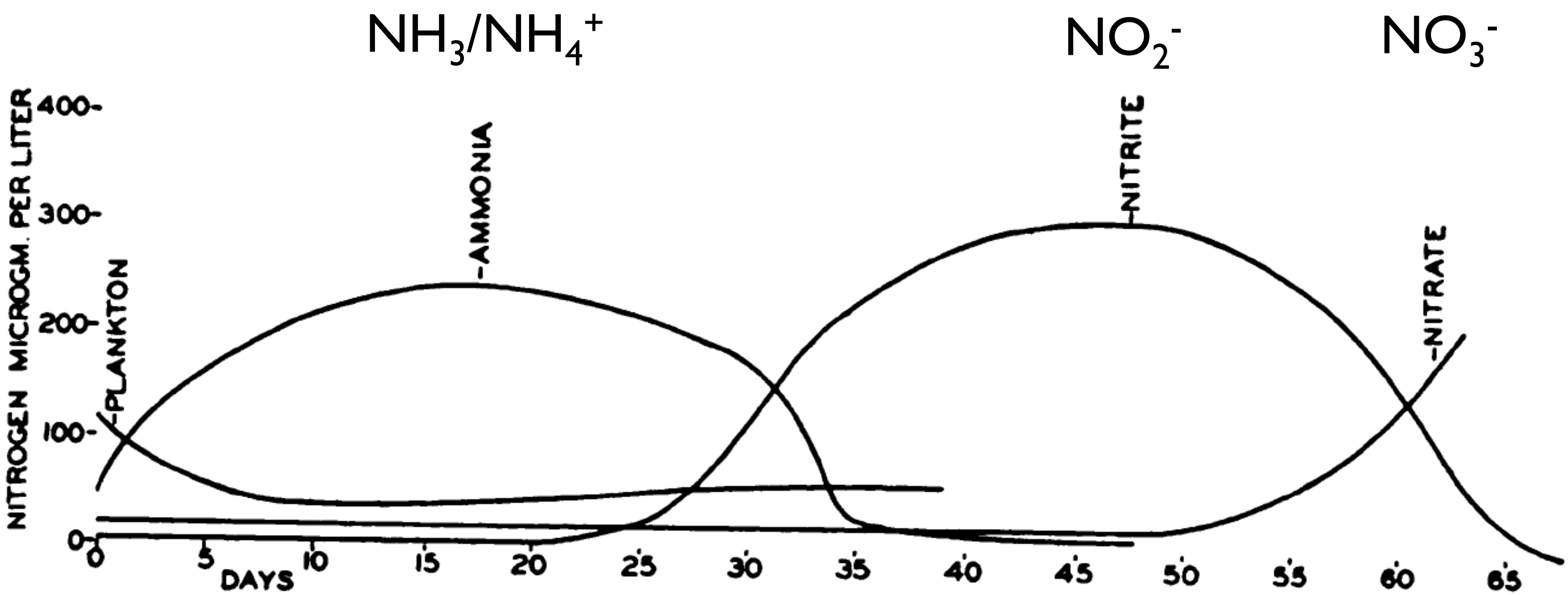
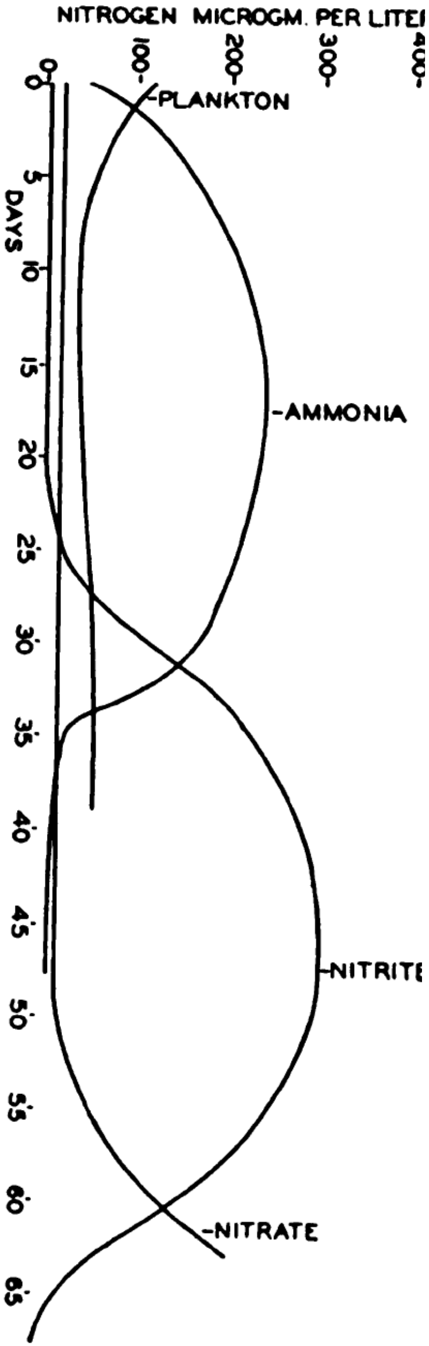
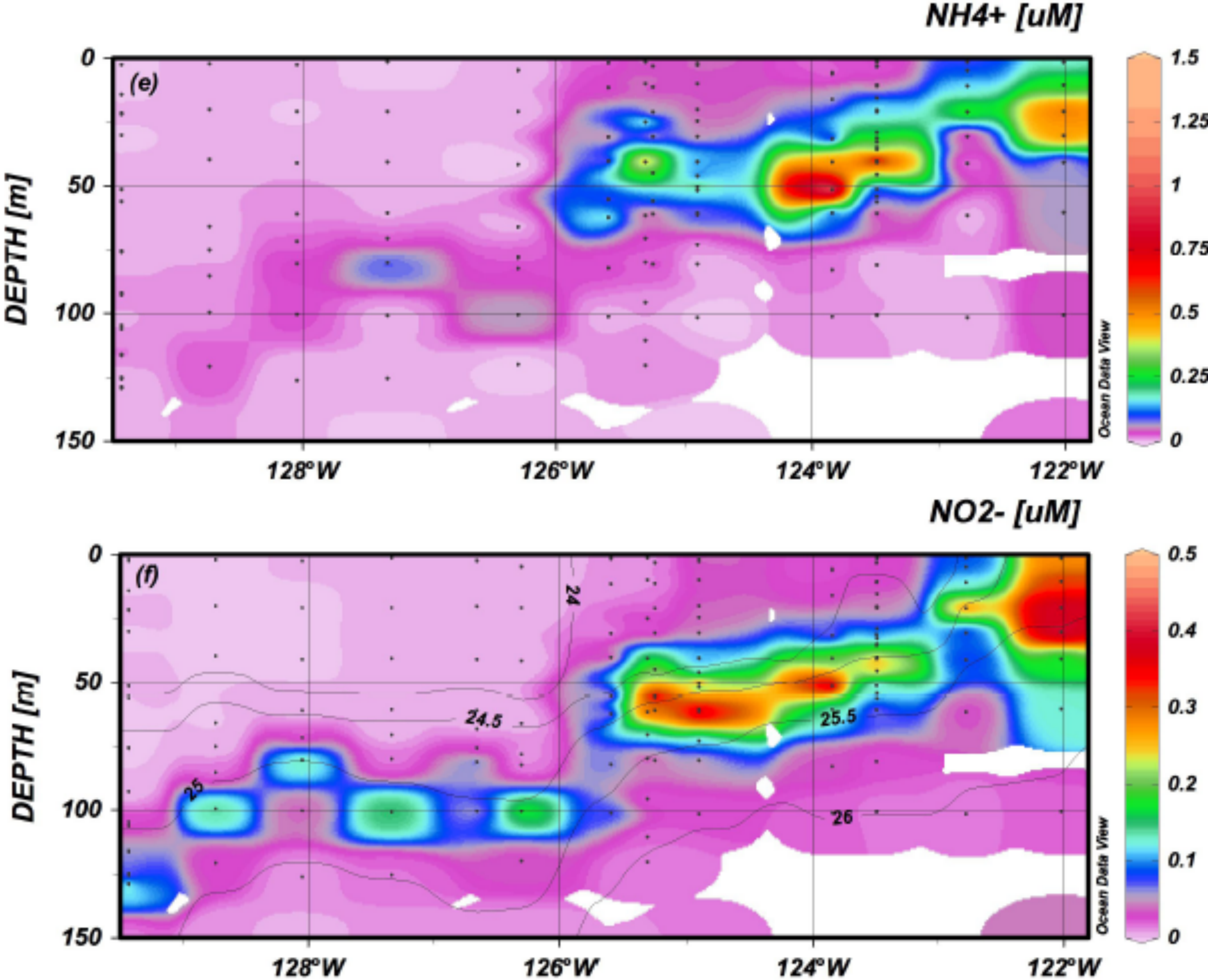



FIG. 2. Series IV. The decomposition of nitrogenous organic matter in mixed plankton, showing the appearance of soluble nitrogen compounds in the water in which it is suspended. Plankton previously filtered through No. 8 bolting silk.




Santoro et al. 2013; *Biogeosciences*; Data: J. Plant and C. Sakamoto

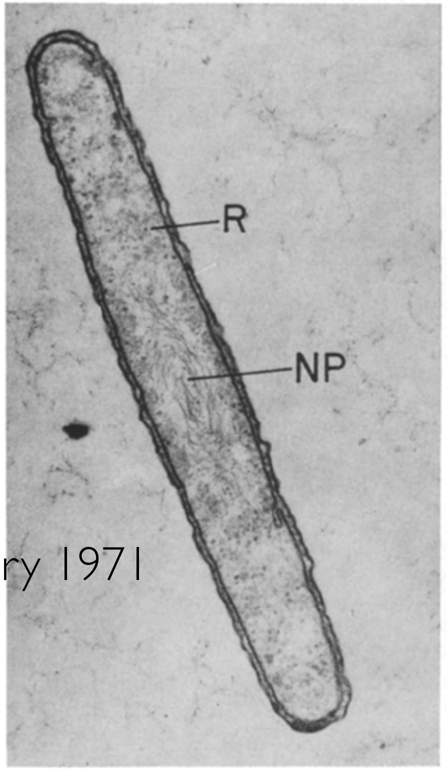
# Nitrification proceeds in two steps by two separate groups of organisms

ammonia oxidation: $NH_3 \longrightarrow NH_2OH \longrightarrow NO_2^-$

nitrite oxidation: $NO_2^- \longrightarrow NO_3^-$

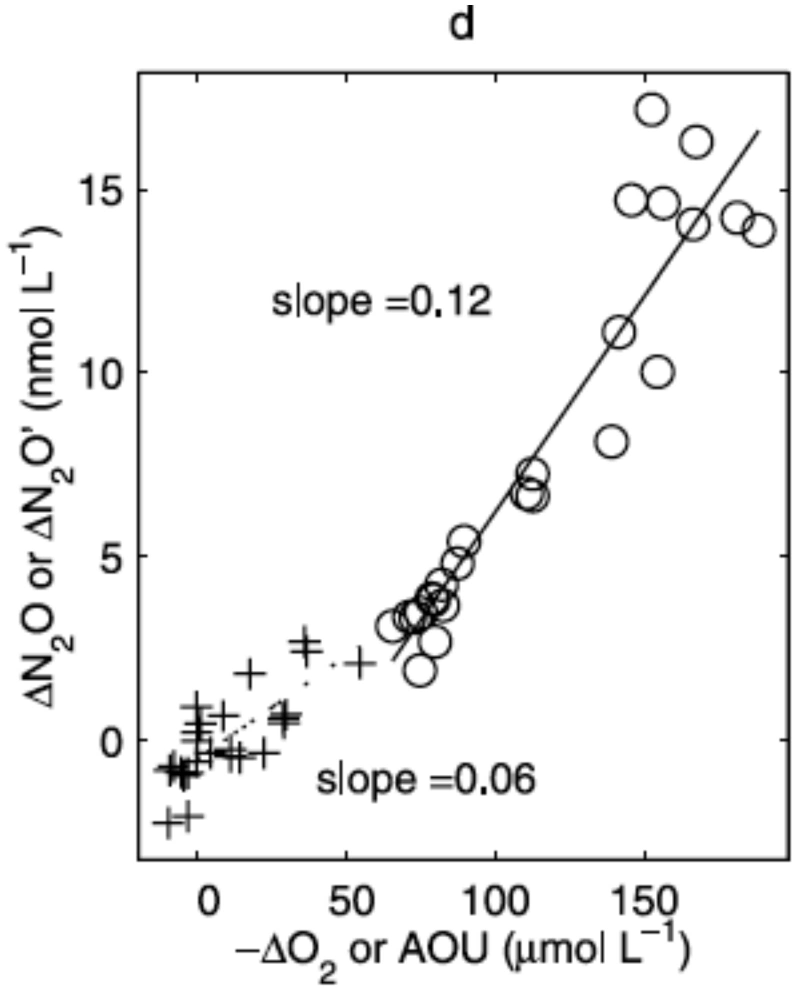
Most ammonia oxidation in the ocean carried out by ammonia-oxidizing archaea (AOA).

