# Ecosystem models to evaluate the role of trophic vertical exchange processes on forage and predator productivity within oceanic ecosystems

Jim Ruzicka, Stacy Calhoun-Grosch, Jesse van der Grient, Jacob Snyder & Réka Domokos

Grant#: G231805

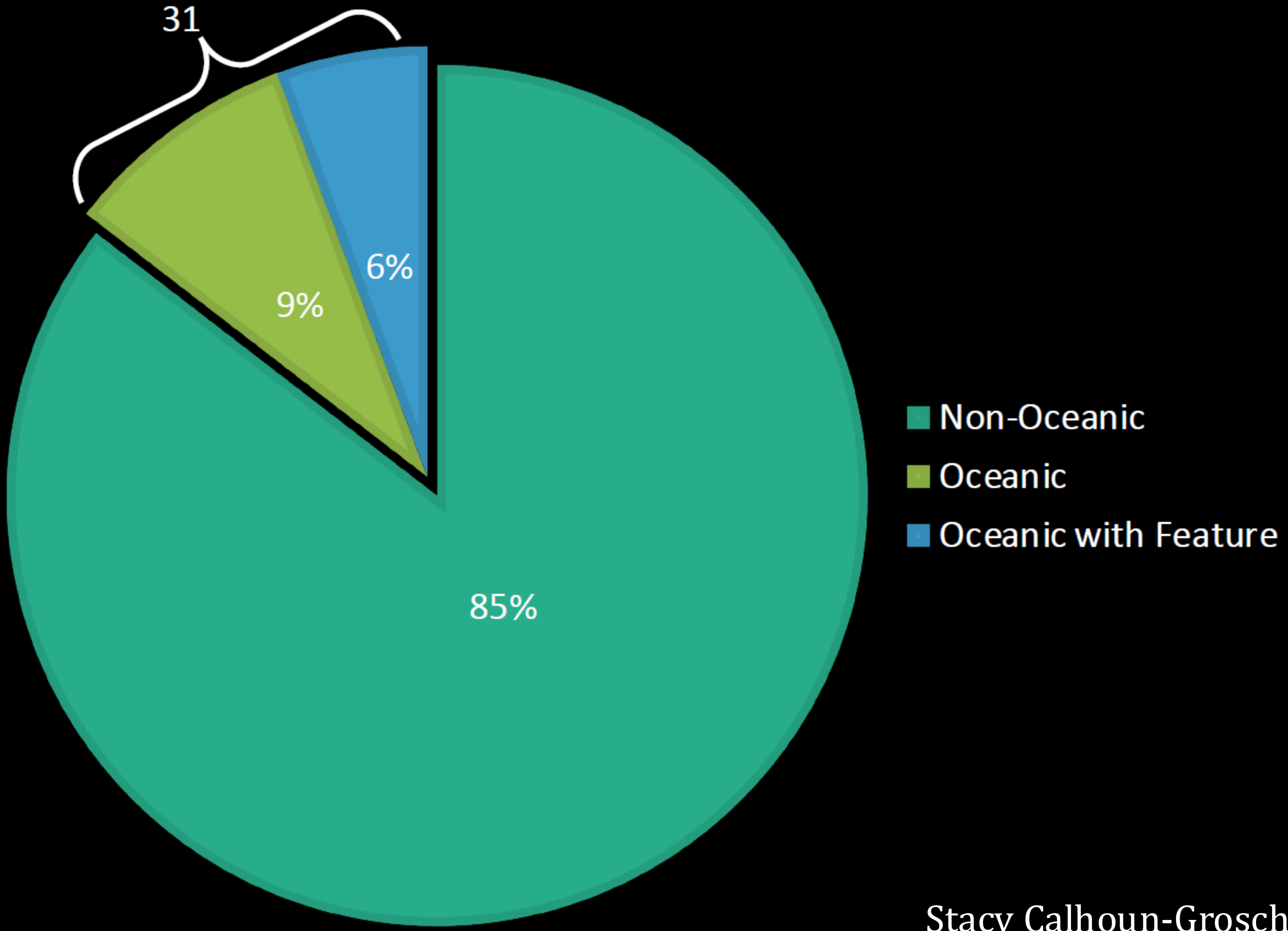
# Vertically-resolved models for Oceanic ecosystems

## Why?

- To manage potential large, untapped resource: mesopelagic fish → fish meal for aquaculture
- To understand the Biological Carbon Pump and its role in Climate Change
- To understand dynamics of the forage base for valuable oceanic fisheries
- To be prepared to manage effects of deep-sea mining

