OCB Workshop, Rutgers University 3-6th March 2019
"Towards a better understanding of fish contribution to carbon flux"

FORMS OF CARBON - INORGANIC CARBON

Gut production and excretion of calcium carbonate by marine fish

Prof. Rod W. Wilson

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UNIVERSITY OF EXETER

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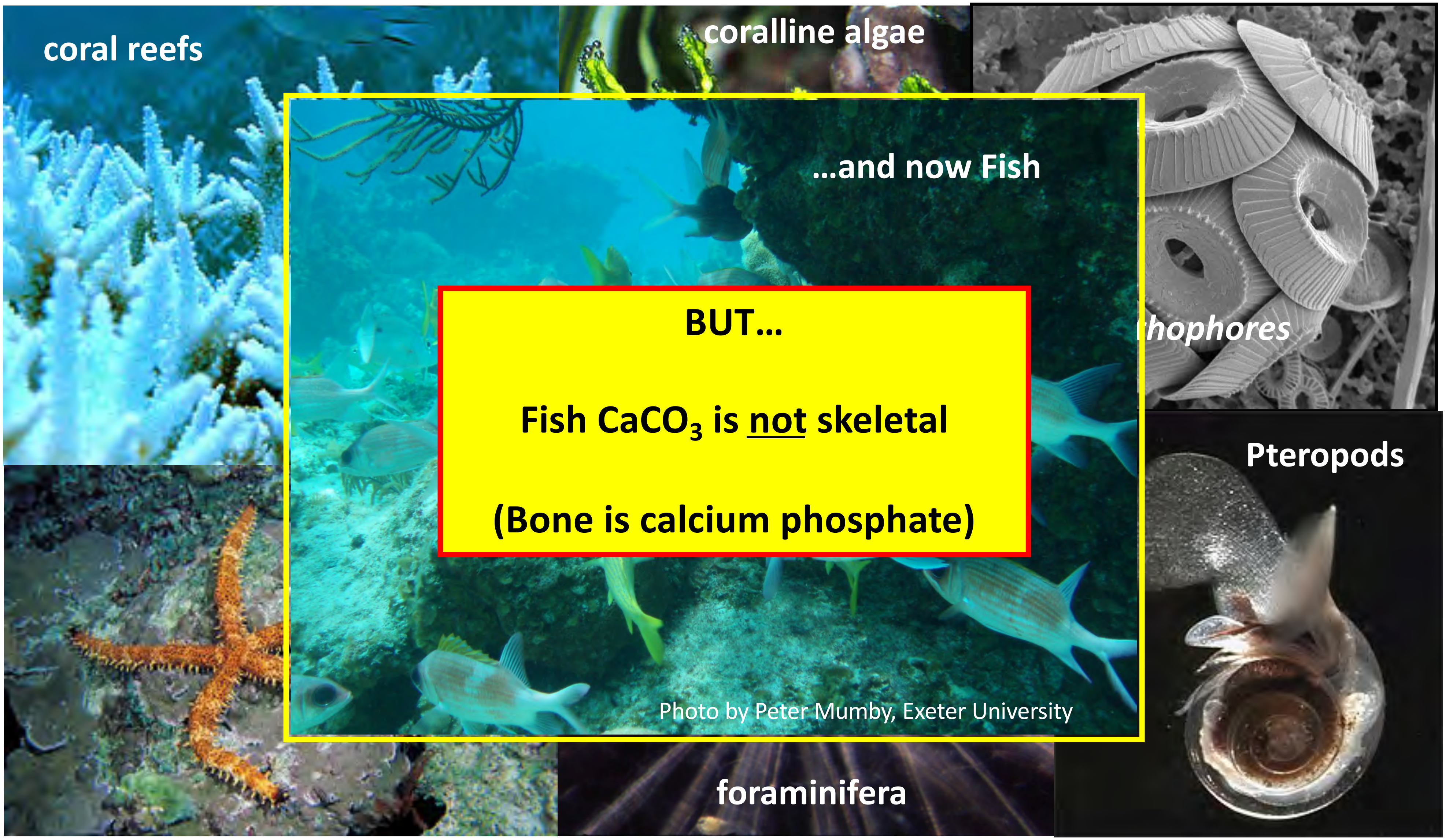
Marine Calcifiers (calcite or aragonite skeletons)



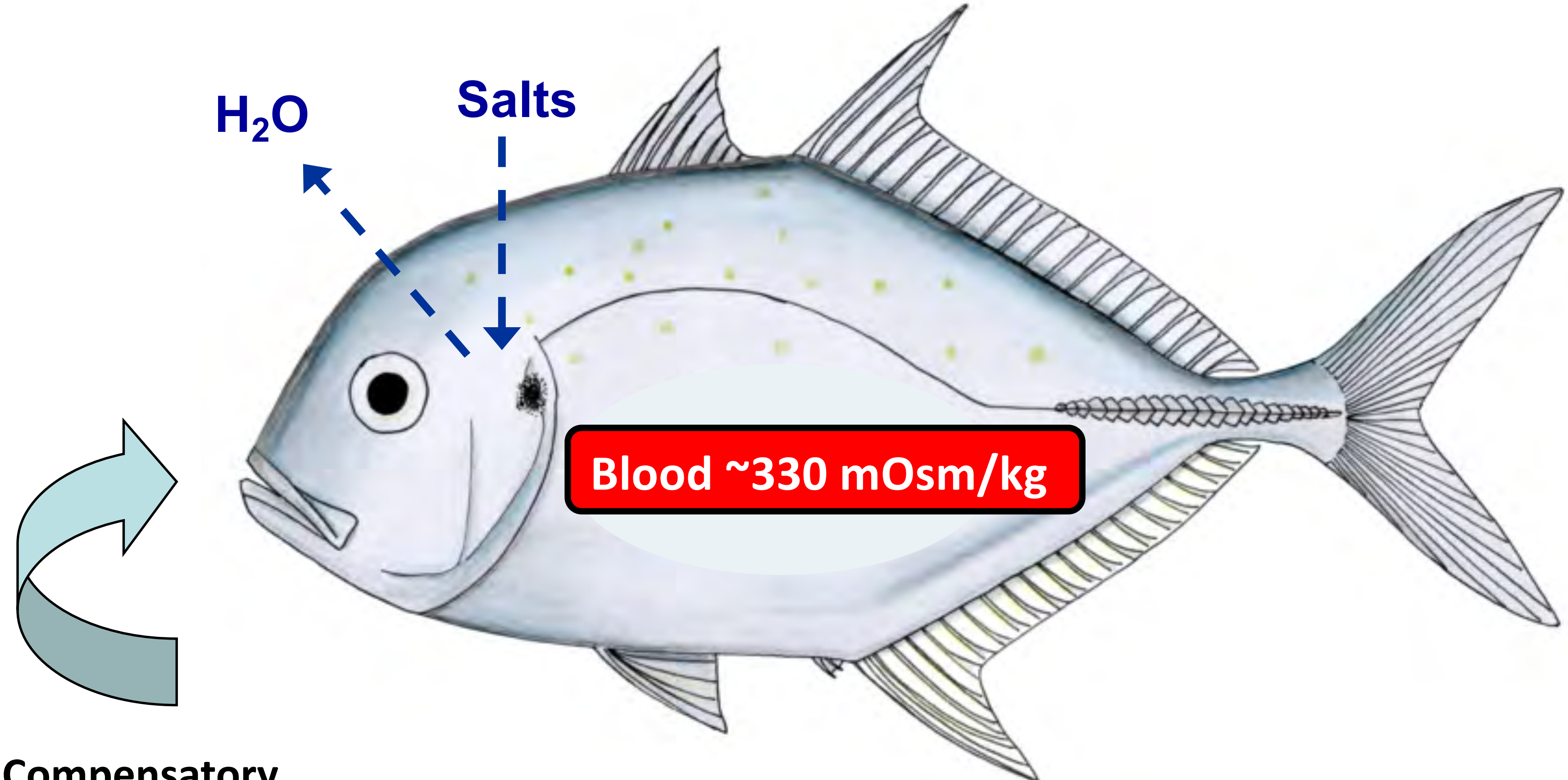
Modified from Dr. Toby Tyrell (NOC, Southampton)

1) Teleost Osmoregulation Physiology
(Why and How they do it…)

Seawater Ions (mM):

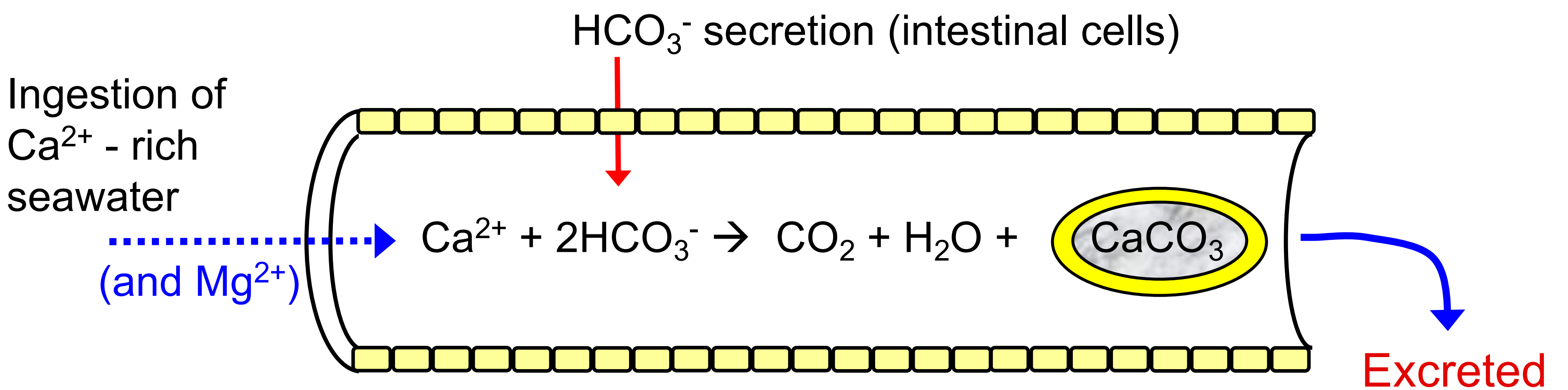
Na^+	~ 470	Cl^-	~ 550
Mg^{2+}	~ 53	SO_4^{2-}	~ 28
Ca^{2+}	~ 10		
K^+	~ 10		

Sea Water ~1050 mOsm/kg



Compensatory Drinking (1-5 ml/kg/h)

How? - Alkaline precipitation of ingested Ca^{2+} in the intestine



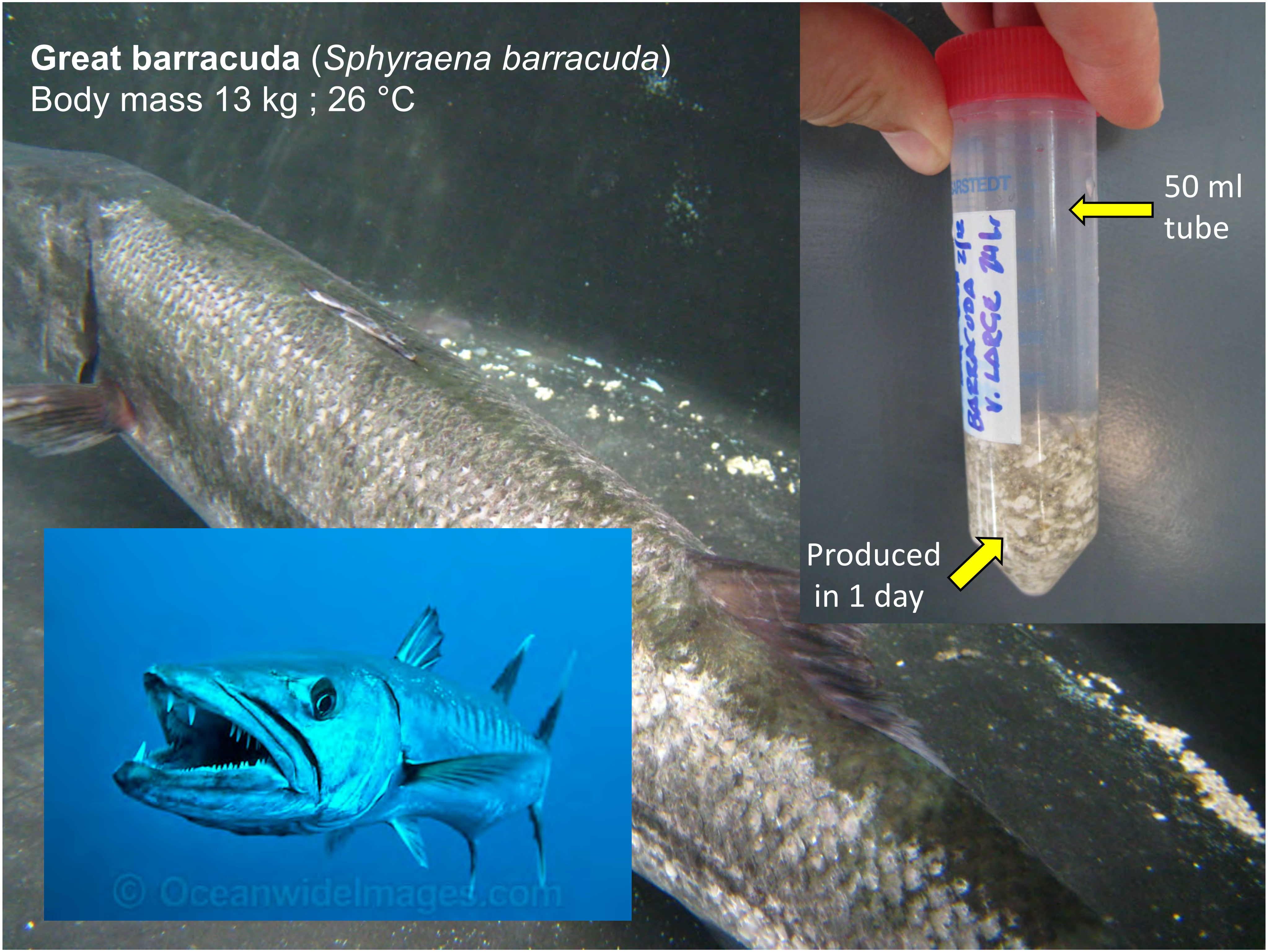
	Intestinal Fluid	Seawater
pH	8.3-9.2	8.0-8.2
$[HCO_3^-]$	30 to >100 mM	2 mM