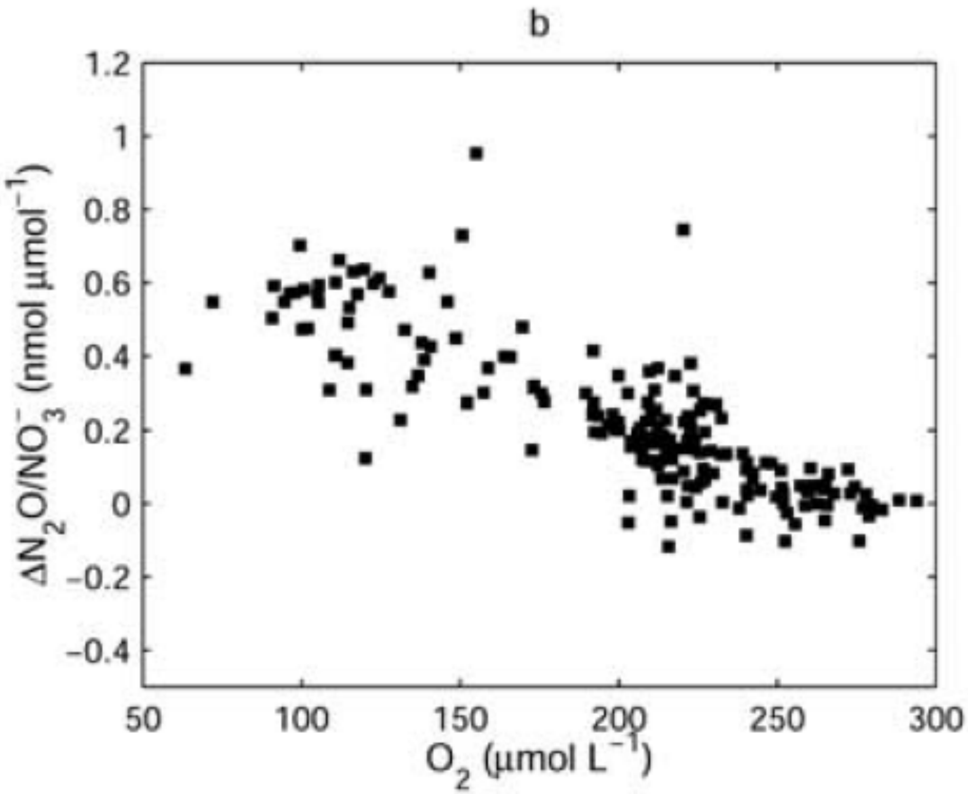
All cultivated marine nitrifiers (AOA and NOB) are chemolithoautotrophic . . .fussy, slow growing.