# Oceanic ECOPATH Food Web Models

EcoBase:
213 available models




Stacy Calhoun-Grosch

# *EcoTran*: end-to-end food web modeling of pelagic ecosystems

Physical Model

climate
oceanography
stressors

Food Web Model

Fisheries

Social Impacts

resilience
adaptation
well-being

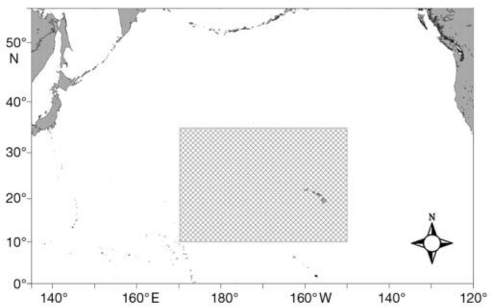
*EcoTran*

Food Web
*Ecopath*
*Rpath*

Spatial resolution
Physiologies
Diel Vertical Migration

**Finding the way to the top: how the composition of oceanic mid-trophic micronekton groups determines apex predator biomass in the central North Pacific**

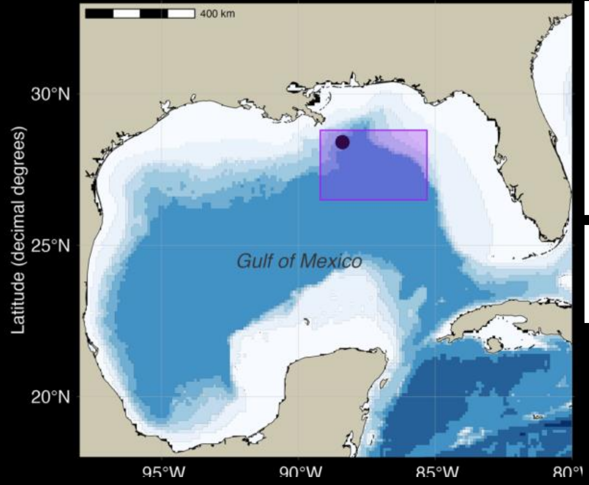
C. Anela Choy[1,*], Colette C. C. Wabnitz[2], Mariska Weijerman[3], Phoebe A. Woodworth-Jefcoats[4,5], Jeffrey J. Polovina[4]




MARINE ECOLOGY PROGRESS SERIES
Vol. 549: 9–25, 2016
doi: 10.3354/meps11680

**40 live groups**

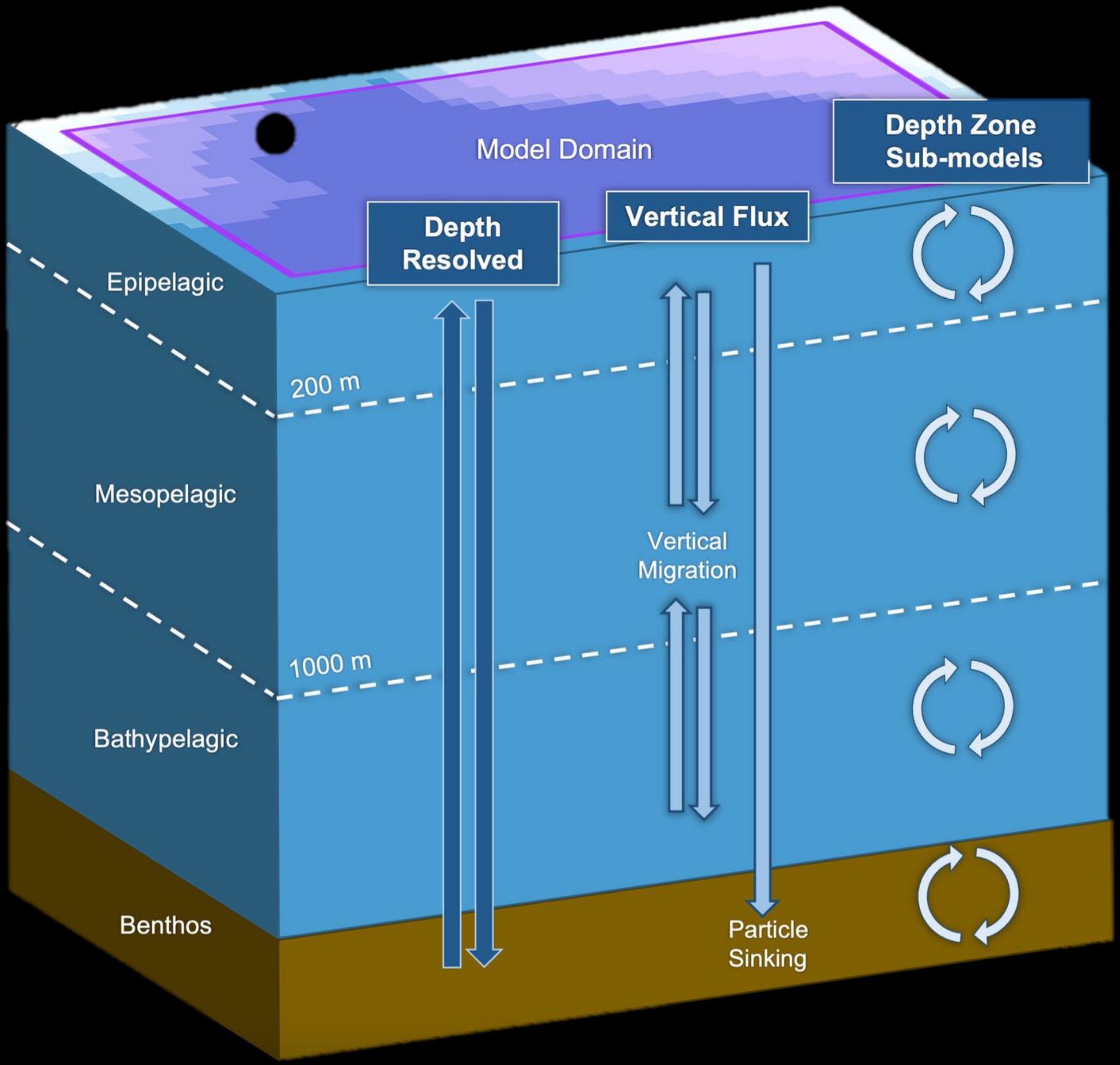
**Simulating productivity changes of epipelagic, mesopelagic, and bathypelagic taxa using a depth-resolved, end-to-end food web model for the oceanic Gulf of Mexico**