Excreted $CaCO_3$ crystals
(and $MgCO_3$)

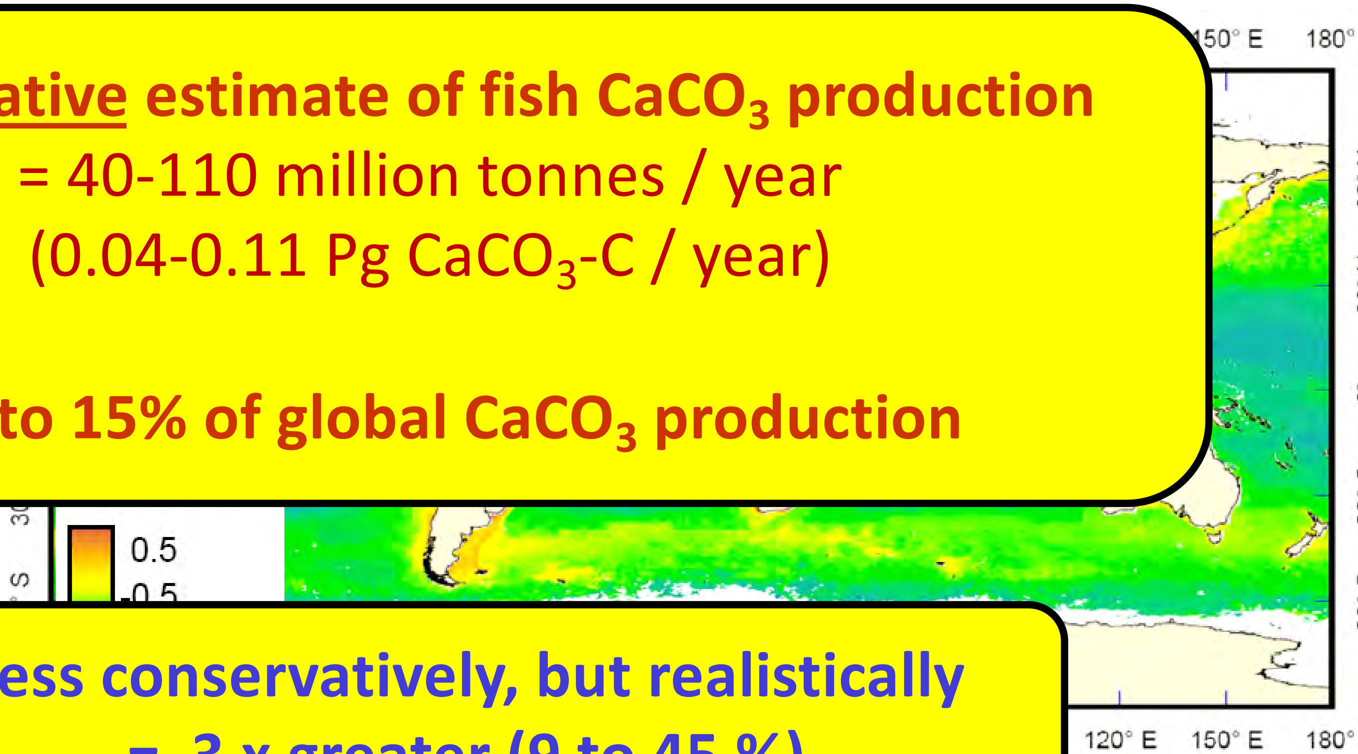
Pellets break down → high Mg calcite crystals
(Perry et al., 2011 – *PNAS*; Salter et al., 2012,2014 – *Sedimentology*)

Ellipsoidal **Straw-bundle** **Dumbbell** **Semi-spheres** **Spheres**

< 1 µm → **10-20 µm**


Great barracuda (*Sphyraena barracuda*)
Body mass 13 kg ; 26 °C
50 ml tube
Produced in 1 day
© OceanwideImages.com

Size-b
Macr
Mode
(Simo



<u>Conservative</u> estimate of fish $CaCO_3$ production

= 40-110 million tonnes / year

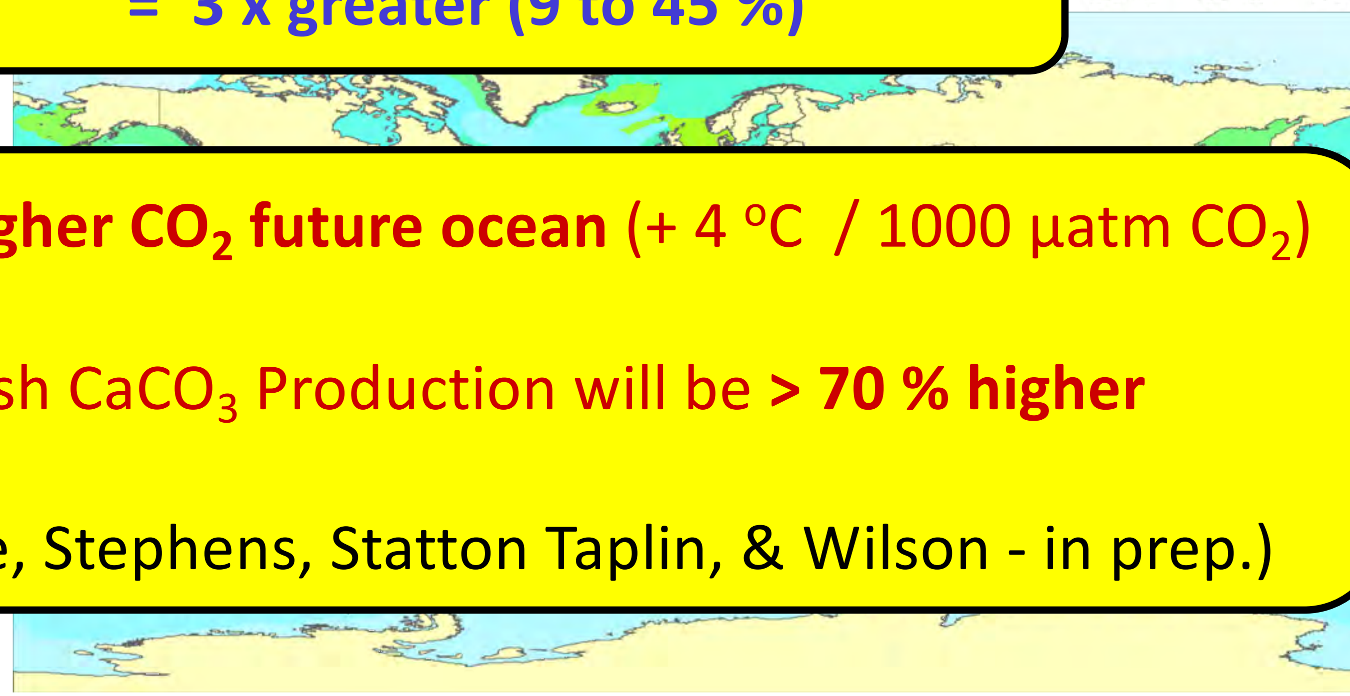
(0.04-0.11 Pg $CaCO_3$-C / year)

= 3 to 15% of global $CaCO_3$ production

Less conservatively, but realistically

= 3 x greater (9 to 45 %)

Large Marine
Ecosystems (LMEs)



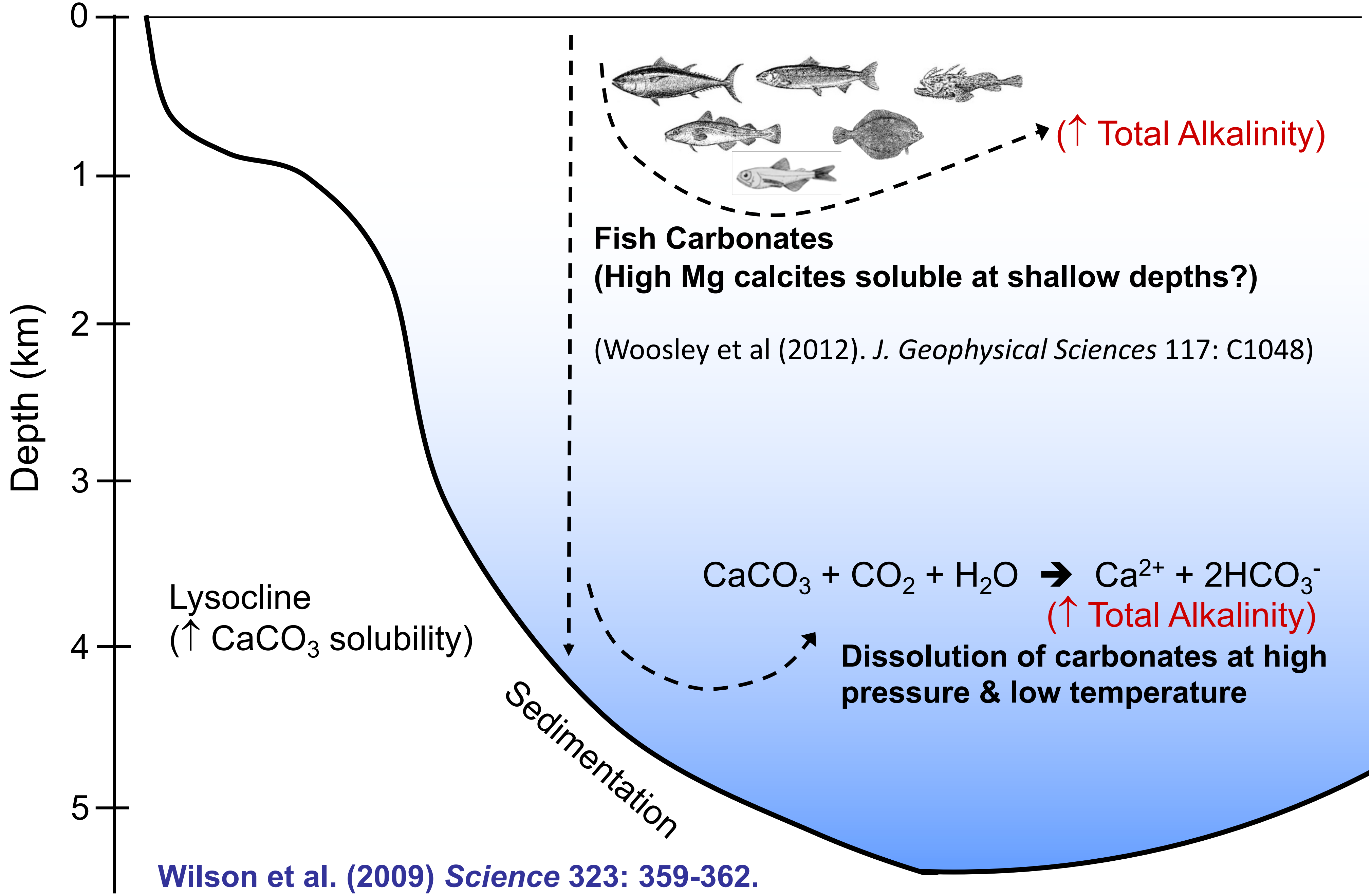
In a warmer, higher CO_2 future ocean (+ 4 °C / 1000 µatm CO_2)

Predict Fish $CaCO_3$ Production will be **> 70 % higher**

(Reardon, Cole, Stephens, Statton Taplin, & Wilson - in prep.)