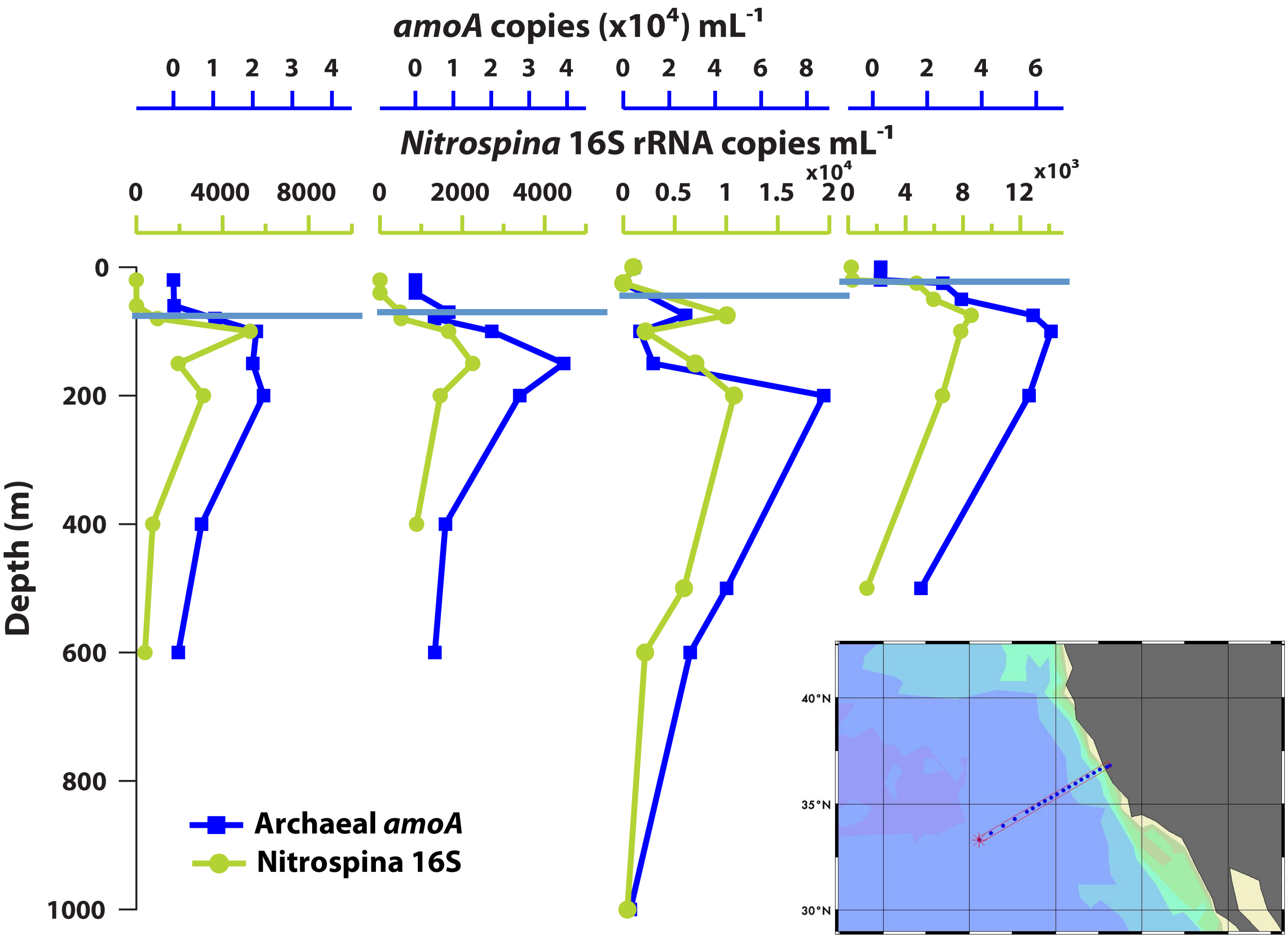

*Nitrospina gracilis*
Watson and Waterbury 1971

# Nitrogen remineralization is linked to production of nitrous oxide ($N_2O$)



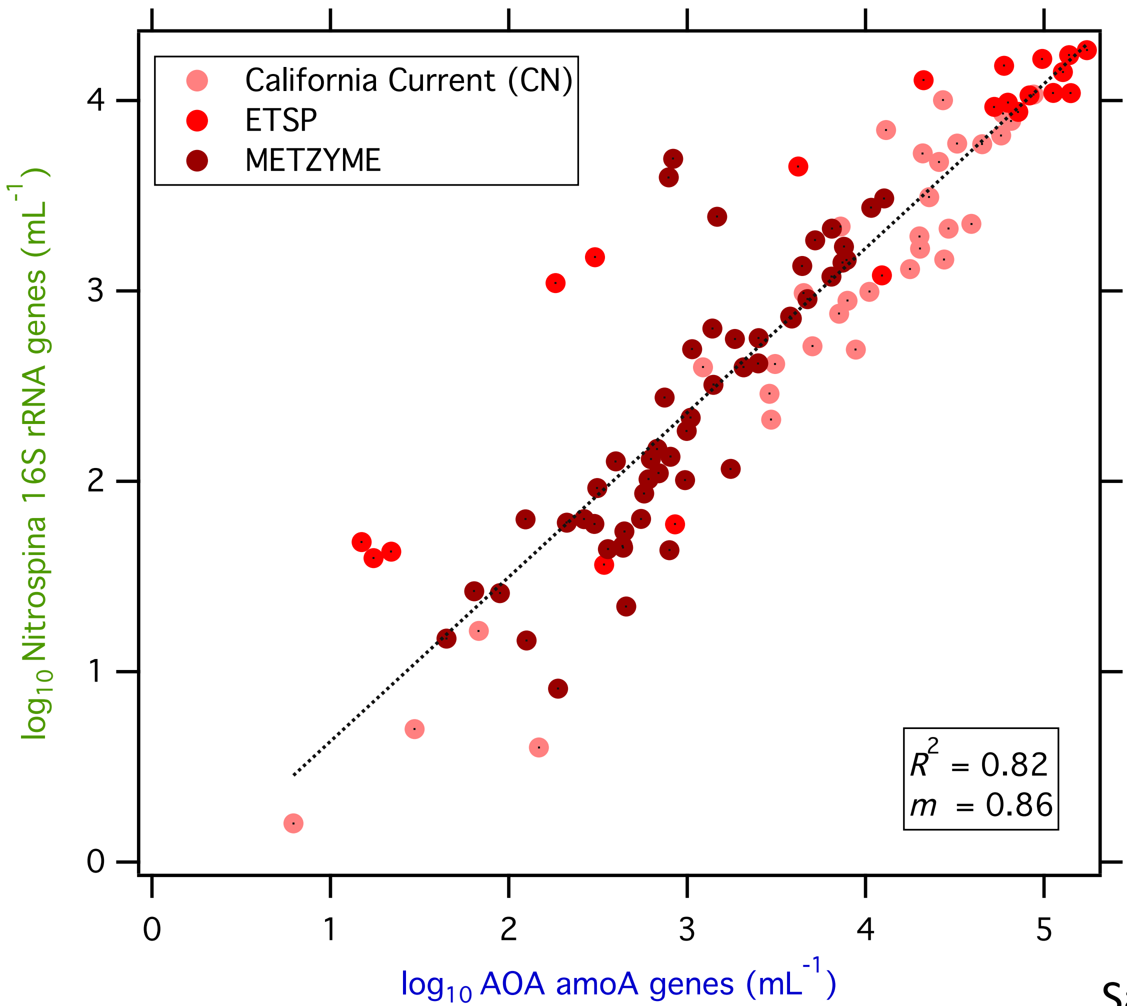




Nevison et al. 2003



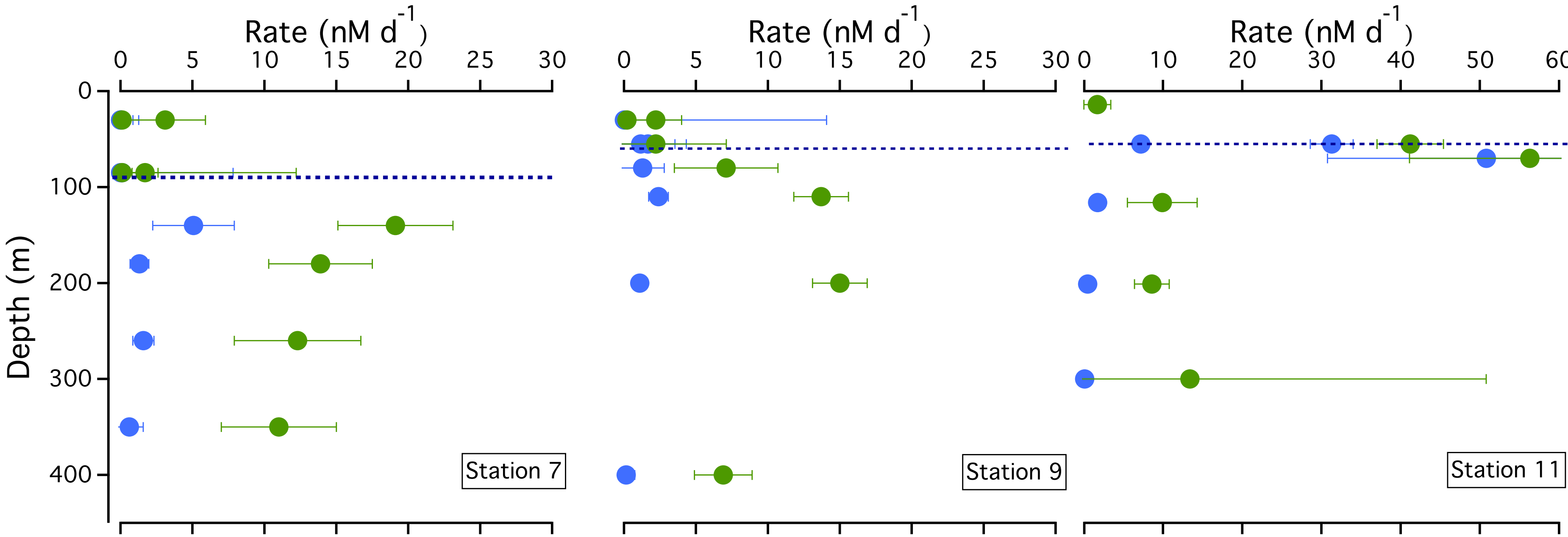

Santoro et al. 2010; *Environ. Microbiol.*

# AOA and NOB correlated throughout the Pacific



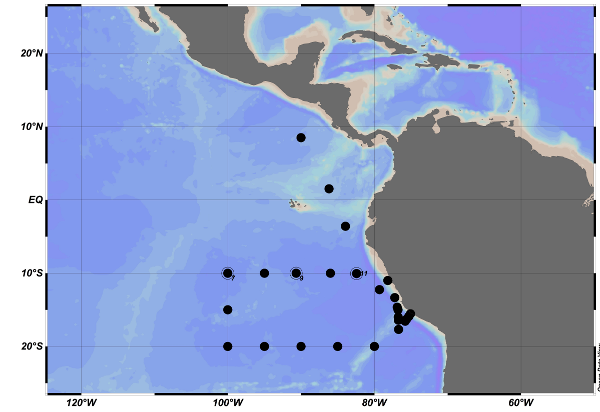

Santoro, *unpublished*

# Offset between ammonia oxidation and nitrite oxidation




Ammonia oxidation

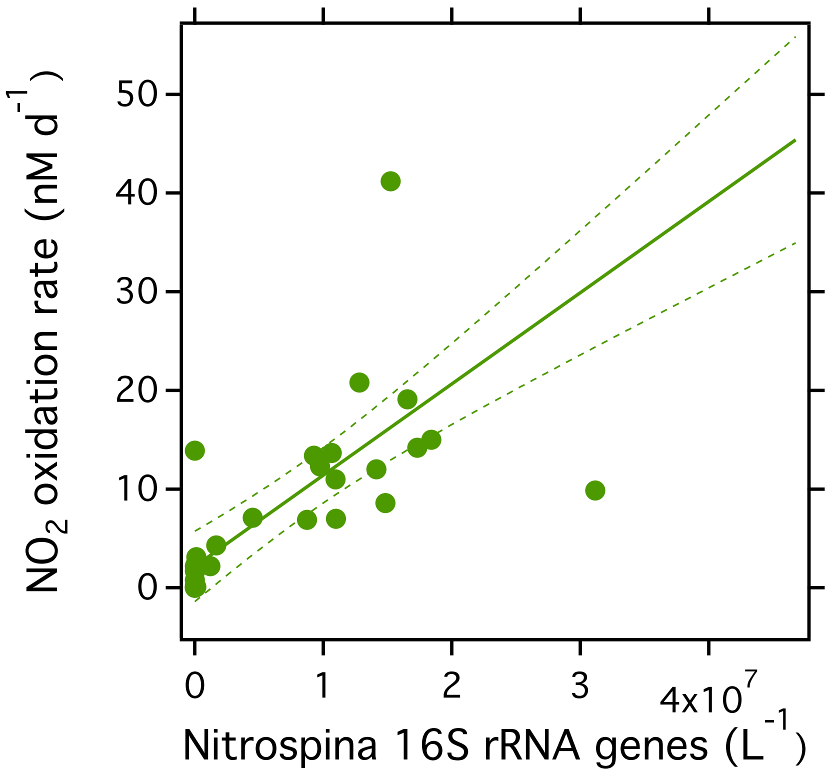
Nitrite oxidation

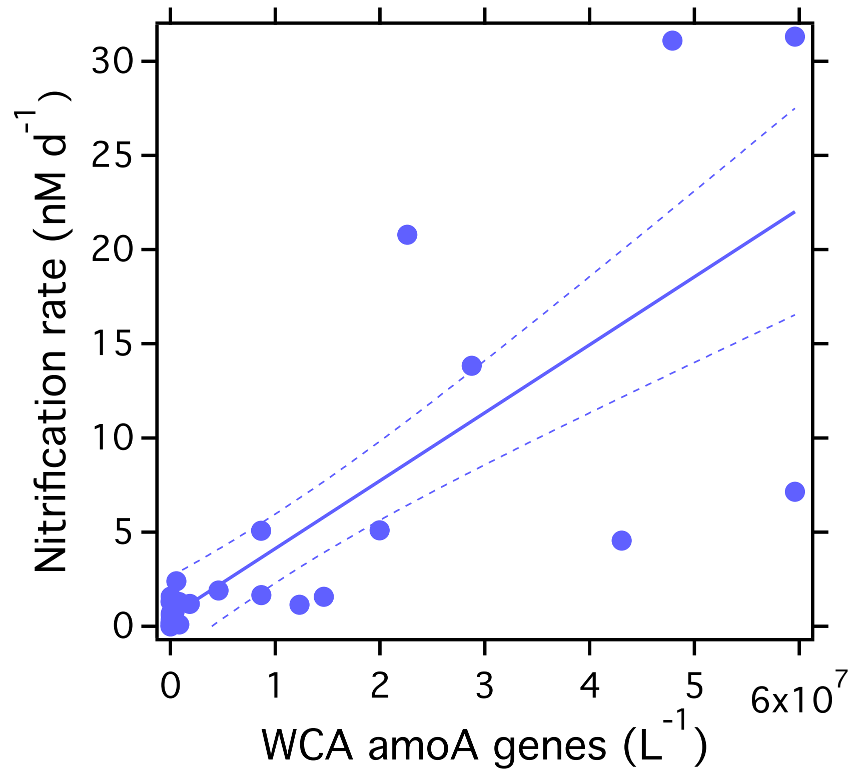



Santoro, Buchwald, Casicotti; *unpublished*

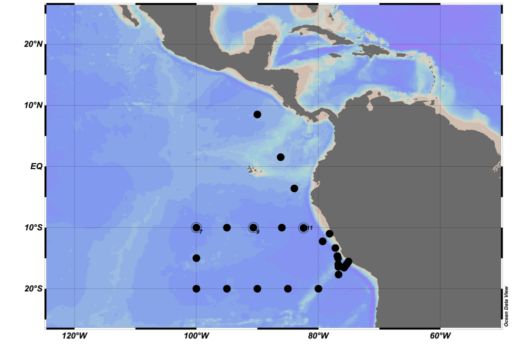
See also Lipschultz et al. 1990; Füssel et al. 2012

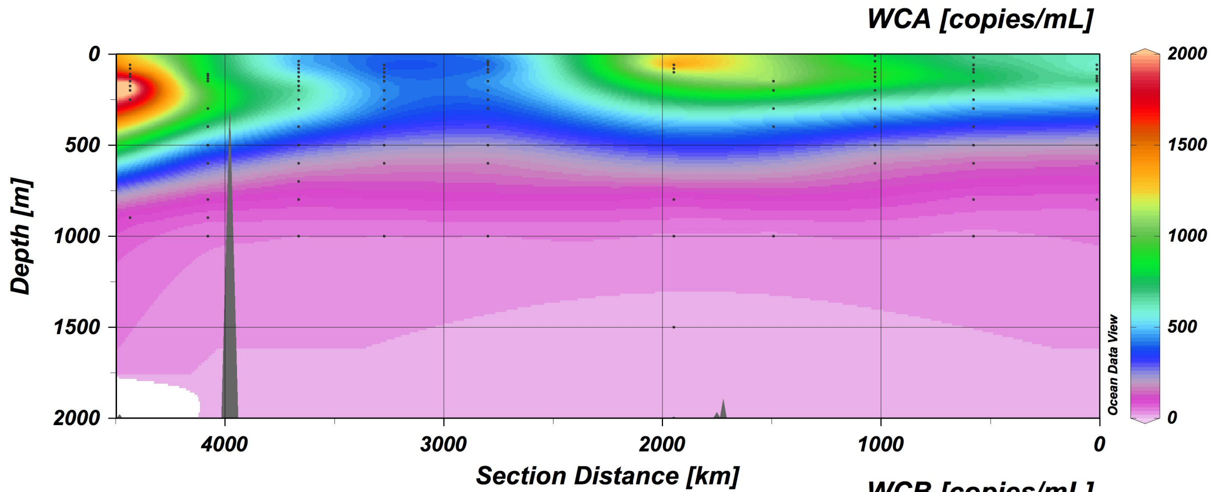
# Significant relationships between rates and clade-specific gene abundance