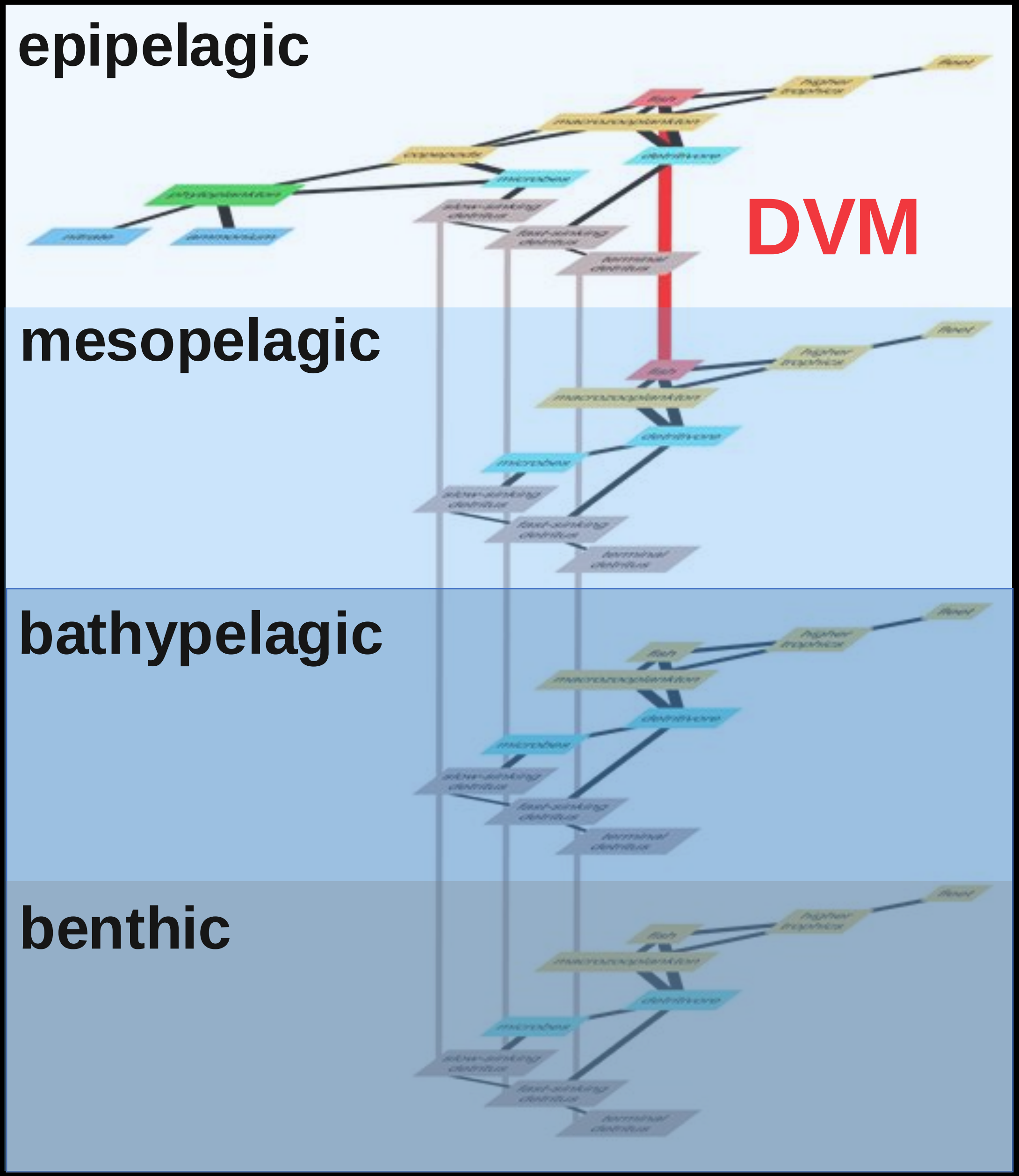



Stacy Calhoun-Grosch, Jim Ruzicka, Kelly Robinson, Verena Wang, Tracey Sutton, Cameron Ainsworth, Frank Hernandez