Wilson et al. (2009)
Science 323: 359-362.

Rapid dissolution of fish carbonates – may explain surface ocean chemistry phenomenon

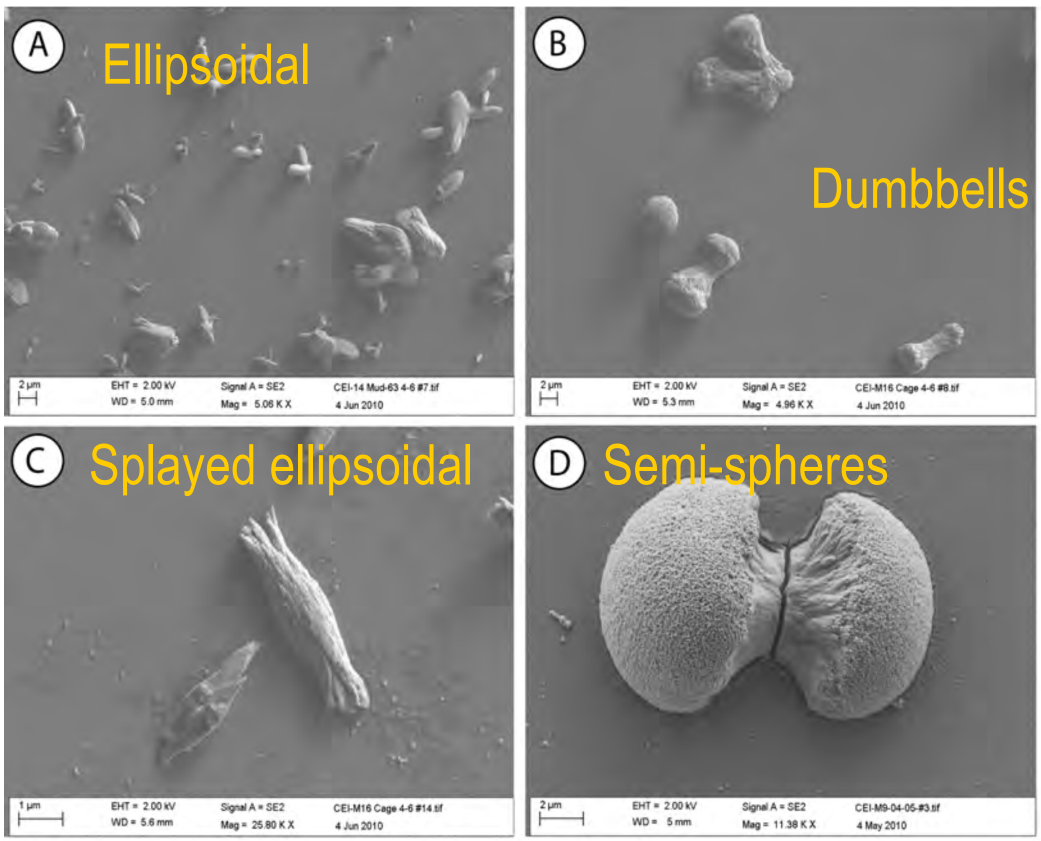


BUT … Also evidence of fish carbonate preservation in sediments

Prof. Chris Perry (Geography, UoE)

Cape Eleuthera Island
The Bahamas

- Warm
- Shallow
- Lots of fish !



Fish carbonates in sediments of <u>all</u> 7 Bahamian habitats

Bahamas Fish:

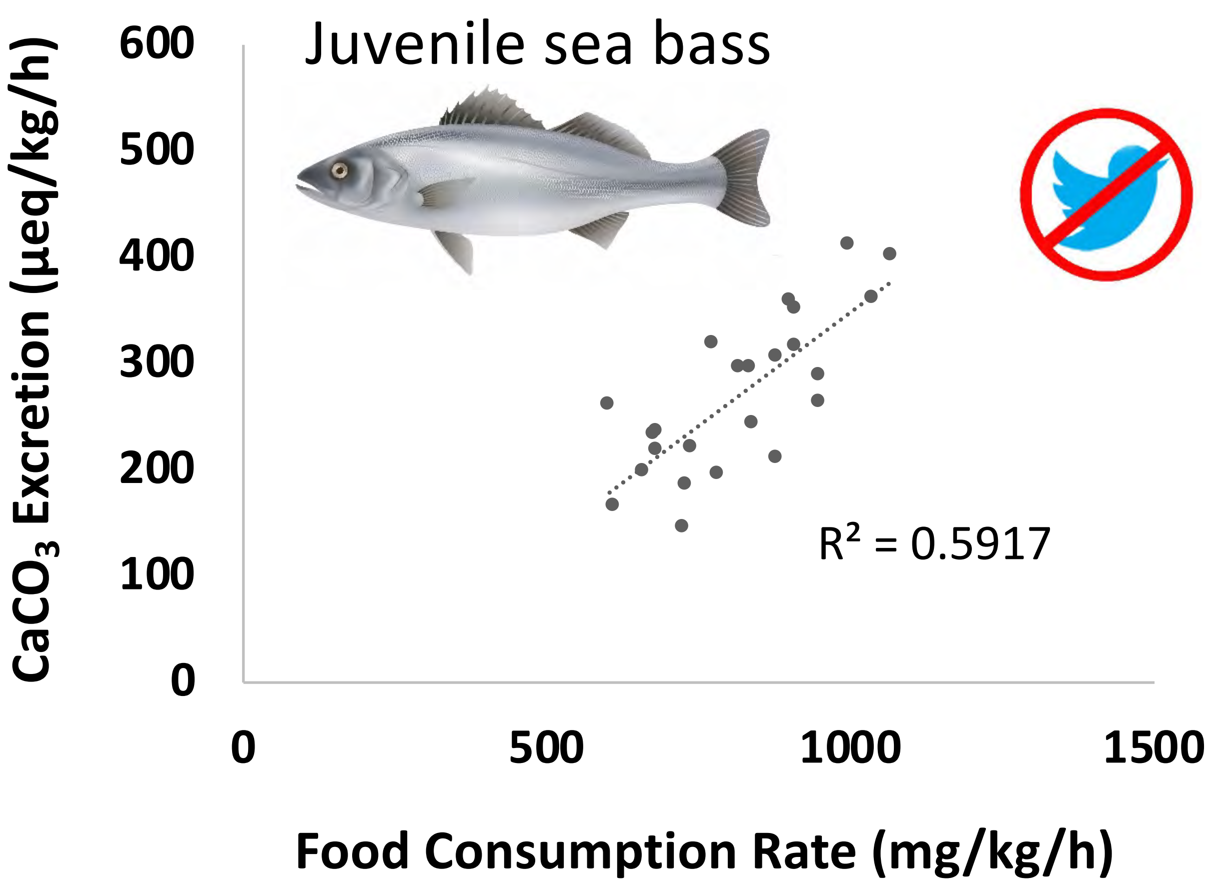
14 % of total $CaCO_3$ mud production

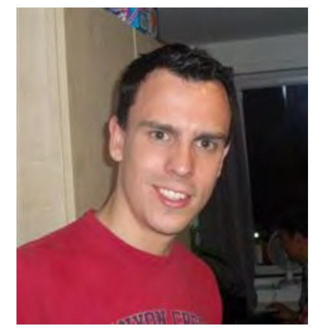
70% contribution in some habitats (e.g. Mangroves)

Perry et al. (2011) *P.N.A.S.* 108: 3865-

Effect of Feeding on $CaCO_3$ excretion rate:

1) **Proportional to individual feeding rates**
2) **Mean rate is 10-fold higher than when starved**
3) **Substantial incorporation of precipitated phosphate**

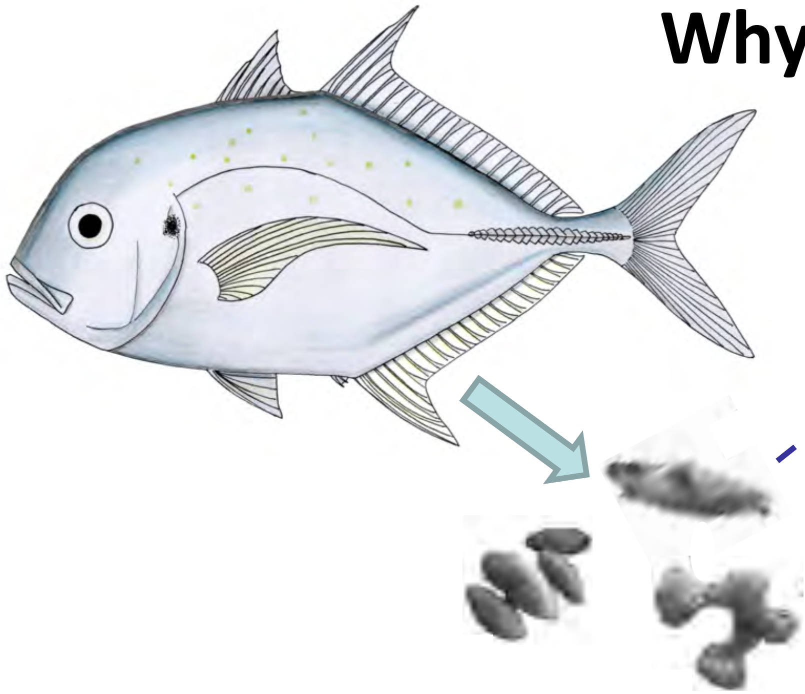




(Sam Newbatt - PhD)

(Christine Stephens - PhD)

Why does it matter?



$CaCO_3$ Dissolution

↓

↑ **Alkalinity**

(Depth this occurs at important)

Faecal $CaCO_3$ content

↓

Sinking rate of faecal pellet
(i.e. Organic C - POC)

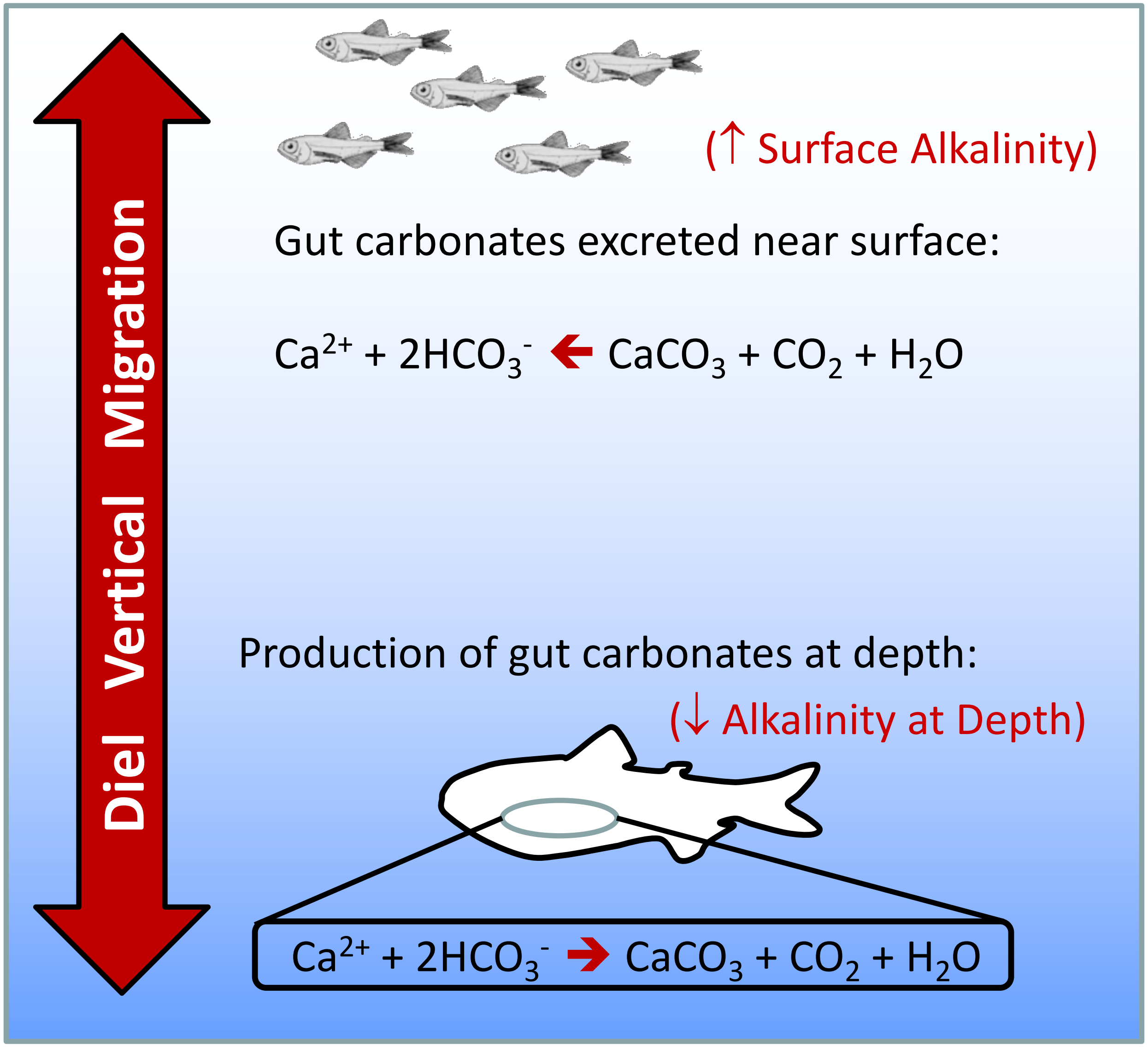
Phosphate Dissolution

↓

↑ **Nutrients**

(Role in primary productivity?)