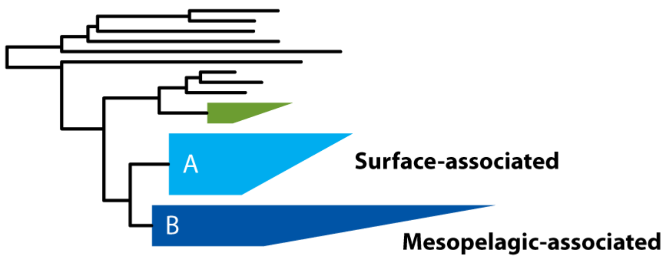


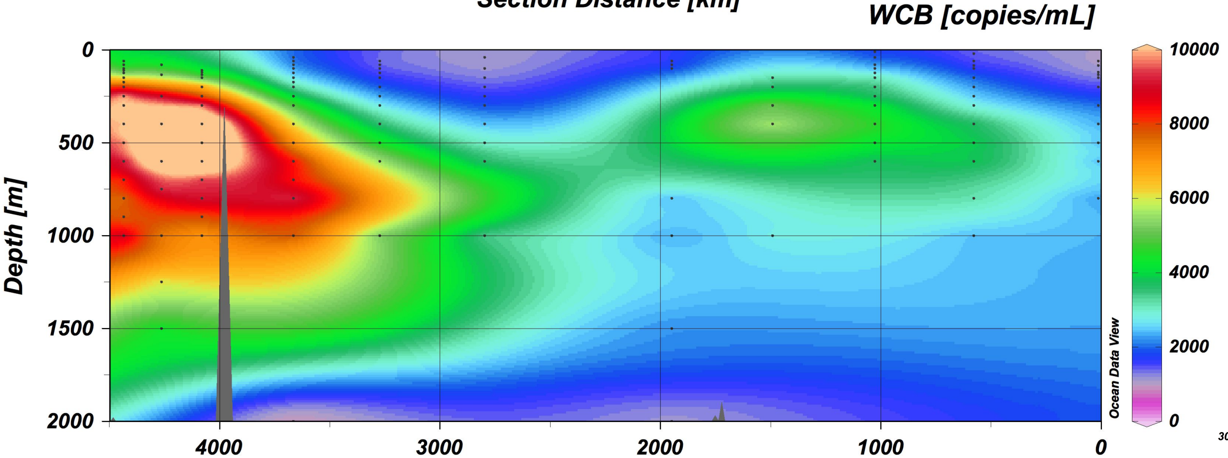




Same relationship demonstrated by Smith et al. (2014) for Monterey Bay



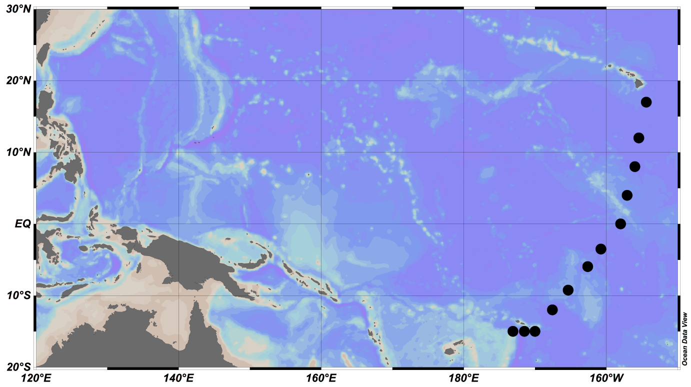


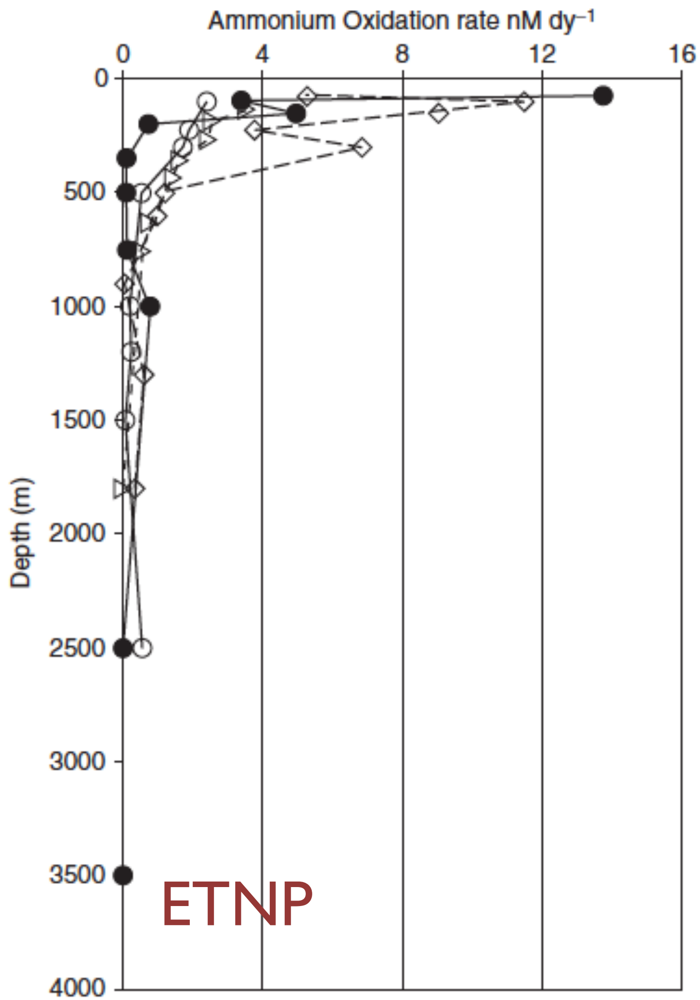

Two AOA ecotypes across the Western Equatorial Pacific.

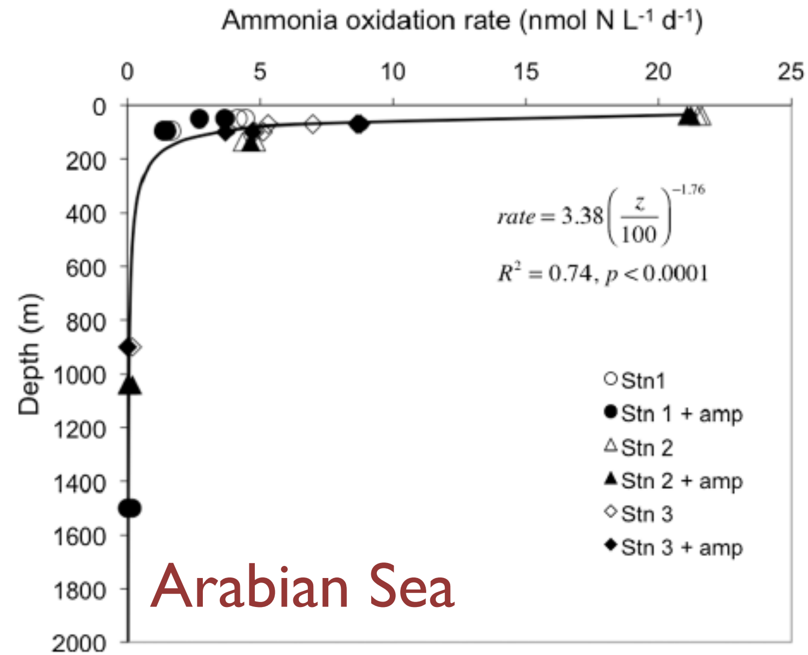
METZYME PIs: Carl Lamborg and Mak Saito



# Balancing PON export and N demand, and fuel for autotrophy in the mesopelagic

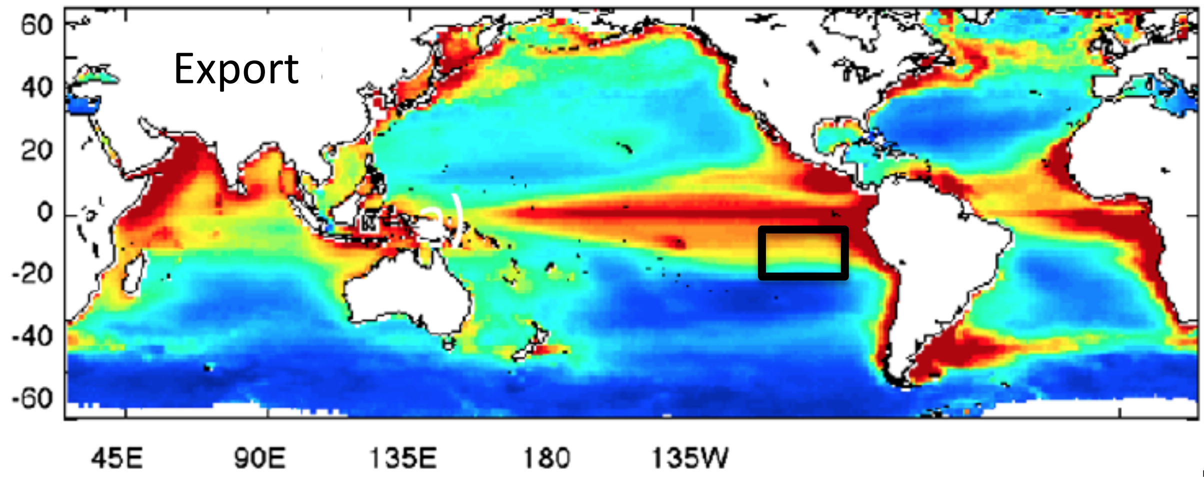
# Relating nitrification rates and PON flux