Ecological Modelling 489 (2024) 110623

**38 live groups**



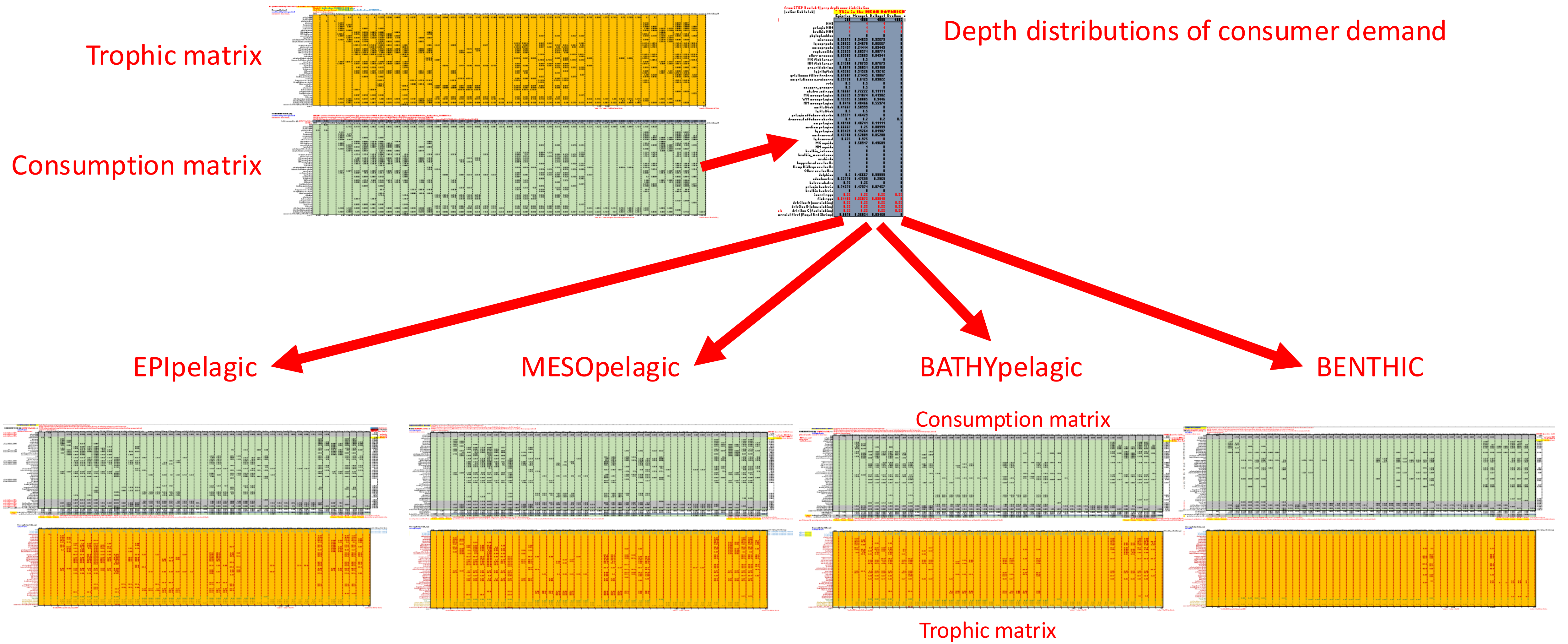




(Stacy Calhoun-Grosch)