Mesopelagic fish – Potential "Upward Alkalinity Pump"



Roberts, C.M. et al. (2017). Marine reserves can mitigate and promote adaptation to climate change. ***P.N.A.S.*** doi: 10.1073/pnas.1701262114

20 species of mid-Atlantic mesopelagic teleost fish caught at 55 and 450 m

Samples c/o Prof. Santiago Hernández León (Gran Canaria) & **Dr. Stephanie Czudaj** (Hamburg)

All species had intestinal $CaCO_3$ pellets

Dr. Erin Reardon
(Exeter)

Acknowledgements

EXETER:

Prof. Chris Perry
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Chris Cooper (PDRA)
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Christine Stephens (PhD student)
Louisa Taplin (MRes)
Chris Cobb (MSc)
Jacob Bill (MSc)
Jenna Corcoran (BSc)
Rebecca Crosta (BSc)
Katie Statton (BSc)
Jan Shears (Tech)
Grega Paull (ARC Manager)
Jo Rabineau (Tech)
Kirsty Bolt (Tech)
Eliane deBastos (Tech)
Karen Knapp (Physics, X-Ray)

OUTSIDE EXETER:

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Simon Jennings (Cefas, UK)
Villy Christensen (UBC, Canada)
Pat Walsh (Ottawa, Canada)
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BBSRC bioscience for the future
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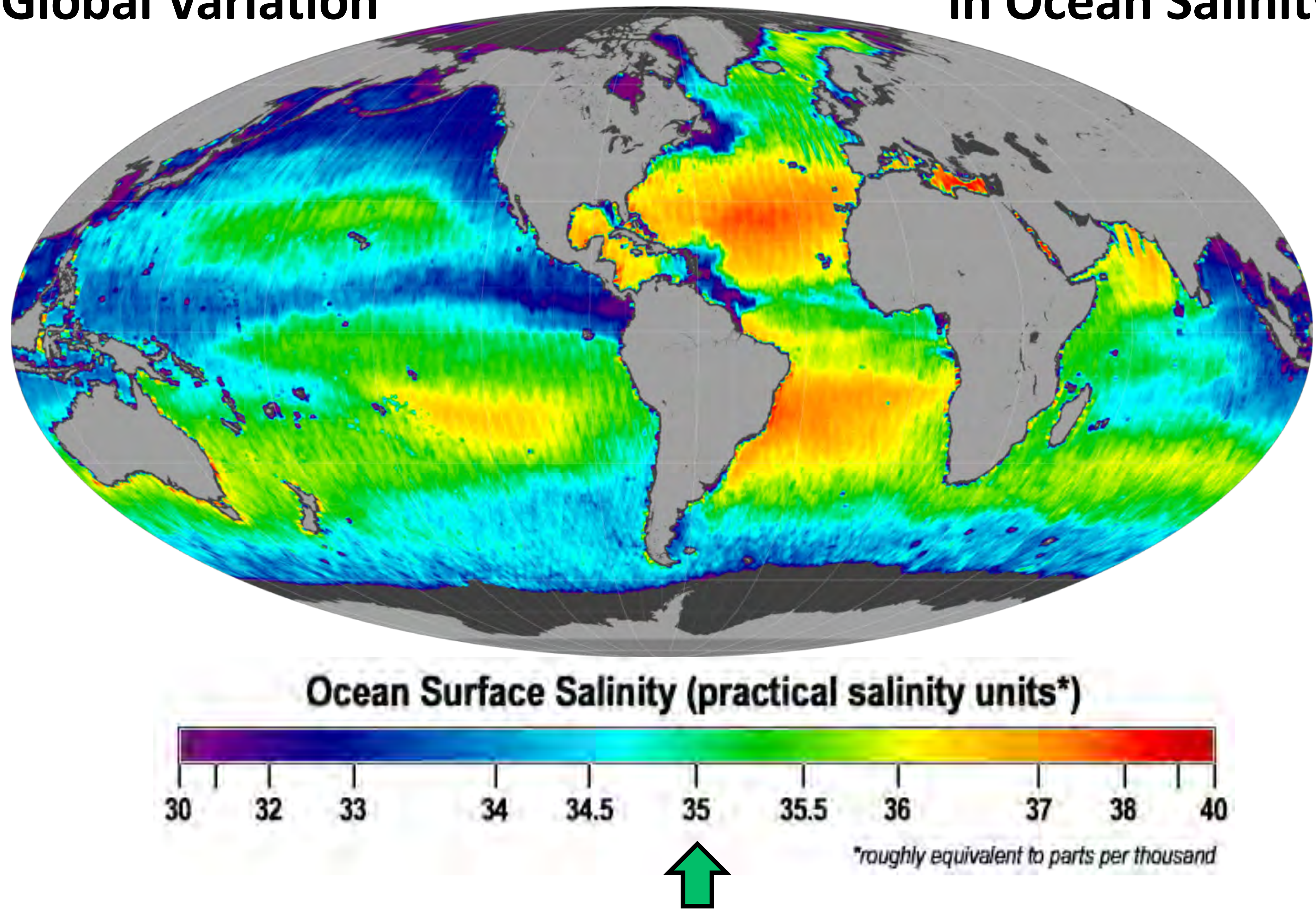
University of Exeter Strategic Development Fund

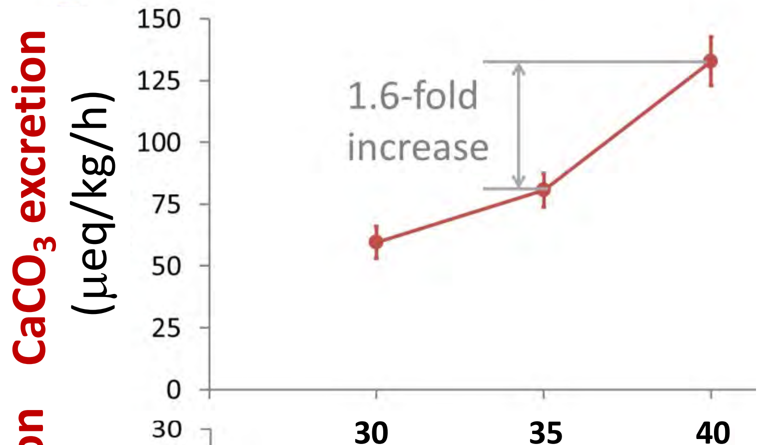
End

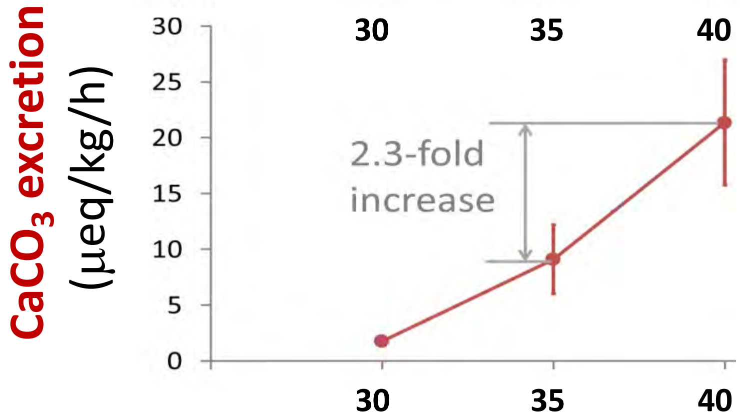
Global Variation in Ocean Salinity

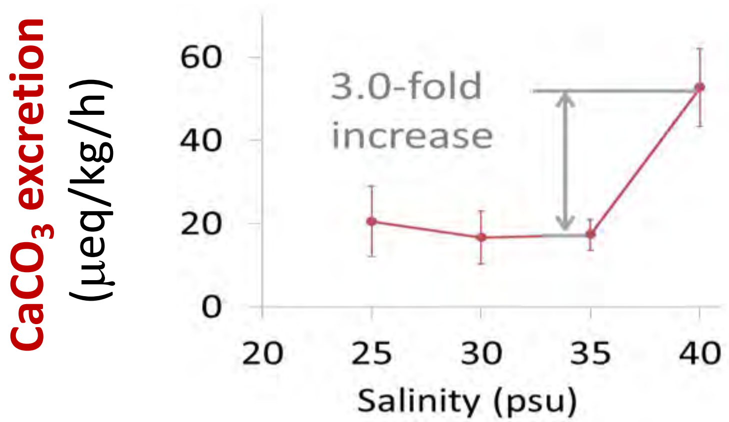


Global Ocean Mean (35 psu)

Effect of salinity on $CaCO_3$ excretion







Shanny
Lipophrys pholis

Goldsinny wrasse
Ctenolabrus rupestris

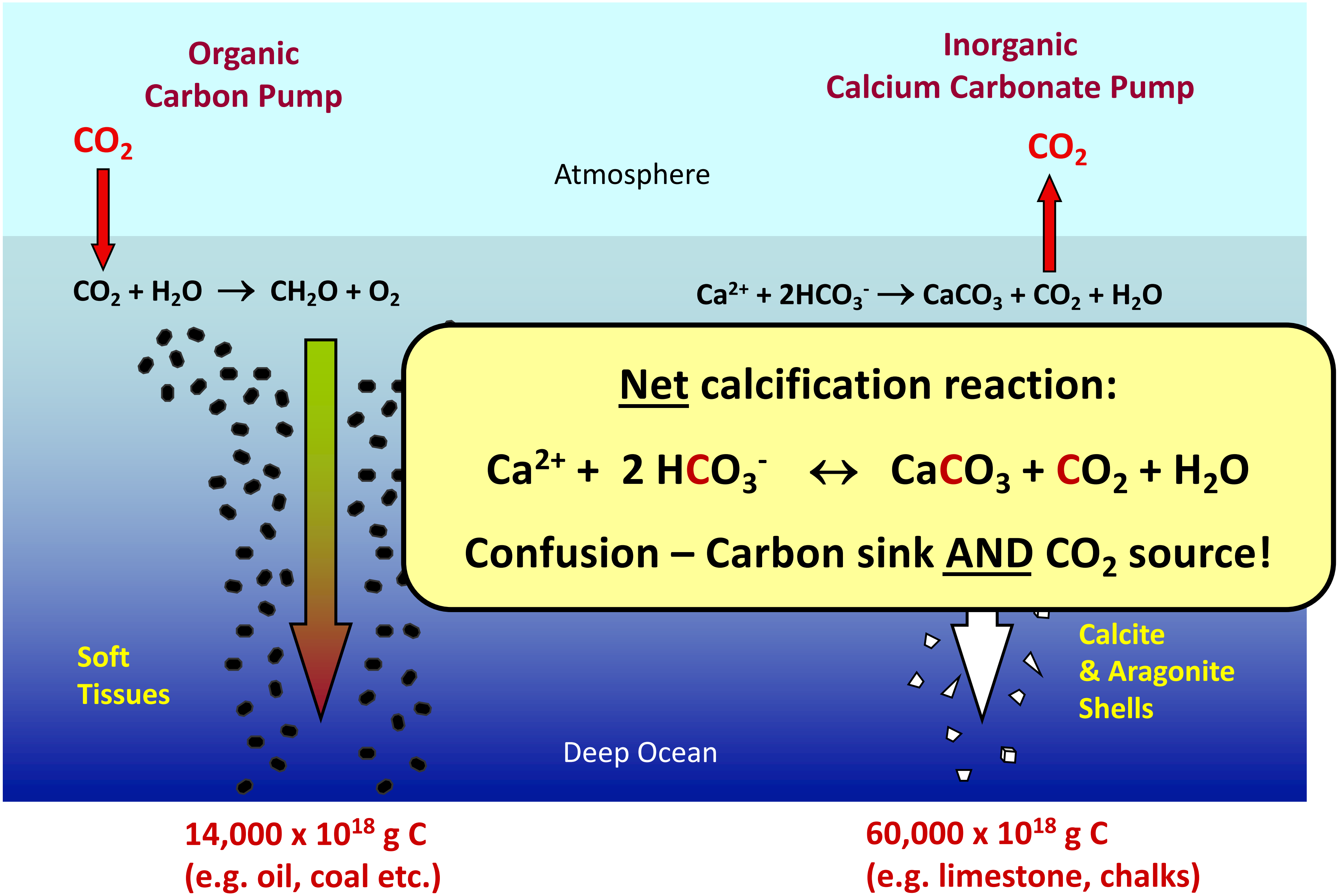
Turbot
Scopthalmus maximus

Measured:

1.6 to 3.0 x ↑ $CaCO_3$
excretion
(35 v. 40 psu)

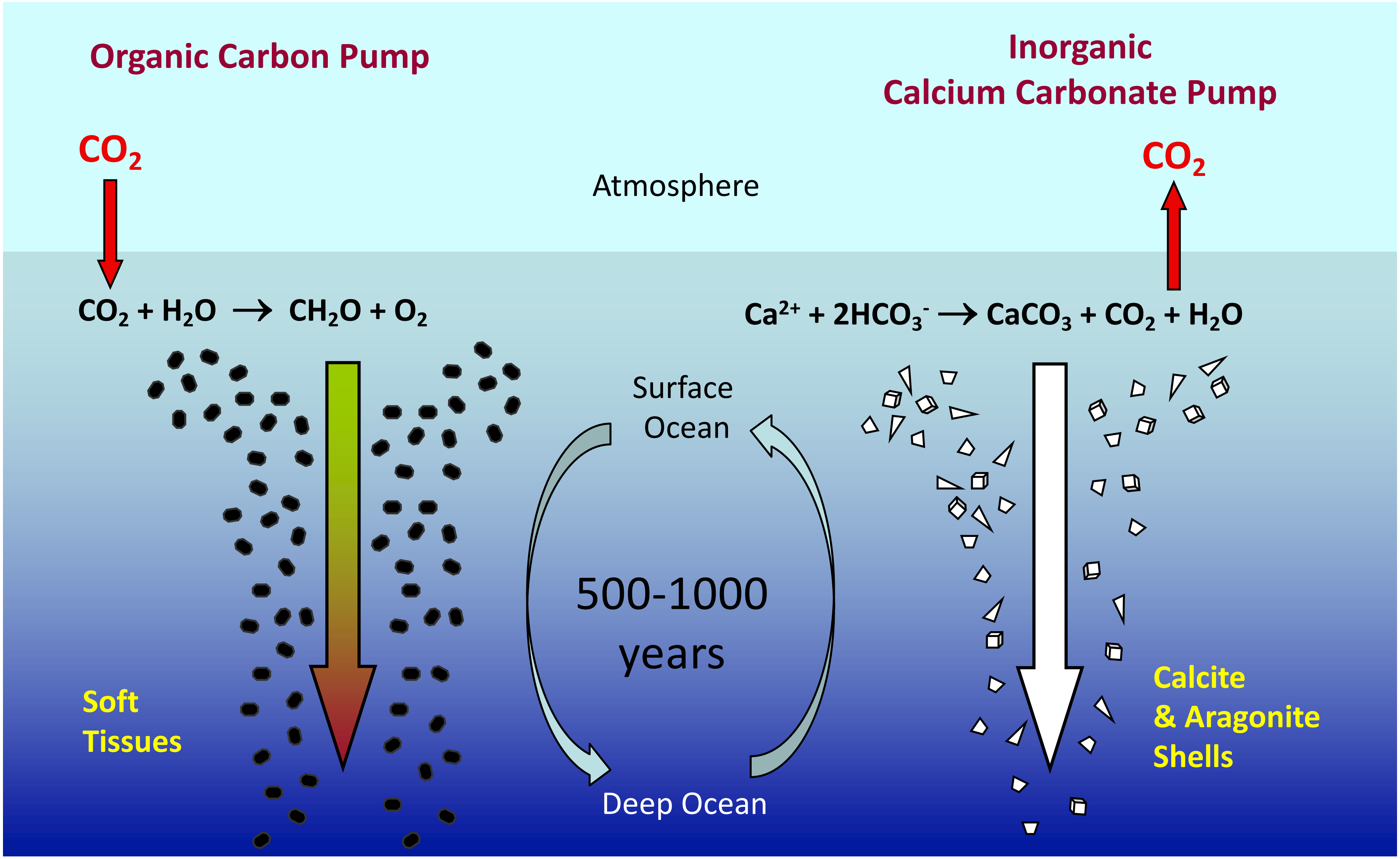
(Christine Stephens – PhD work)

Two Ocean Carbon Cycles



Redrawn after Toby Tyrell (National Oceanography Centre, Southampton)

Two Ocean Carbon Cycles



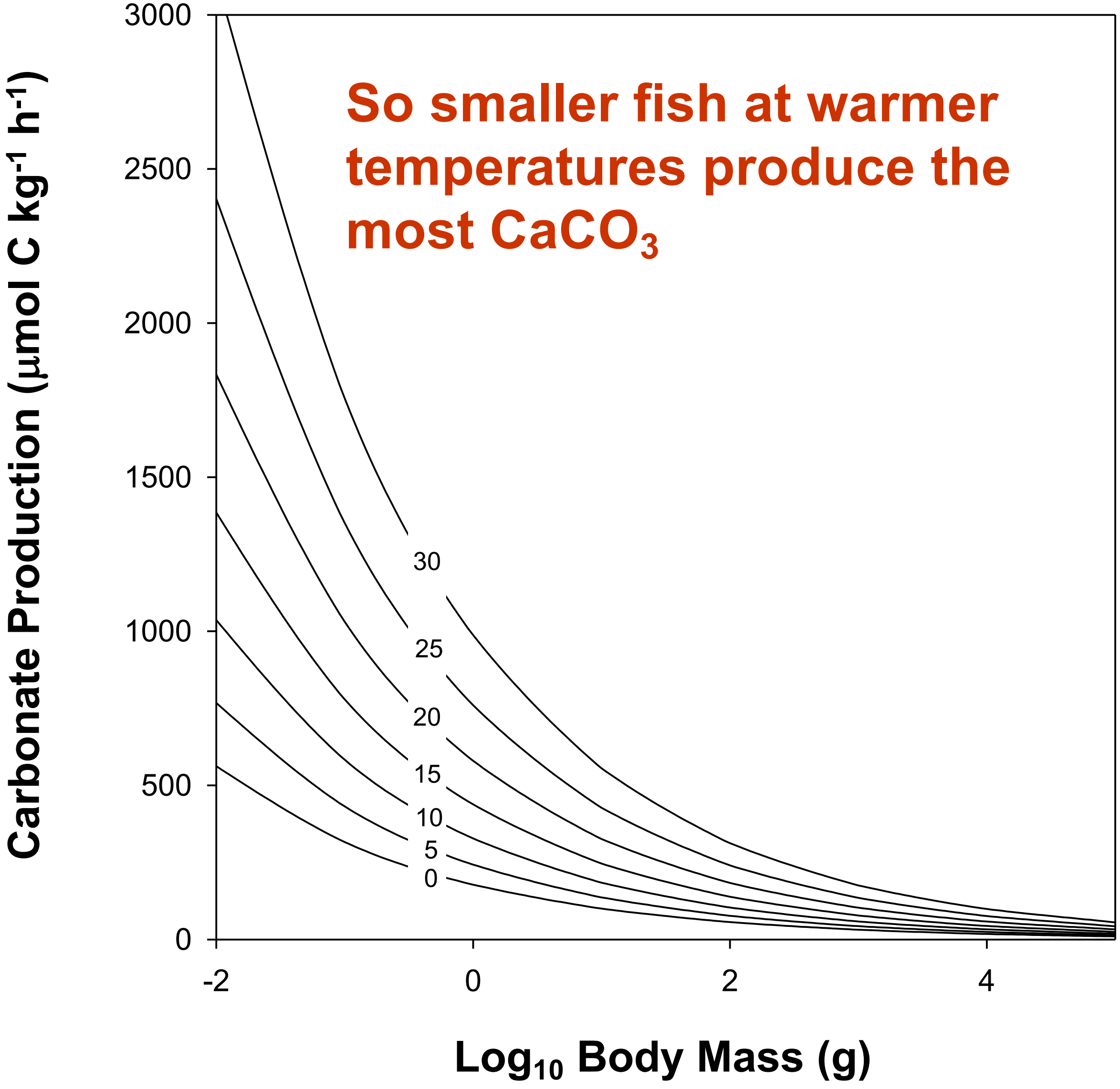
14,000 x 10^{18} g C
(e.g. oil, coal etc.)

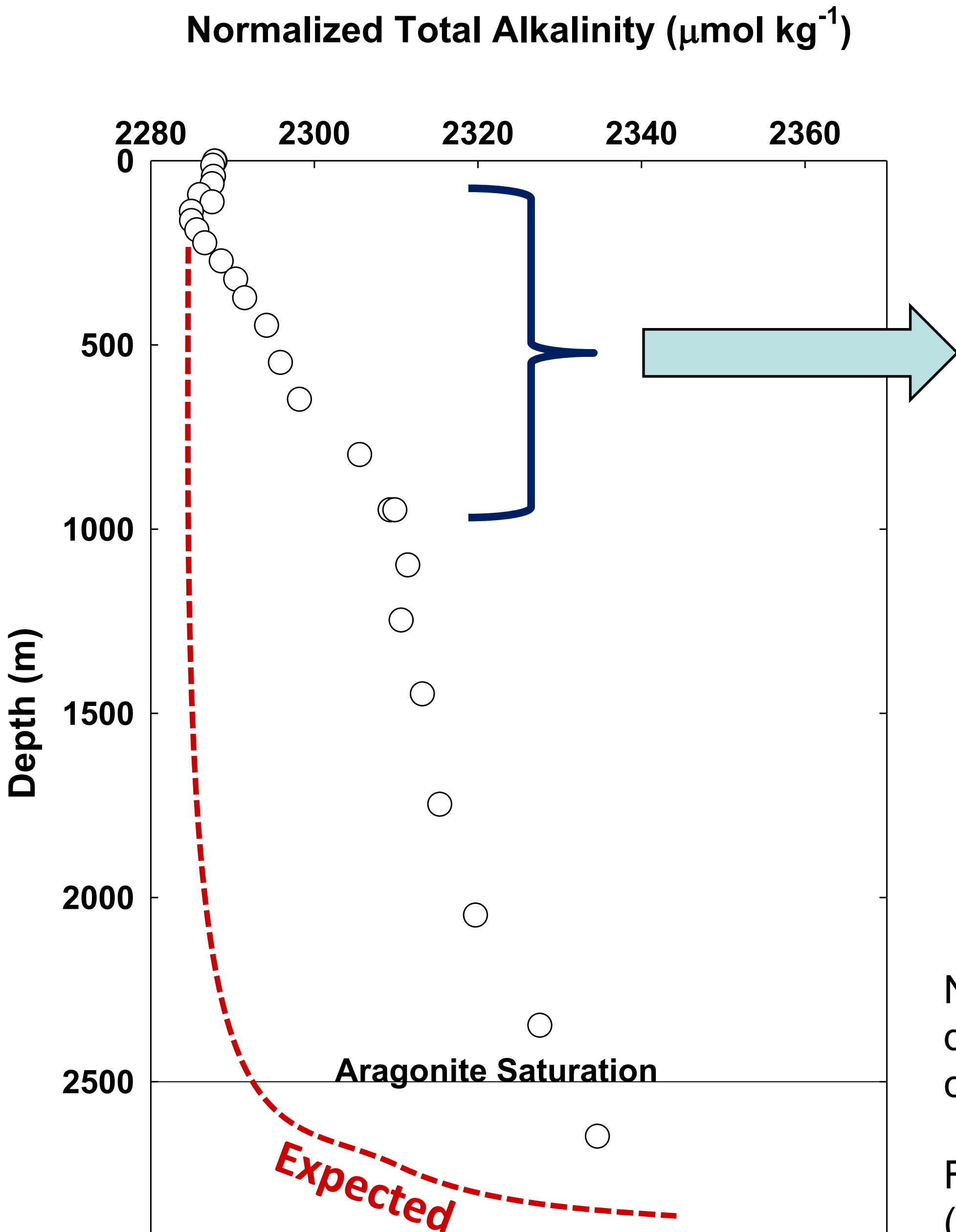
60,000 x 10^{18} g C
(e.g. limestone, chalks)

Redrawn after Toby Tyrell (National Oceanography Centre, Southampton)

1) $CaCO_3$ production rates by individual fish in laboratory:

- increases exponentially with temperature
- scales inversely with body size





Total alkalinity increases at much shallower depths than predicted in Atlantic and Pacific oceans

Normalized total alkalinity of seawater as a function of depth for North Atlantic Waters (30 N and 23 E)
c/o Frank Millero, RSMAS, Miami, USA

Feely et al., *Global Biogeochem. Cycles*, **16**, 1144 - (2002).