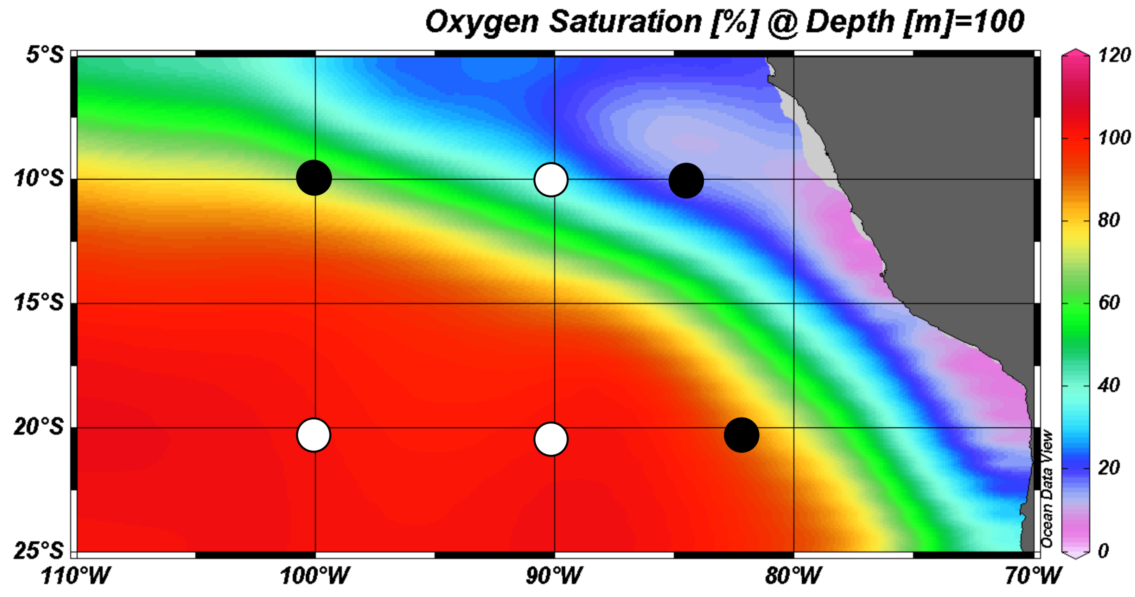


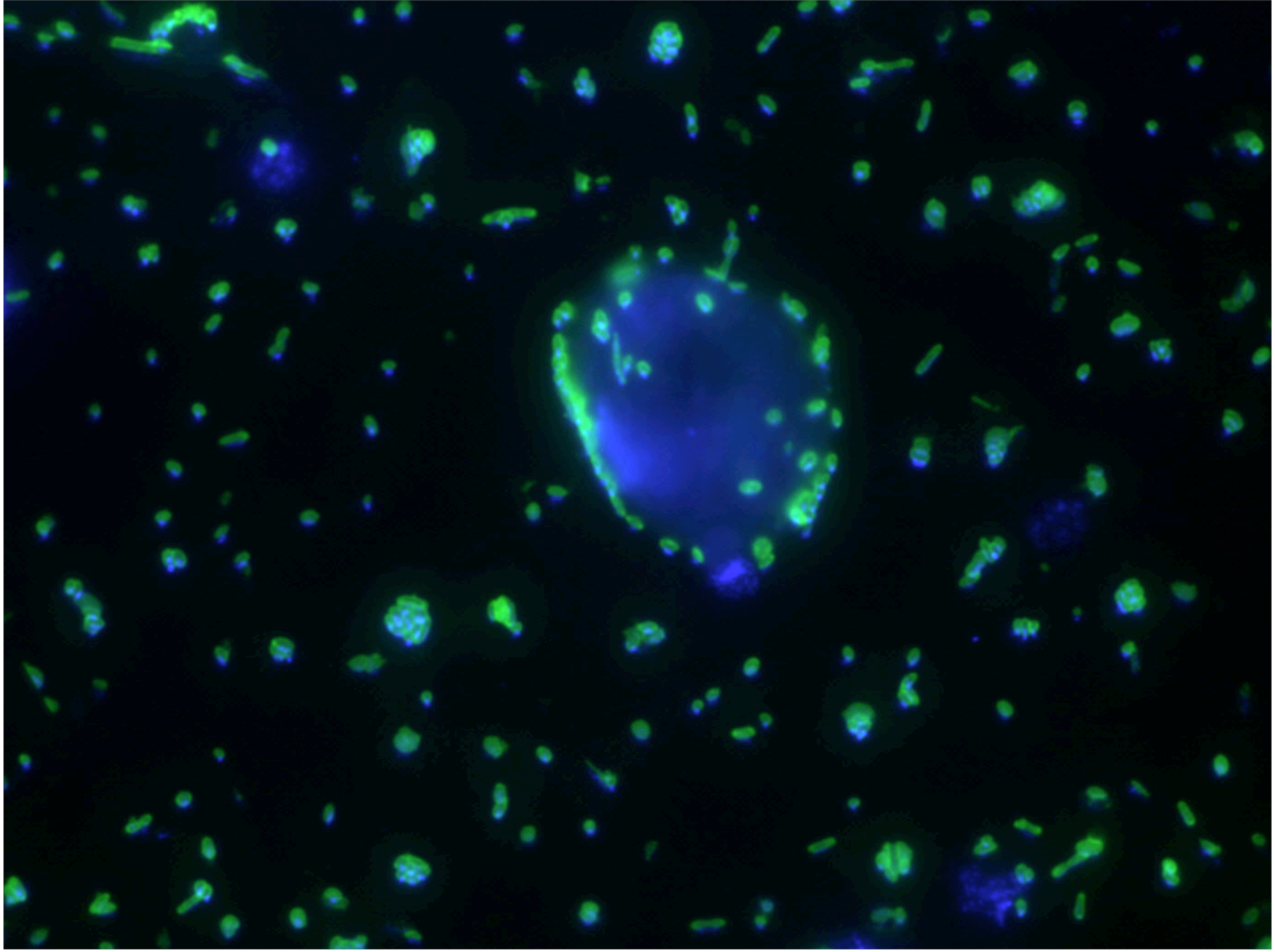

Newell et al. 2011

Ward and Zafiriou 1988, redrawn in Ward 2008

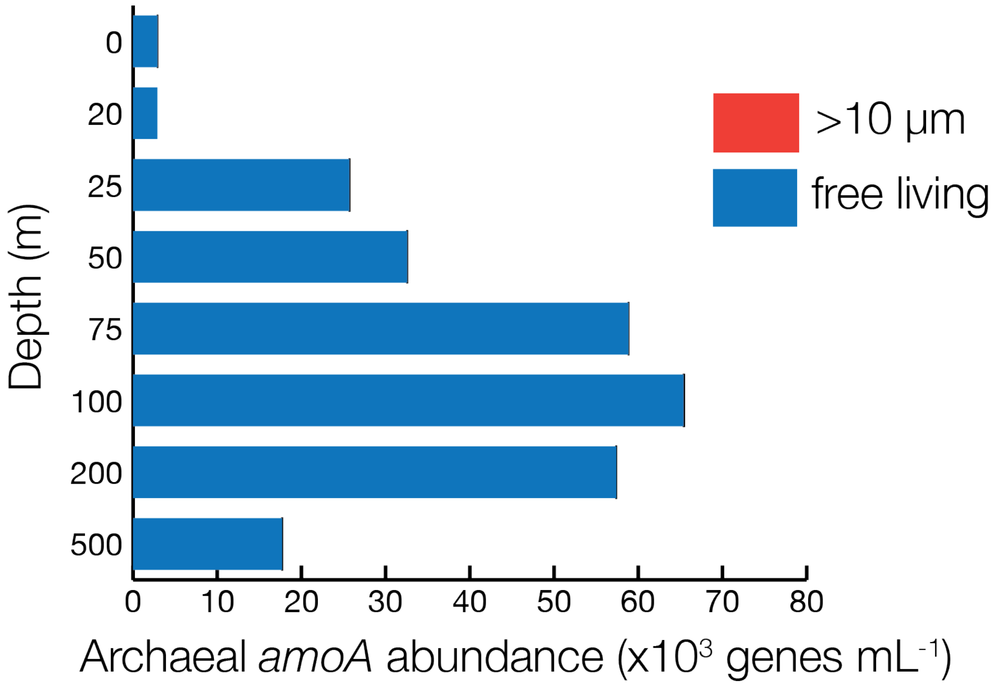


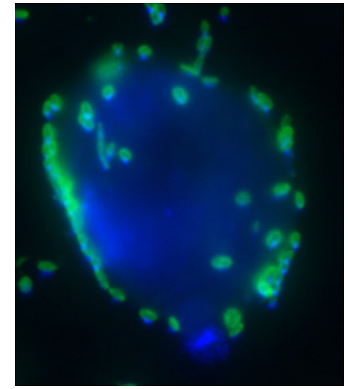




PIs: Karen Casciotti, Doug Capone, Will Berelson, Angie Knapp
Collaborators: Carly Buchwald and Rachel Foster

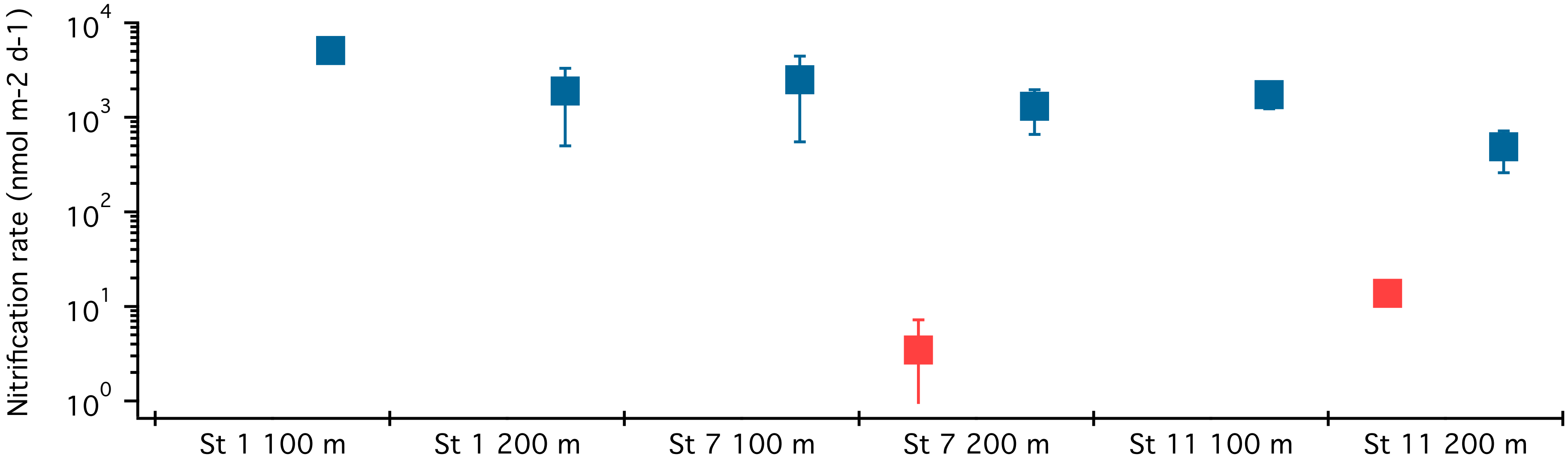


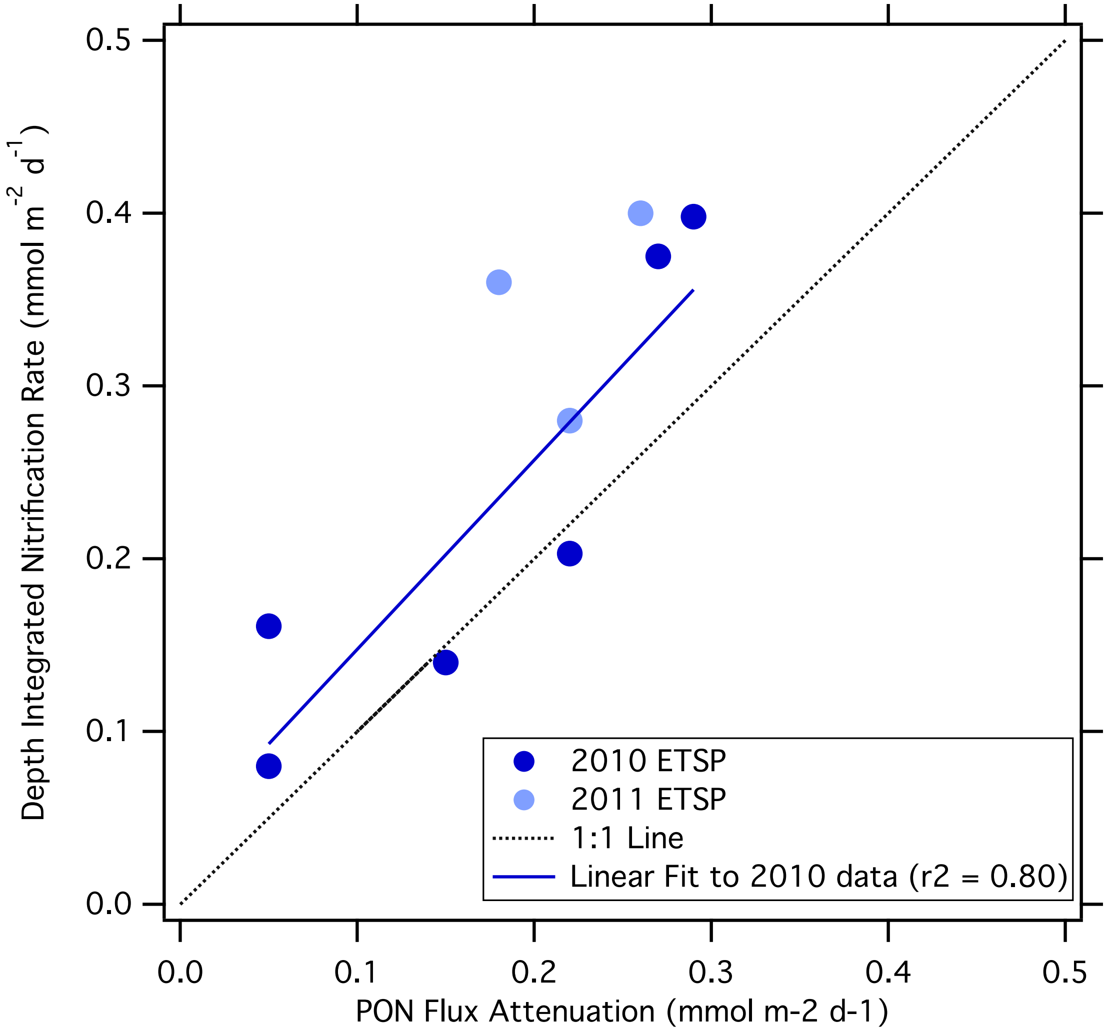
Foster, Santoro, and Berelson unpublished



5/6 trap samples:
No detectable AOA or NOB.