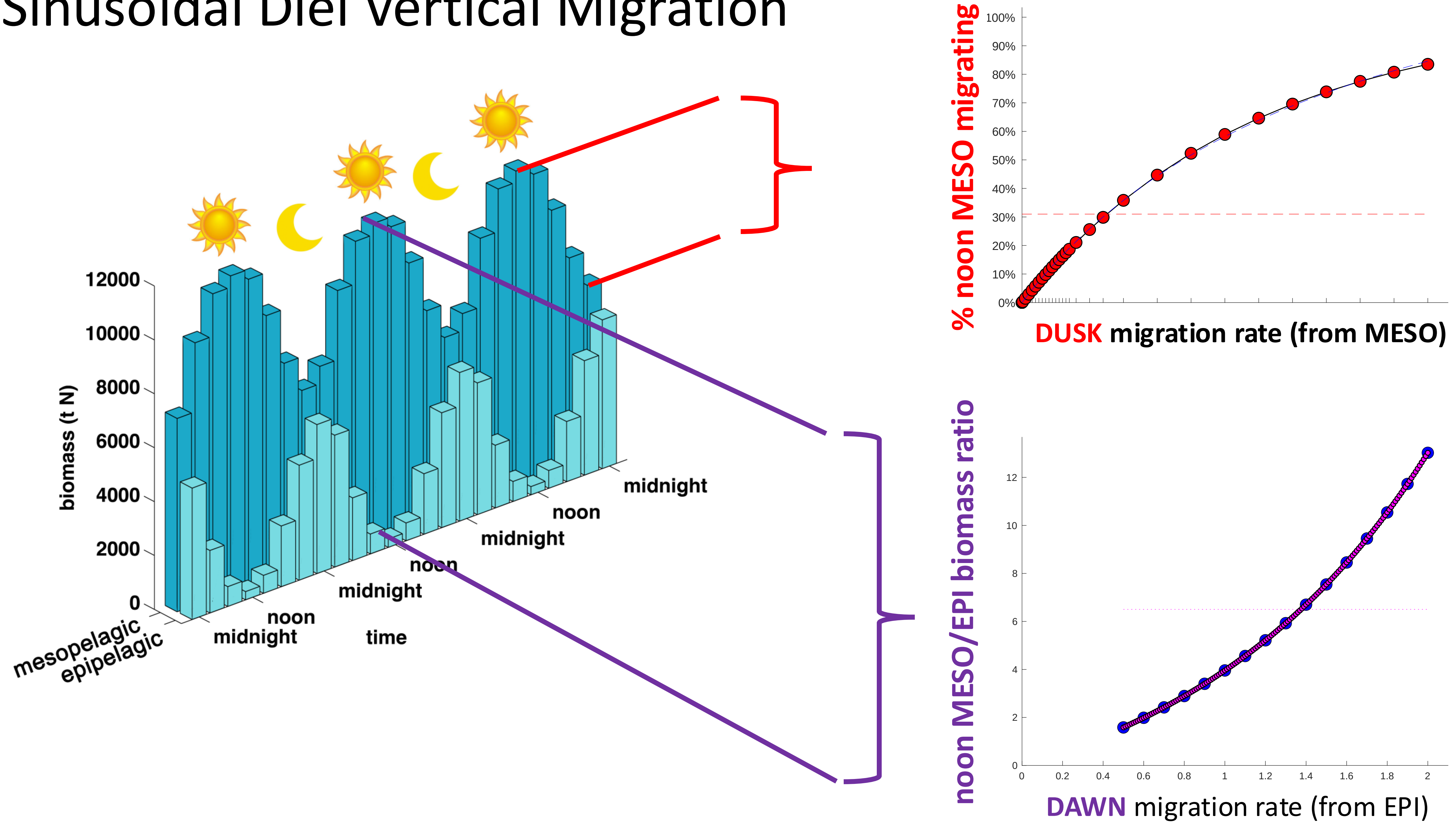
# From a vertically-integrated ECOPATH model