Chung et al., *Global Biogeochem. Cycles,* **17**, 1093 - (2003).

Marine reserves can mitigate and promote adaptation to climate change

doi: 10.1073/pnas.1701262114

Callum M. Roberts[a], Bethan C. O'Leary[a], Douglas J. McCauley[b,c], Philippe Maurice Cury[d], Carlos M. Duarte[e], Jane Lubchenco[f], Daniel Pauly[g], Andrea Sáenz-Arroyo[h], Ussif Rashid Sumaila[g], Rod W. Wilson[i], Boris Worm[j], and Juan Carlos Castilla[k,l,m,1]

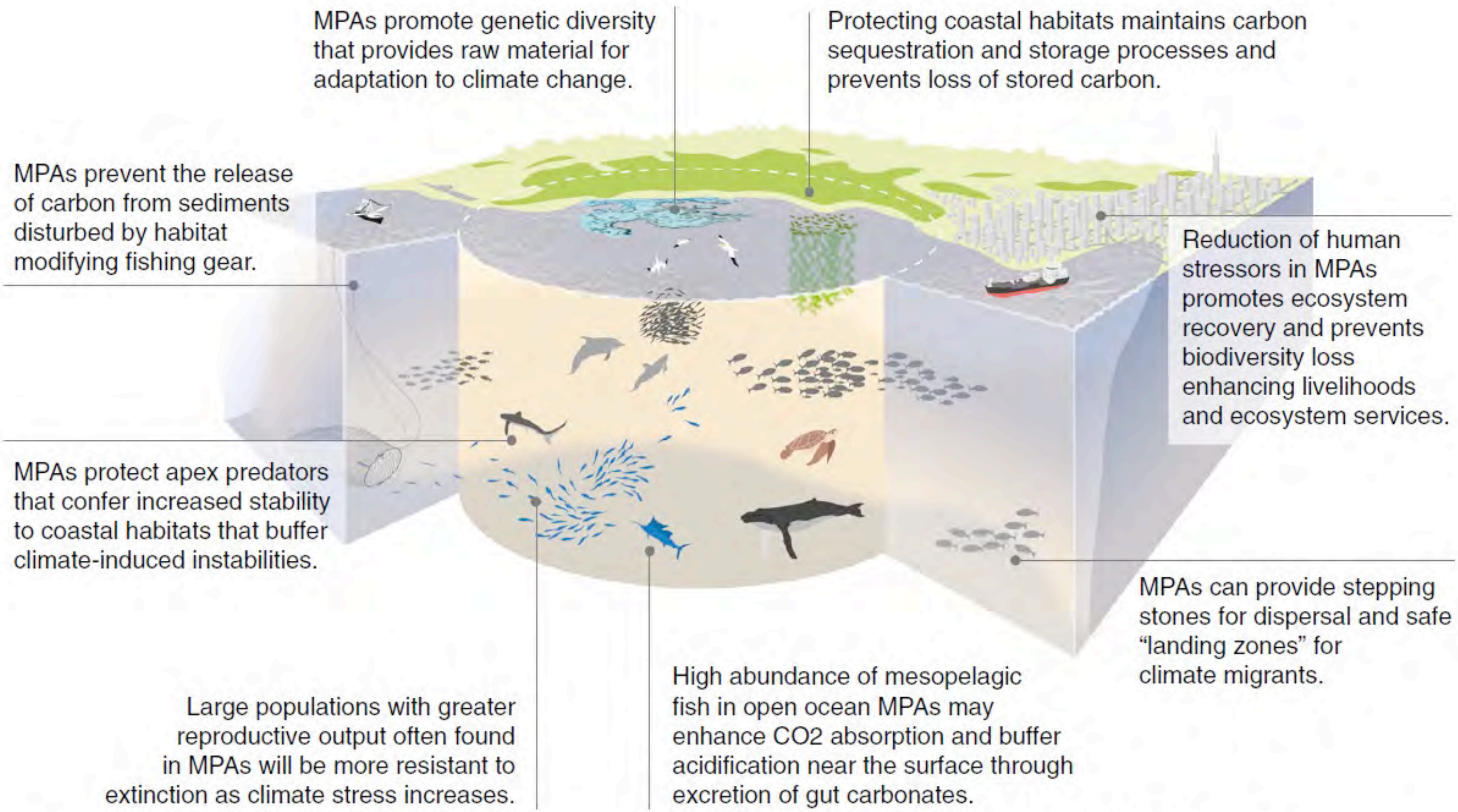
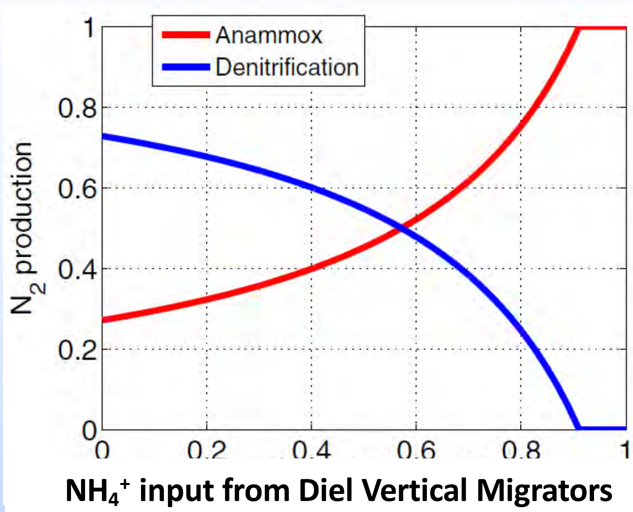


Fig. 1. Eight illustrative pathways by which MPAs can mitigate and promote adaptation to the effects of climate change in the oceans.

Biogeochemical consequences of DSL depth variability

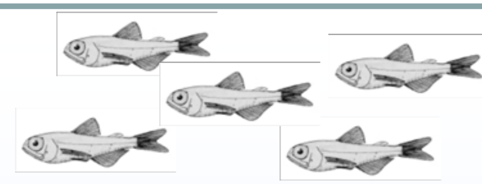
Mesopelagic animals – Continuous ammonia excretion = novel role in N cycle



Ammonia excretion (via gills) from diel vertical animal migration – previously overlooked role in anaerobic ammonium oxidation (Anammox) in deep ocean

(Bianchi et al. 2014 – *PNAS*)

Mesopelagic fish – Potential source of a novel "Upward Alkalinity Pump"



(↑ Surface Alkalinity)

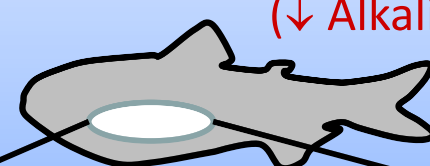
Gut carbonates excreted near surface (dissolution will enhance surface alkalinity):

$Ca^{2+} + 2HCO_3^- \leftarrow CaCO_3 + CO_2 + H_2O$

(Wilson et al. 2009 – *Science*)

Production of gut carbonates at depth:

(↓ Alkalinity at Depth)



$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$

High Pressures – Mesopelagic teleosts (0 to 1,000 m)

Prof. Santiago Hernández León
Instituto de Oceanografía y Cambio Global
Universidad de Las Palmas de Gran Canaria
Spain

Dr. Stephanie Czudaj
Institute of Sea Fisheries
Hamburg
Germany

BIO Hesperides Cruise 2015
"Migrants and Active Flux In the Atlantic ocean"

Fluid extracted from muscle of mesopelagic fish at 2 depths

	Epipelagic Zone (55 m depth) (N = 8)	Mesopelagic Zone (450 m depth) (N = 38)	
$[Na^+]$ (mM)	91.7 ± 13.0	137.4 ± 9.0	P=0.032*
$[Cl^-]$ (mM)	103.2 ± 14.1	159.7 ± 10.8	P=0.027*

3-4 individuals sampled from each of 10 species (order in parenthesis):

Chauliodus cf. schmidti (Stomiiformes),
Electron risso (Myctophiformes),
Diretmus argenteus (Beryciformes),
Argyropelecus cf. sladeni (Stomiiformes),
Astronesthes cf. cyclophotus (Stomiiformes),
Diaphus fragilis (Myctophiformes),
Howella sherboni (Perciformes),
Ichthyococcus ovatus (Stomiiformes),
Argyropelecus affinis (Stomiiformes),
cf. Bathylagus greyae (Clupeiformes)

Effect of Temperature on $CaCO_3$ excretion rate in marine fish

Average Q_{10} for metabolic rate in fish = 1.83 (across 69 species, 0-30 °C)
Clarke & Johnson (1999) *J. Anim. Ecol.* **68**, 893-

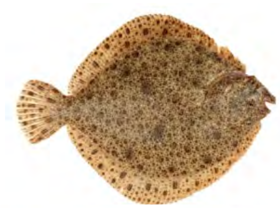
Sheepshead Minnow
(Cyprinodon variegatus) — $Q_{10} = 6.40$

Common Goby
(Pomatoschistus microps) — $Q_{10} = 4.49$

Sea bass
(Dicentrarchus labrax) — $Q_{10} = 3.40$

European Flounder
(Platichthys flesus) — $Q_{10} = 2.94$

Turbot
Scophthalmus maximus — $Q_{10} = 2.67$



Shanny
(Lipophrys pholis) — $Q_{10} = 1.96$

Mean Q_{10} = 3.64

(Reardon, Cole, Stephens, Statton Taplin, & Wilson - in prep.)