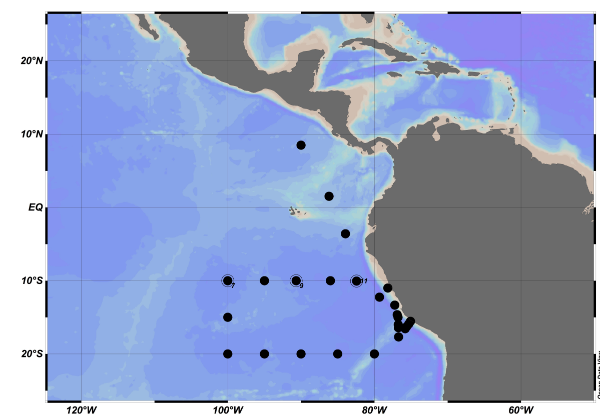


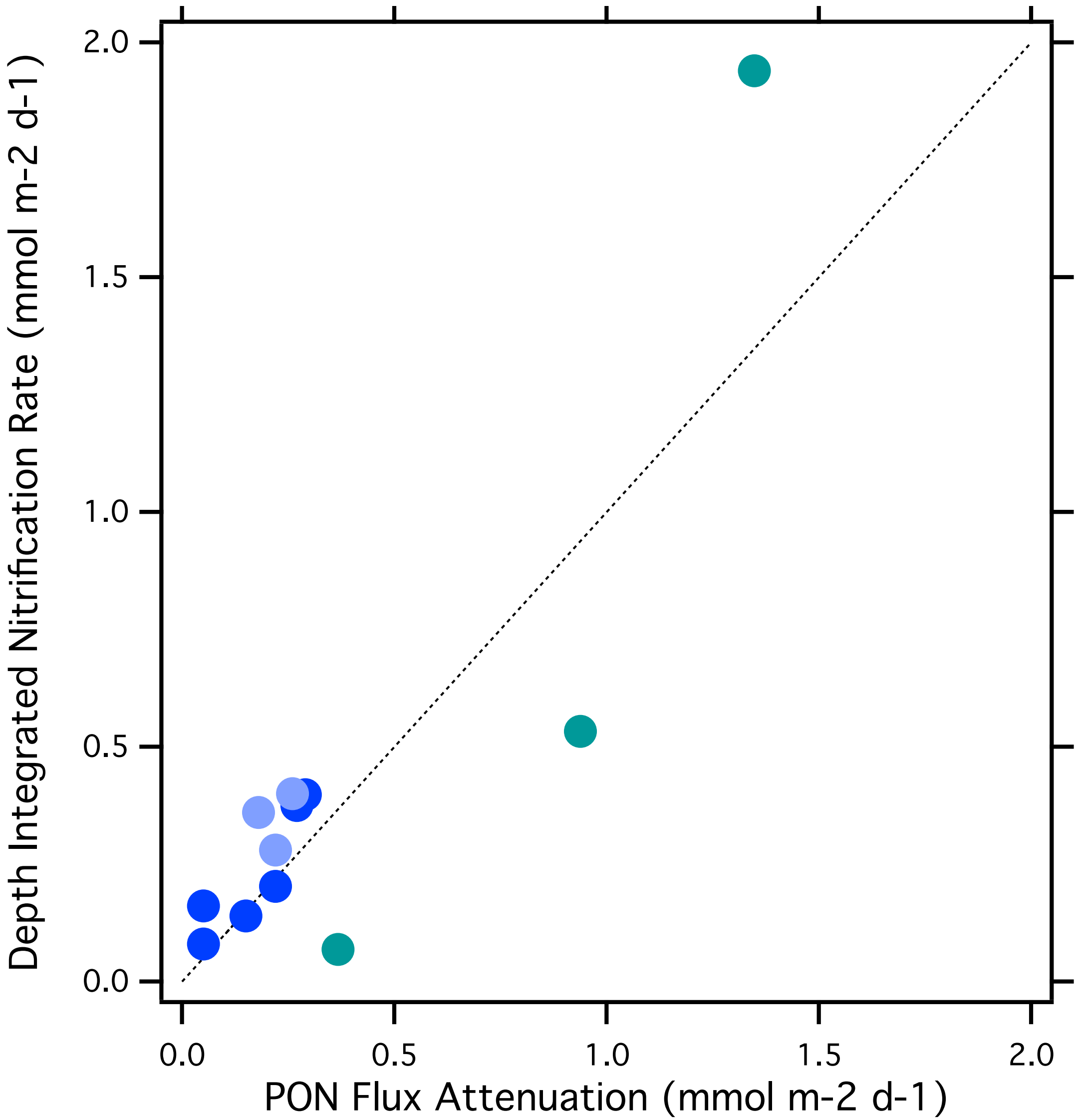



Trap data: Will Berelson (USC)

Depth integrated nitrification from the base of the euphotic zone to 200 m.

PON loss over the same interval.

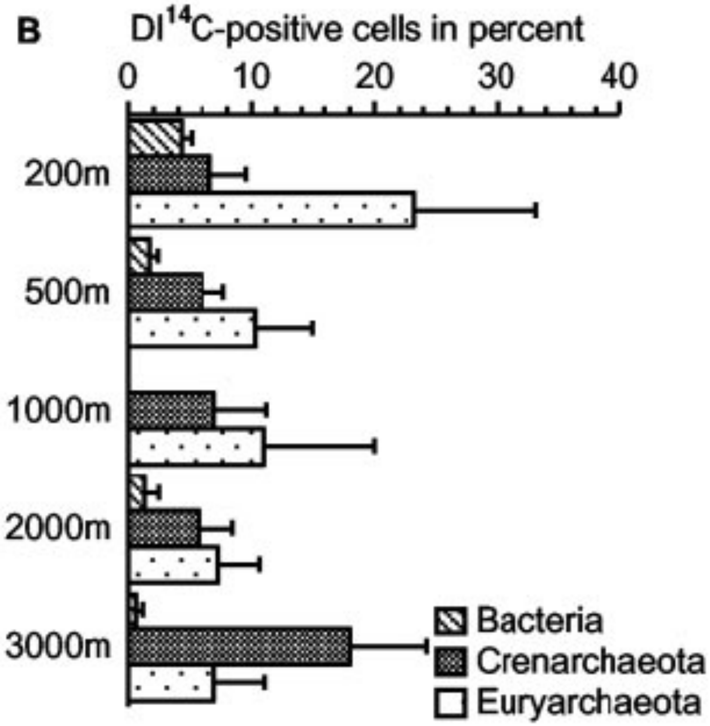





Trap PON loss is balanced by nitrification rate.

METZYME Flux data: Carl Lamborg

# How much autotrophy in the mesopelagic could be fueled by nitrification?




$6.5 \times 10^{13}$ mol C $y^{-1}$
(0.8 Pg $y^{-1}$)

Herndl et al. 2005

Carbon export: 6 Pg C $y^{-1}$
*(Siegel et al. 2014)*

Nitrogen export: 0.91 Pg N $y^{-1}$

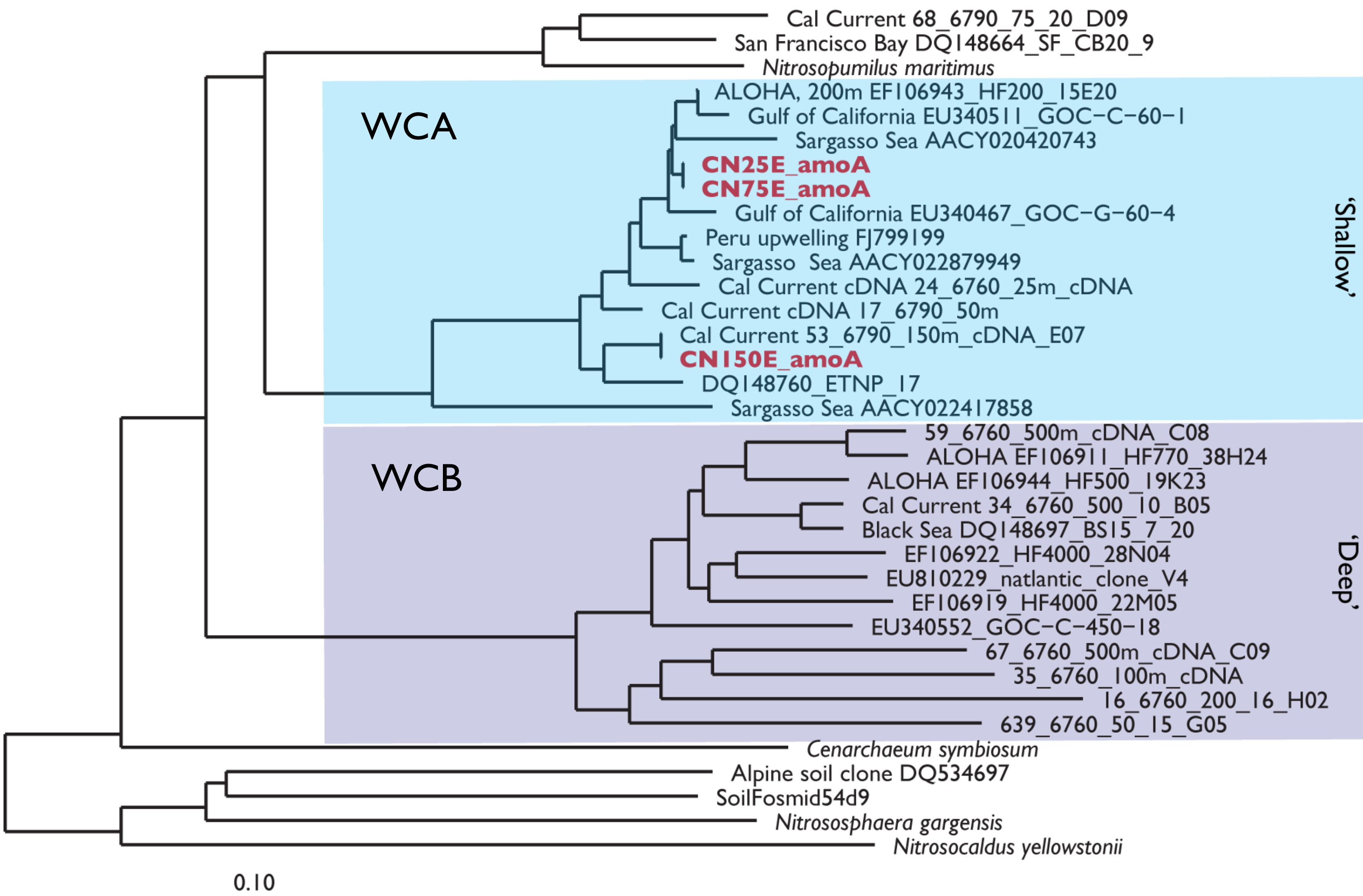
C fix:N ox for AOA: 1:19
*(Könneke et al. 2014)*