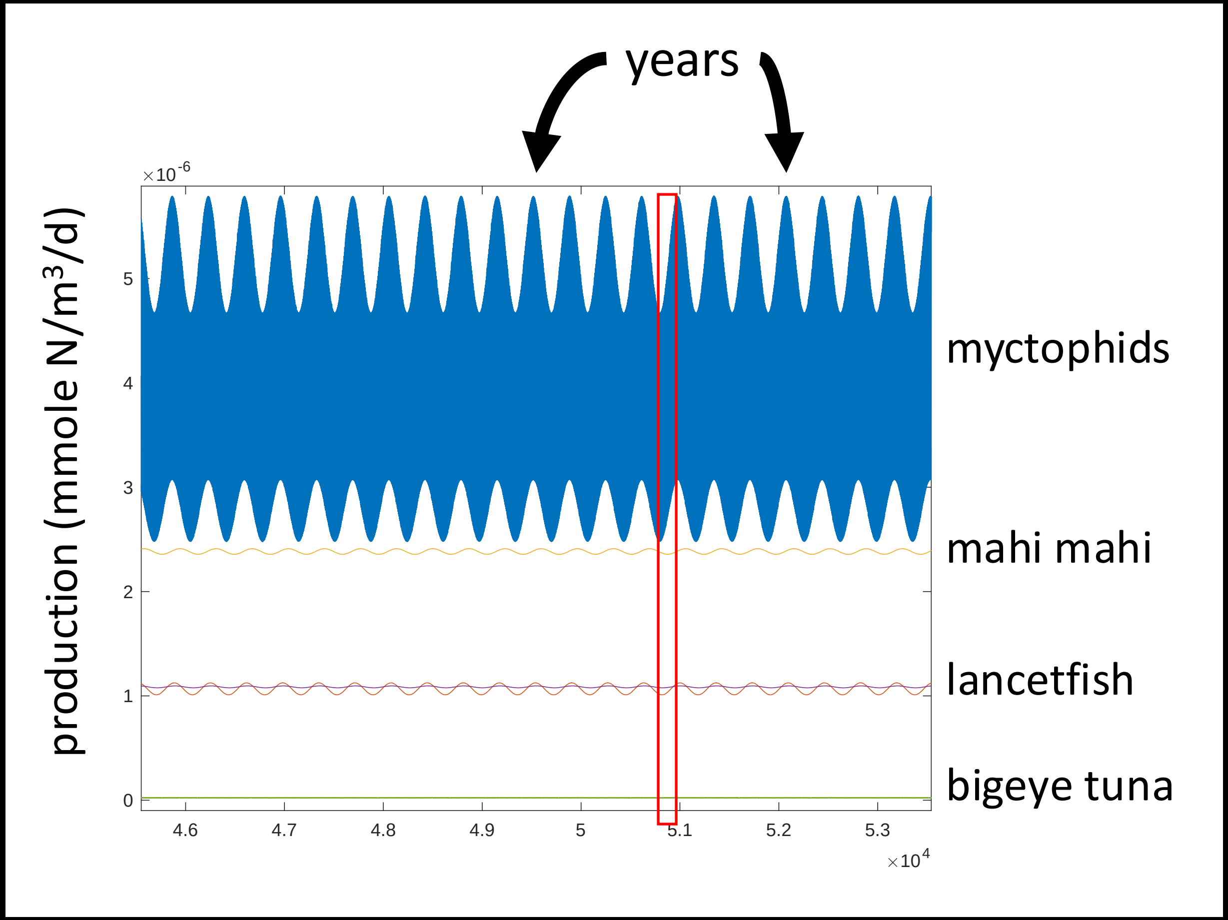
## Rapid depth-resolved food webs:

Reapportion resources among predators @ each depth to create depth-resolved food web (the donor-defined Trophic Matrix is in mass-balance)