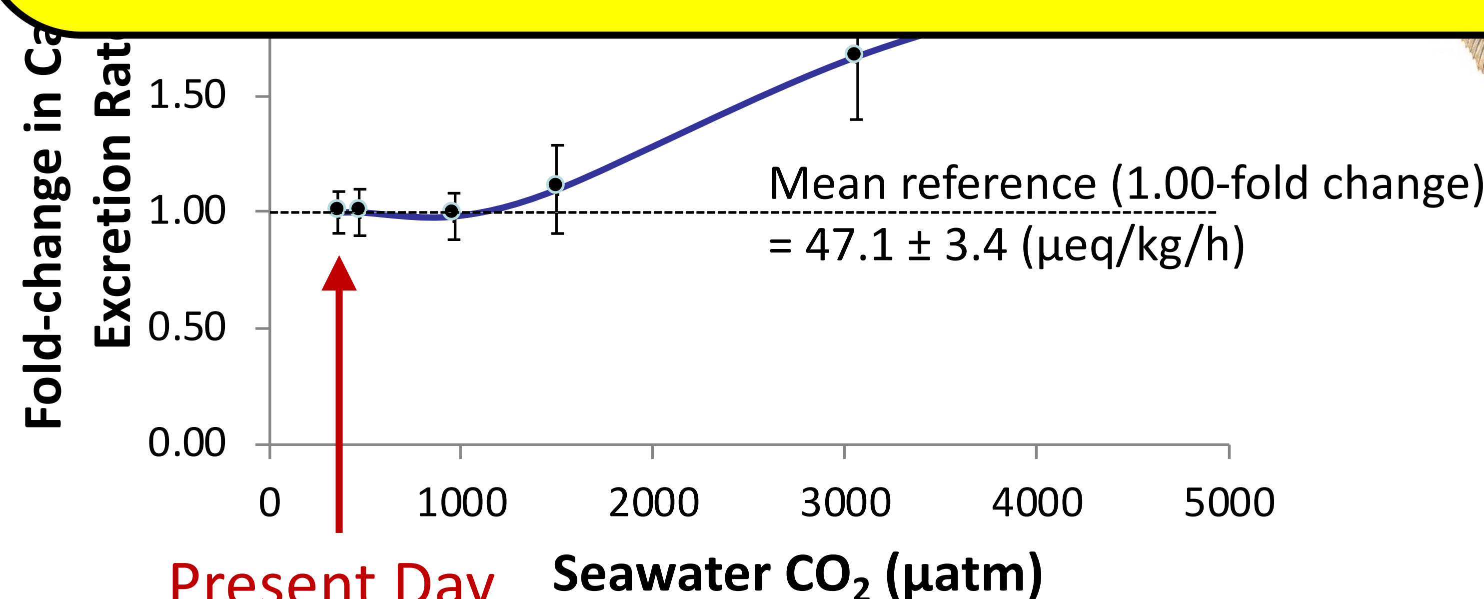
Elevated seawater CO_2 increases gut $CaCO_3$ excretion rate

In a warmer and higher CO_2 future ocean

(+ 4 °C & 1000 µatm CO_2)

Predict gut $CaCO_3$ to be **> 70 % higher**

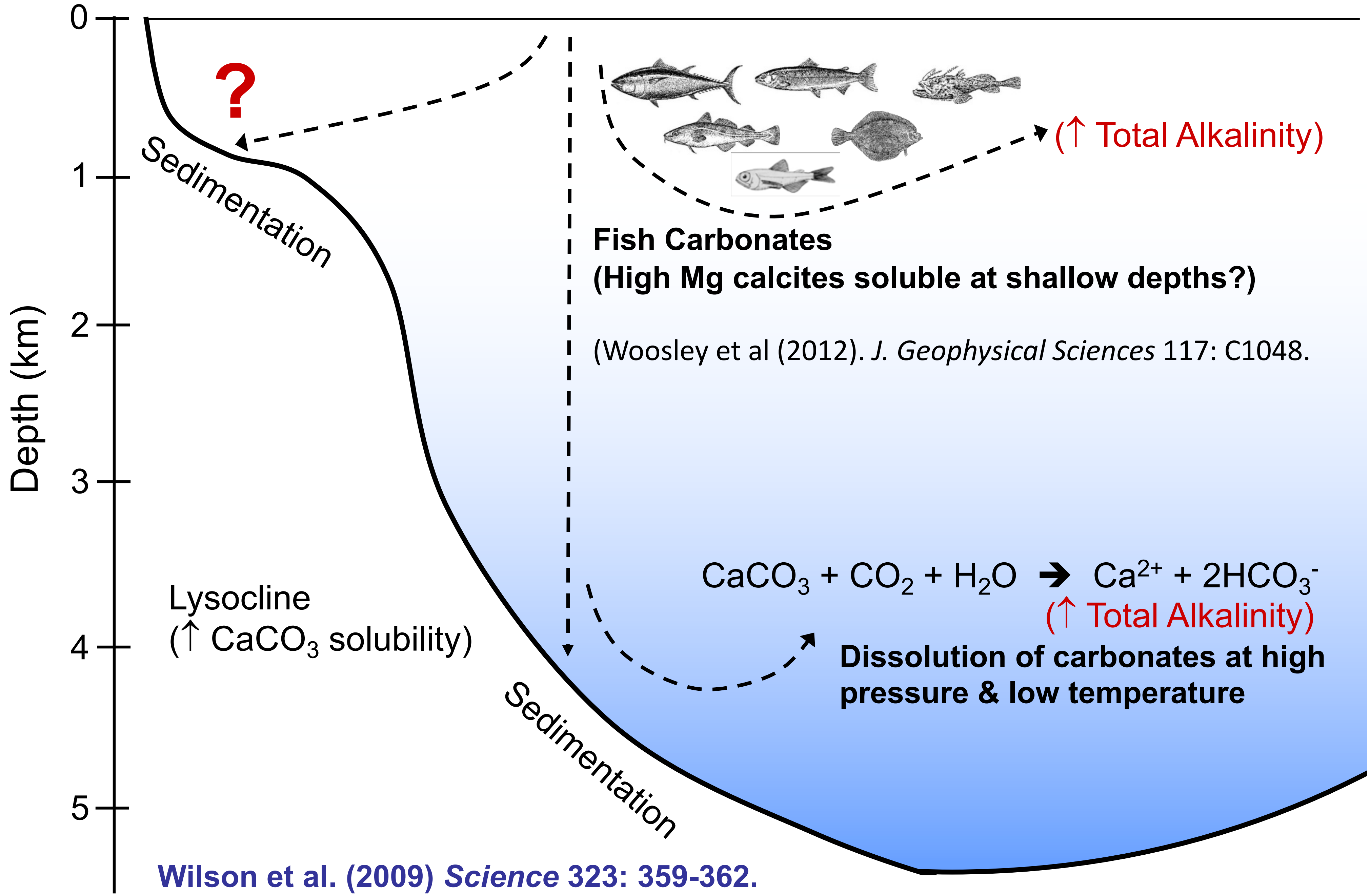
(Reardon, Cole, Stephens, Statton Taplin, & Wilson - in prep.)



Present Day
(400 µatm)

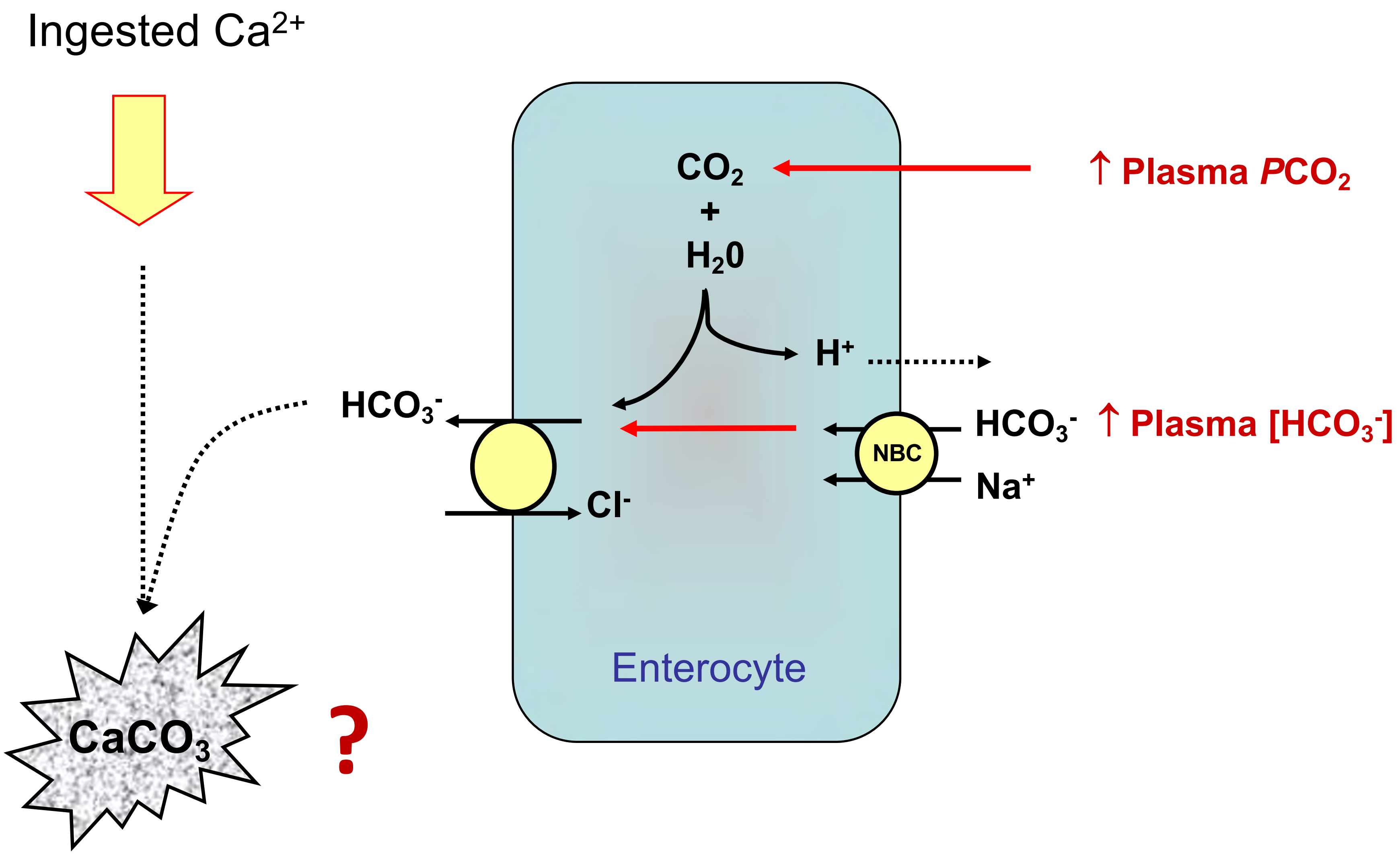
(Cobb, Whittamore, Reardon, Rogers & Wilson - in prep.)

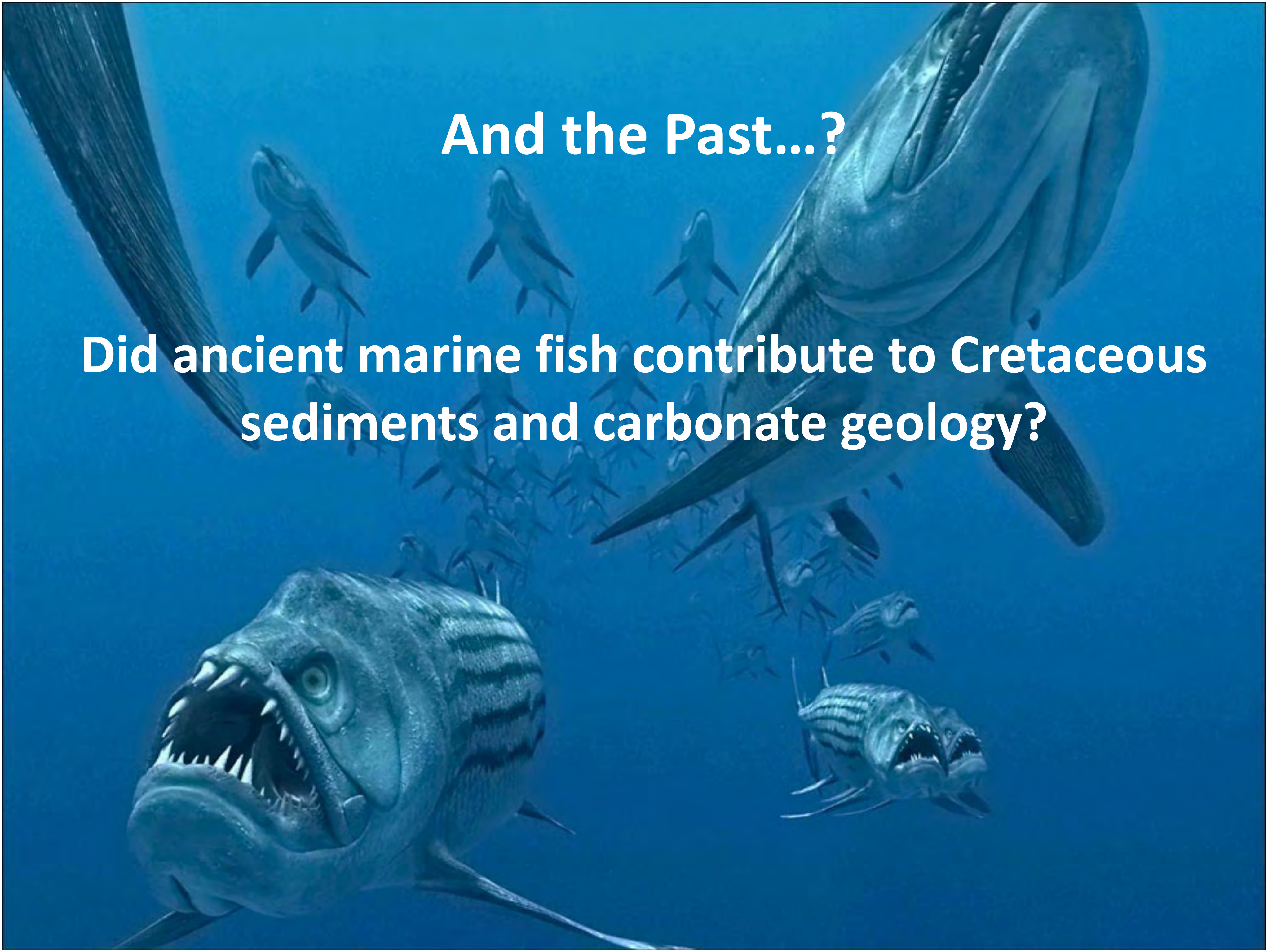
Do all fish carbonates dissolve rapidly?