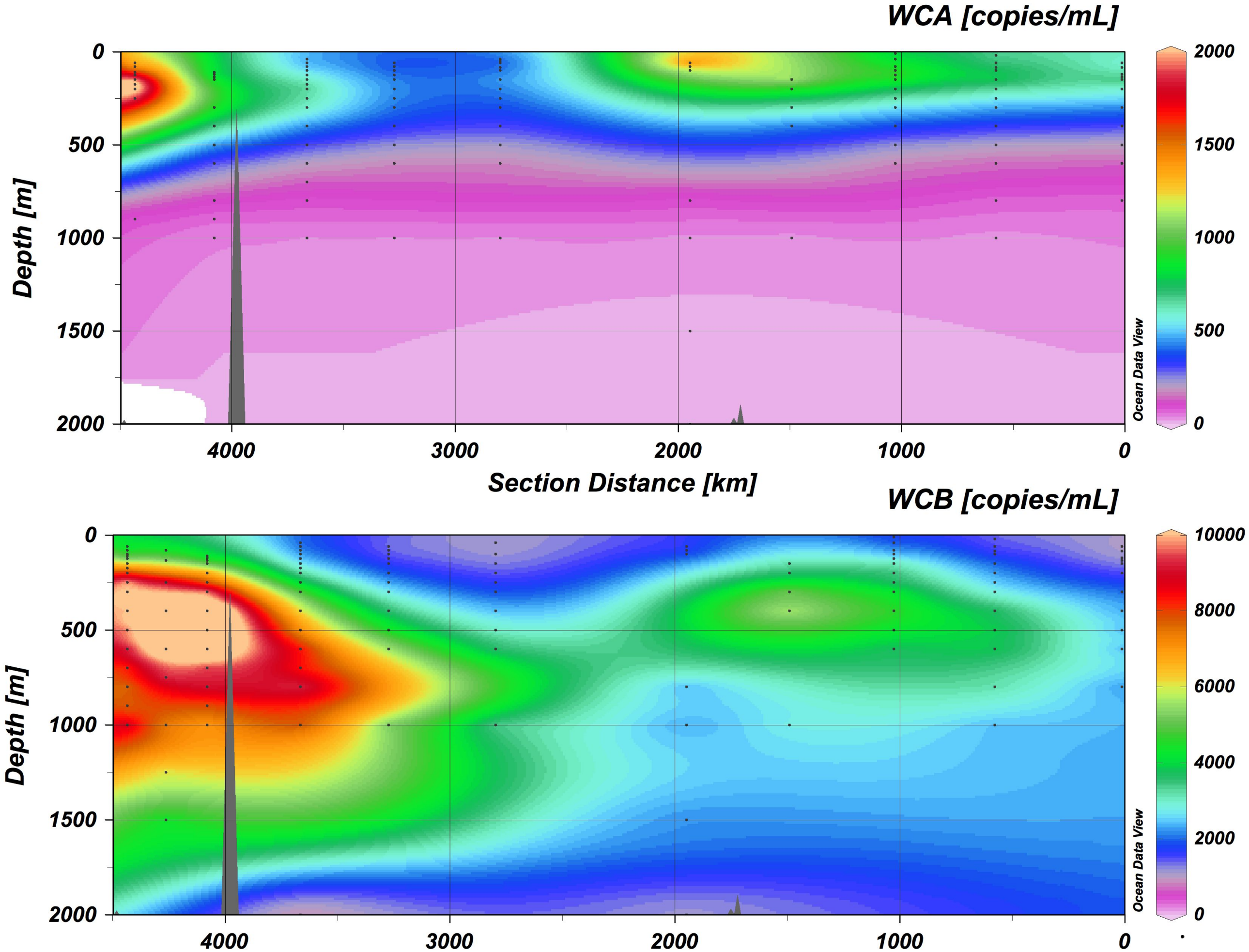
**0.05 Pg C $y^{-1}$ fixed by AOA**
**0.01 Pg C $y^{-1}$ fixed by NOB**

Or about 7% of proposed mesopelagic C fixation.

What do the microbes themselves tell us about the mesopelagic?

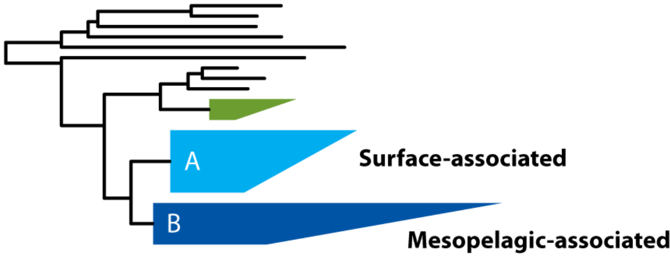
# Two clades of AOA in the open ocean

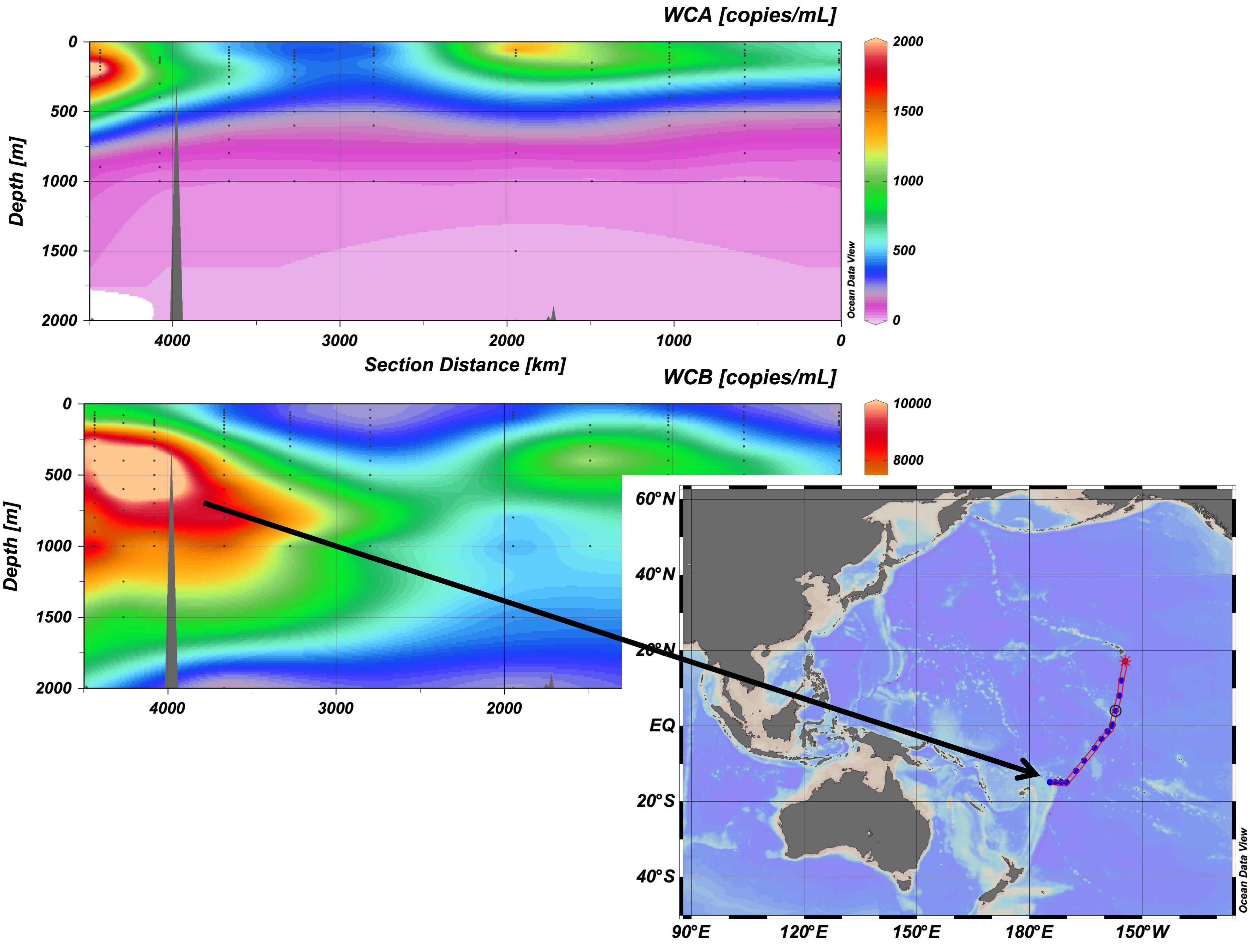




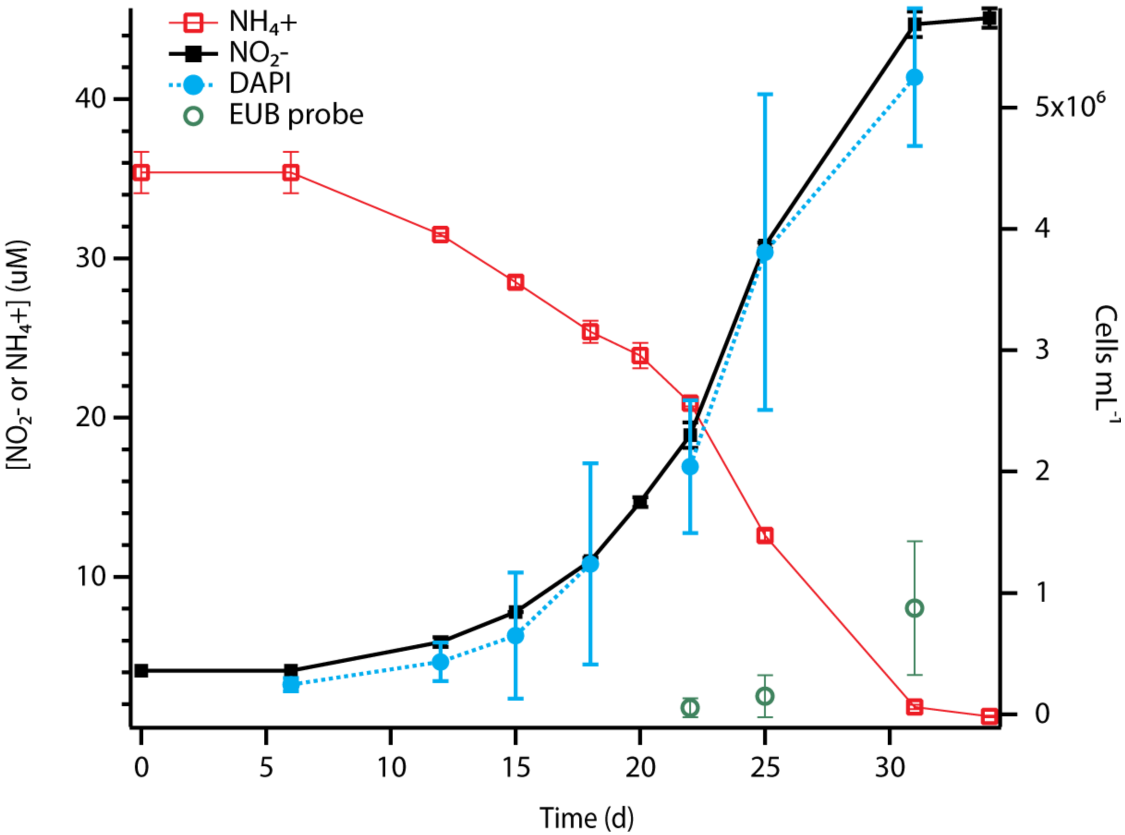

Depth partitioning of AOA ecotypes across the Western Equatorial Pacific.