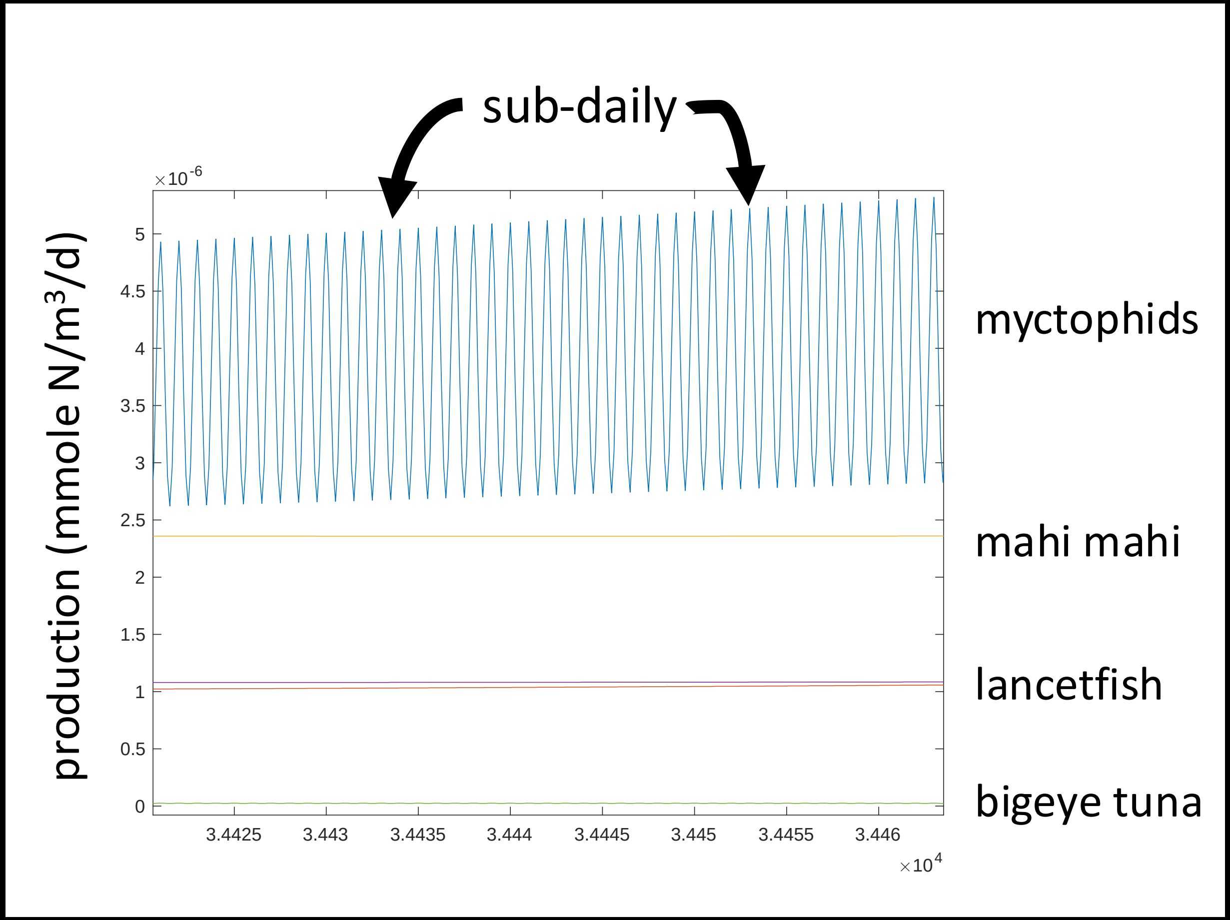


# Sinusoidal Diel Vertical Migration





years
production (mmole N/m3/d)
×10-6
myctophids
mahi mahi
lancetfish
bigeye tuna
×10⁴

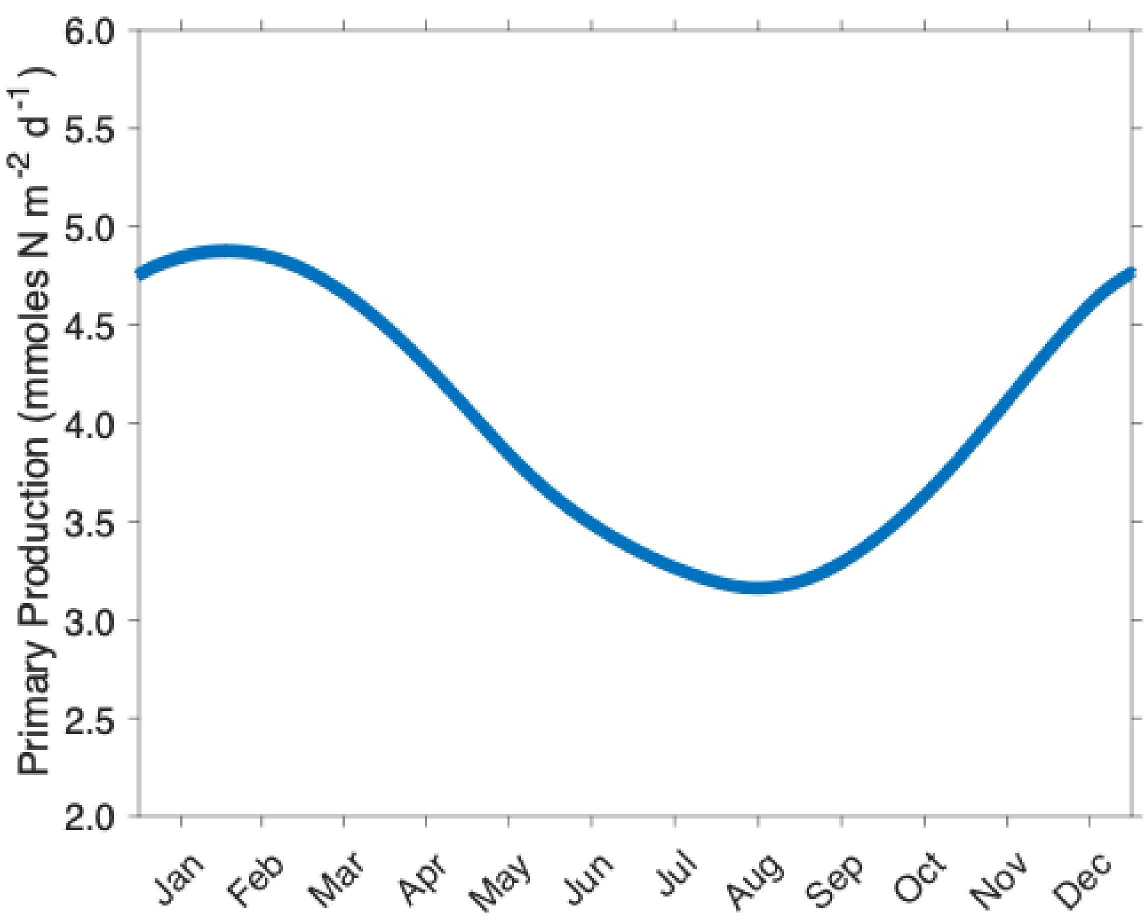
sub-daily
production (mmole N/m3/d)
×10-6
myctophids
mahi mahi
lancetfish
bigeye tuna
×10⁴