Wilson et al. (2009) *Science* 323: 359-362.

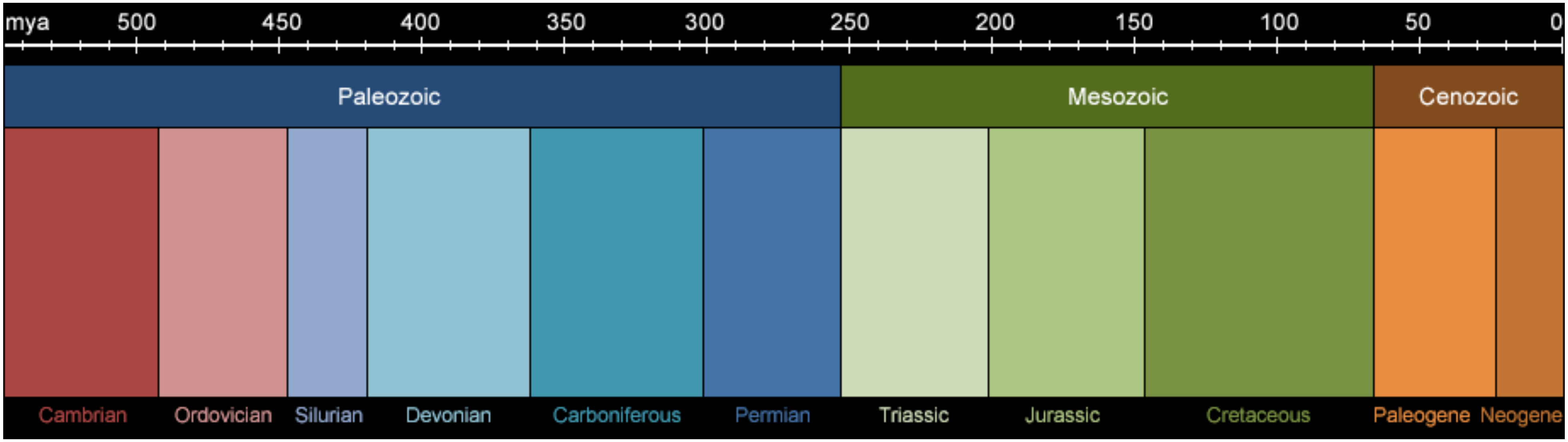
Elevated seawater CO_2 predicted to increase gut $CaCO_3$ production




And the Past…?
Did ancient marine fish contribute to Cretaceous sediments and carbonate geology?

Marine Teleost Evolution

Geological eras from the Paleozoic to today http://www.kerbtier.de/Pages/Themenseiten/enPhylogenie.html



Ancestors of teleosts evolved in freshwater

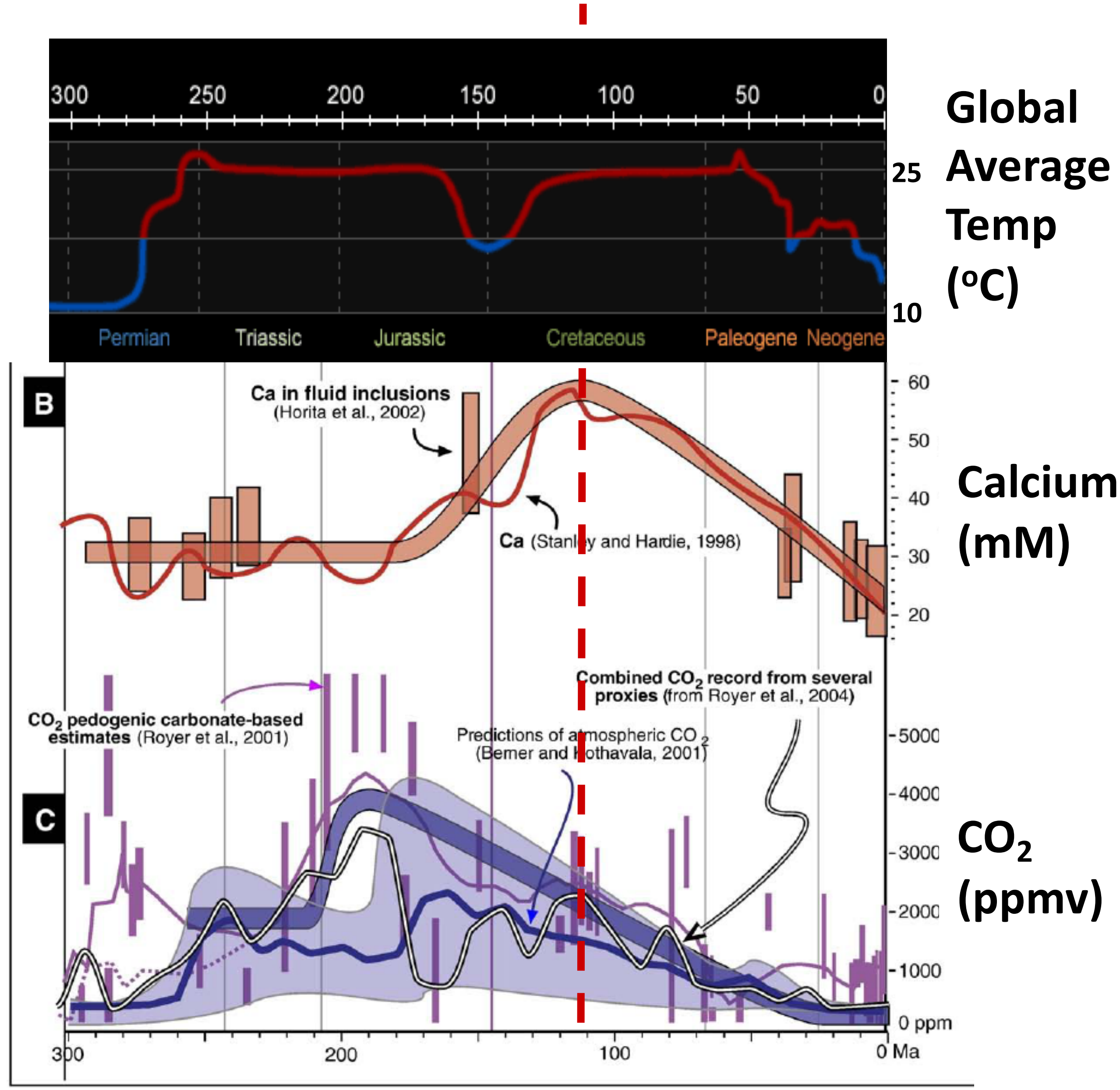
Teleosts found in marine fossils

Spectacular radiation of teleosts and domination of marine vertebrates

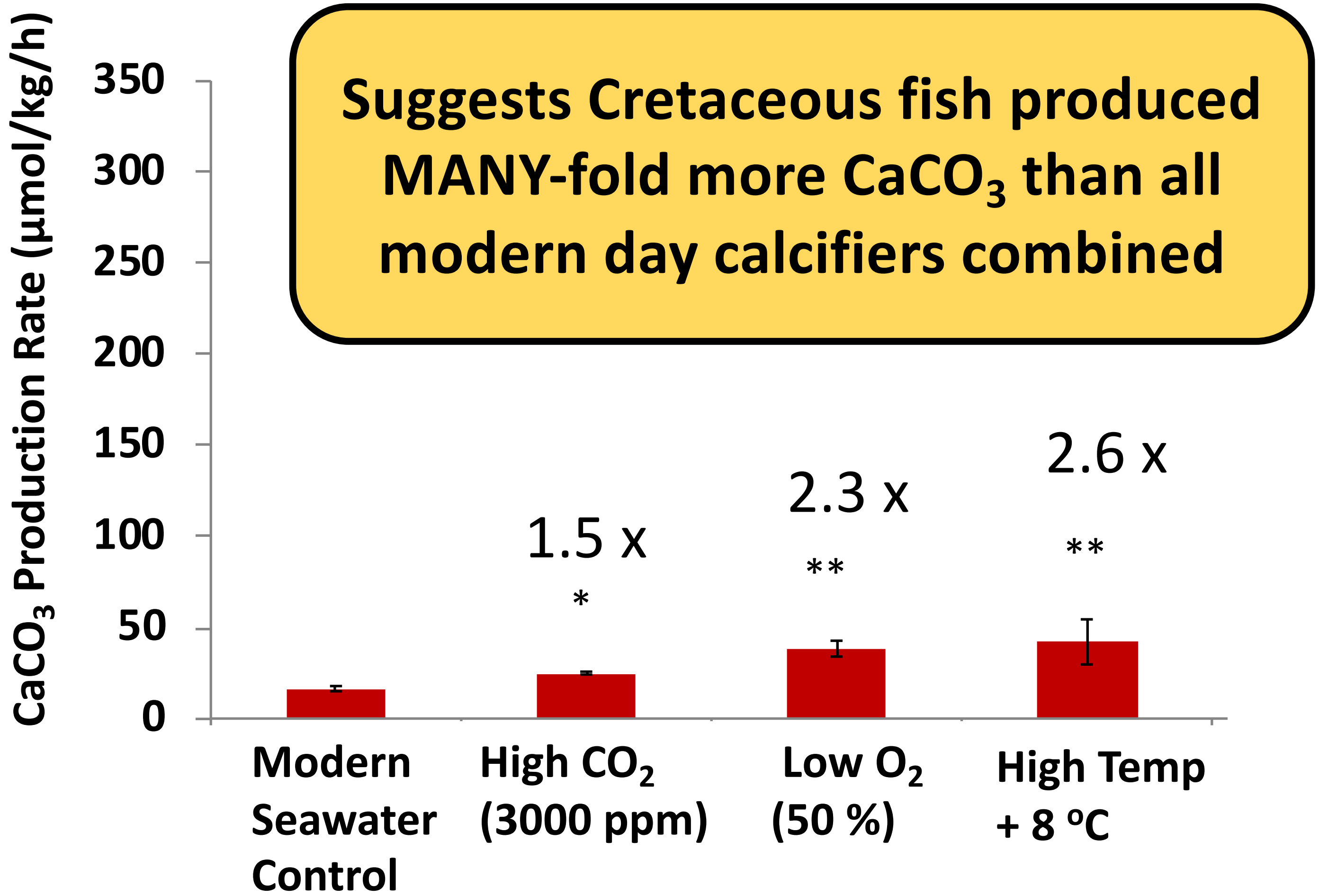
Mid-Cretaceous Marine Conditions (110 Mya):

7 factors predicted to ↑ $CaCO_3$ production by fish:

Temp (+ 8 °C)
Ca^{2+} (3-4 x higher)
CO_2 (5-10 x higher)
O_2 (lower)
Salinity (+ 5 psu?)
Mg^{2+} (lower)
SO_4^{2-} (lower)



L. Pomar, P. Hallock / Earth-Science Reviews 87 (2008) 134–169



And 2-4 x lower Mg content

= GREATER preservation potential

Wilson, RW (2014). Chapter 3.6 *Fish*. In: IUCN REPORT
The Significance and Management of Natural Carbon Stores in the Open Ocean
pp 81-94. ISBN: 978-208317-1692-3.

Media Headlines may be a little …. misleading ?

YAHOO! NEWS

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Fish poop helps balance ocean's acid levels

Climate Ark

Climate Change and Global Warming Portal

Featuring Customized Climate Search of Reviewed, Authoritative Content

Fish poop fights climate change

CBCnews.ca

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Story Tools: E-MAIL | PRINT | Text Size: S M L XL | REPORT TYPO | SEND YOUR FEEDBACK

Fish feces reduce ocean CO2 levels: study

FT FINANCIAL TIMES

Fish offer ocean climate hope

Discovery CHANNEL

Fish Poop Helps Balance Ocean Acidity

Associated Press

NewScientist

Fish 'an ally' against climate change

Wilson, RW, Millero, FJ, Taylor, JR, Walsh, PJ, Christensen, V, Jennings, S, Grosell, M. (2009) Contribution of fish to the marine inorganic carbon cycle. *Science* **323**: 359-362.