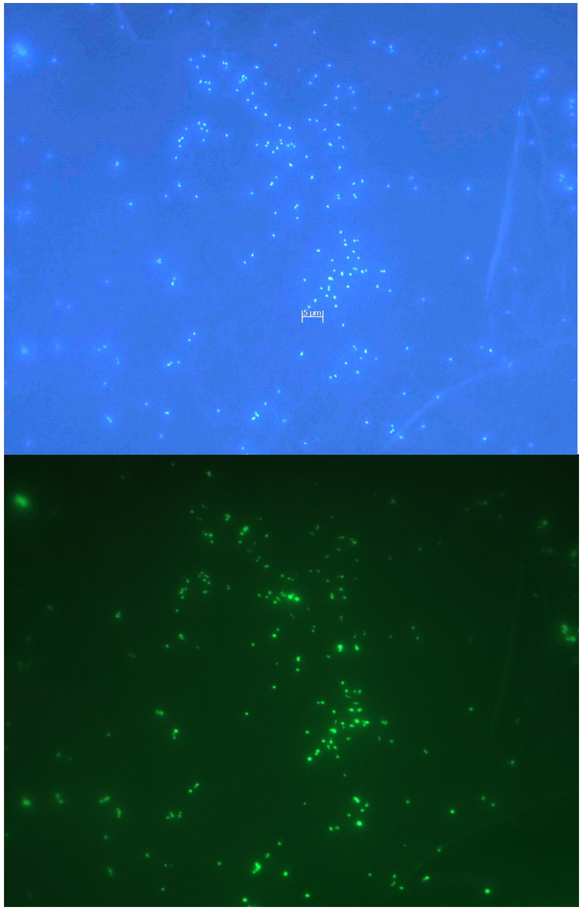
But what do these ecotypes mean?




WCA [copies/mL]
Depth [m]
Section Distance [km]
Ocean Data View
WCB [copies/mL]
Depth [m]
60°N
40°N
20°N
EQ
20°S
40°S
90°E
120°E
150°E
180°E
150°W
Ocean Data View

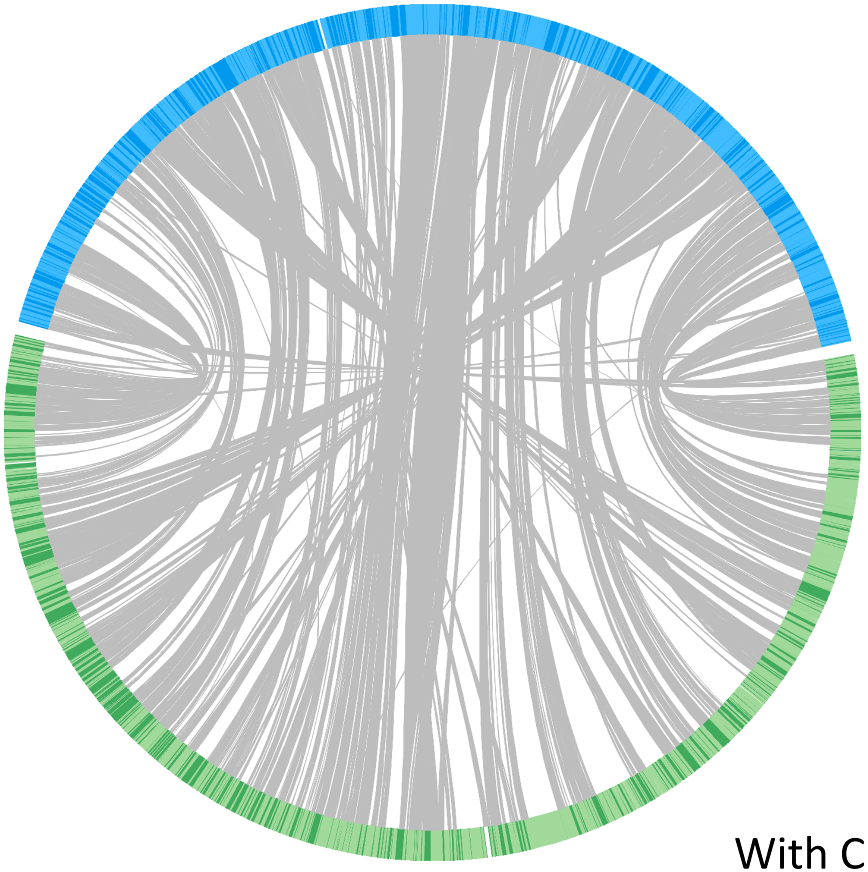
# Only four AOA cultures from the open ocean



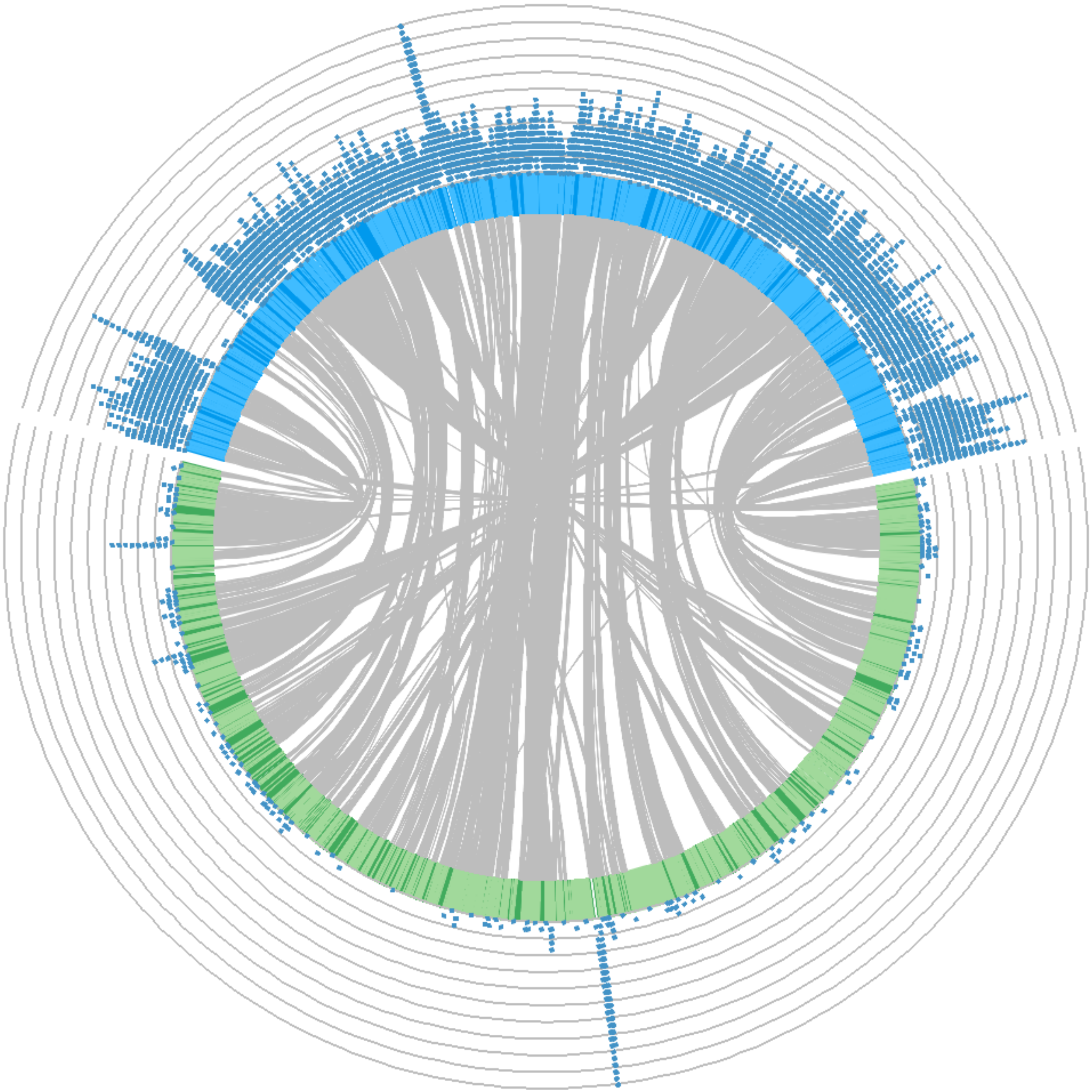



Growth rate = 0.17 $d^{-1}$ , doubling time ~4 d

Santoro and Casciotti, 2011; *ISMEJ*



With Chris Dupont (JCVI) and Mak Saito (WHOI)



GOS data mapped at 90% nucleotide ID

The abundance of ammonia oxidizers (AOA) and nitrite oxidizers (NOB) are tightly coupled in the mesopelagic, and the abundance of specific clades can be correlated with rates.

PON flux and nitrogen remineralization can be balanced in the upper mesopelagic.

The distribution of microorganisms in the mesopelagic may tell us about the processes happening there, but we lack cultures of representative organisms with which to fully interpret the data.

# Funding sources

<u>California Current:</u>

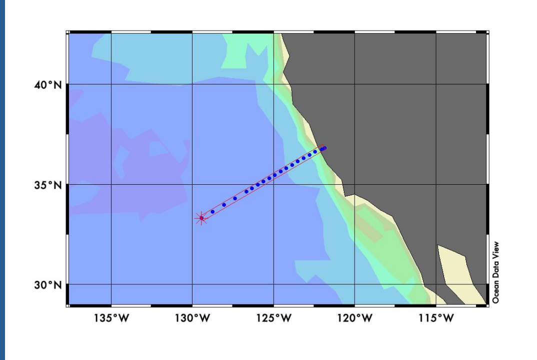
- WHOI Postdoctoral Fellowship

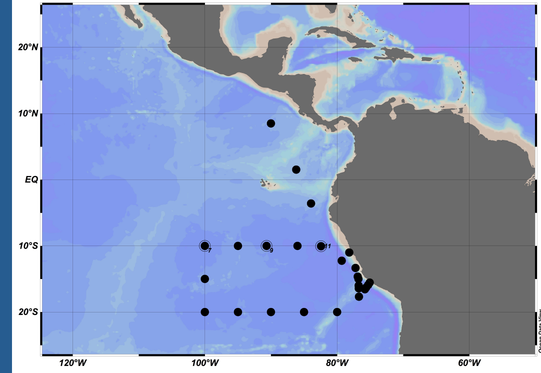
<u>ETSP and METZYME:</u>

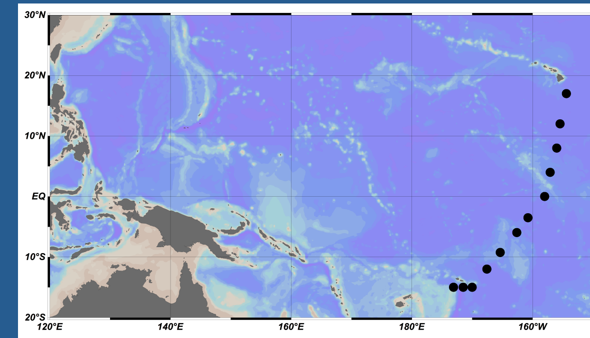
- NSF Bio OCE
- NSF Chem Oce
- UMCES start up funds

<u>Culture work:</u>

- WHOI Ocean Life Institute
- NSF Bio OCE




Marguerite Blum (MBARI)
Francisco Chavez (MBARI)
Chris Francis (Stanford)
Ken Johnson (MBARI)
Tim Pennington (MBARI)
Josh Plant (MBARI)
Jason Smith (MBARI)
Carole Sakamoto (MBARI)
Alexandra Worden (MBARI)
R/V *Western Flyer*

Carly Buchwald (WHOI)
Karen Casciotti (Stanford)

Doug Capone (USC)
Will Berelson (USC)
Rachel Foster
Will Haskell (USC)
Angie Knapp (FSU)
Matt McIlvin (WHOI)
Masha Prokopenko (Pomona)
Nick Rollins (USC)
R/V *Atlantis*
R/V *Melville*

Carl Lamborg (WHOI)
Mak Saito (WHOI)

R/V *Kilo Moana*