# Model Drivers: Nitrate & detritus

Primary production cycle: Hidalgo-Gonzalez et al. (2005)

2.9 mmoles N/m2/d summer-fall

5.1 mmoles N/m2/d winter-spring

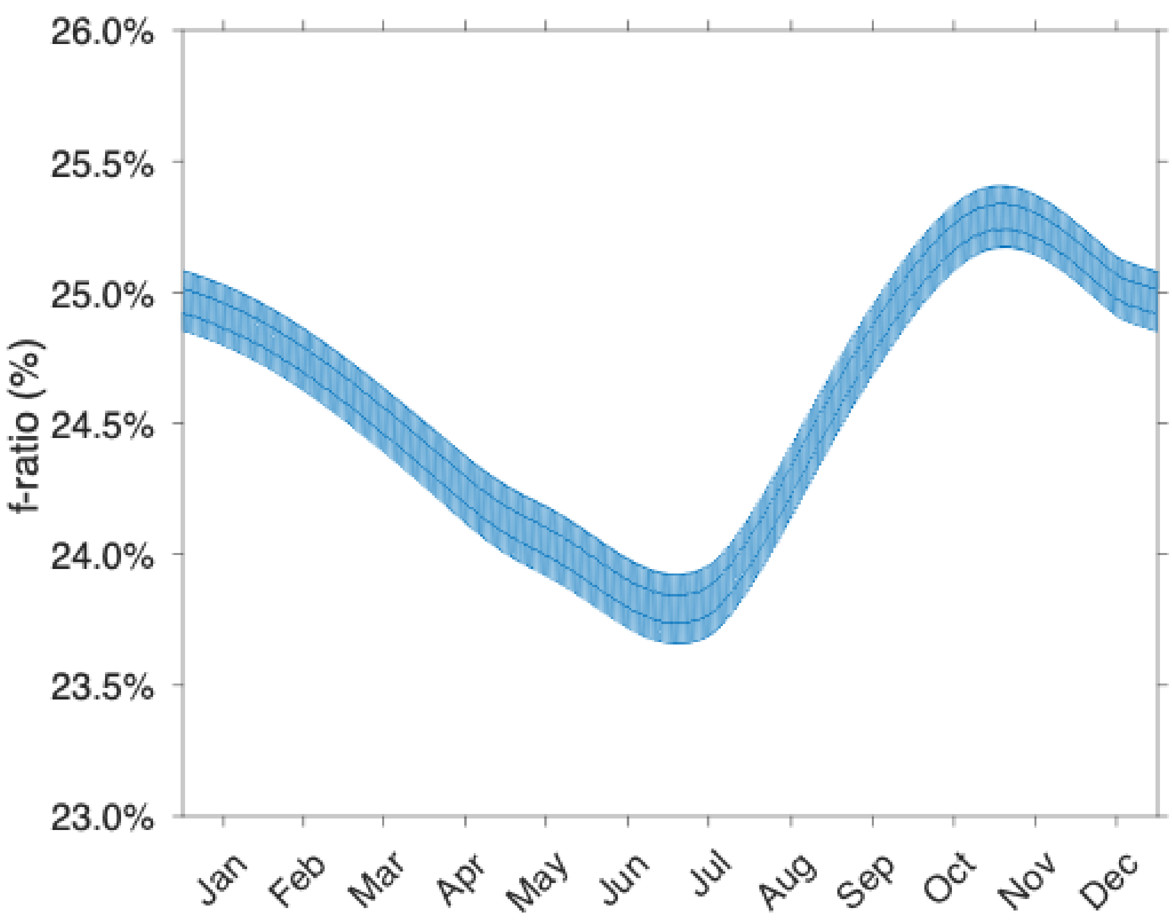



# Model tuning: f-ratio only

Primary production supported by $NO_3/(NO_3+NH_4)$

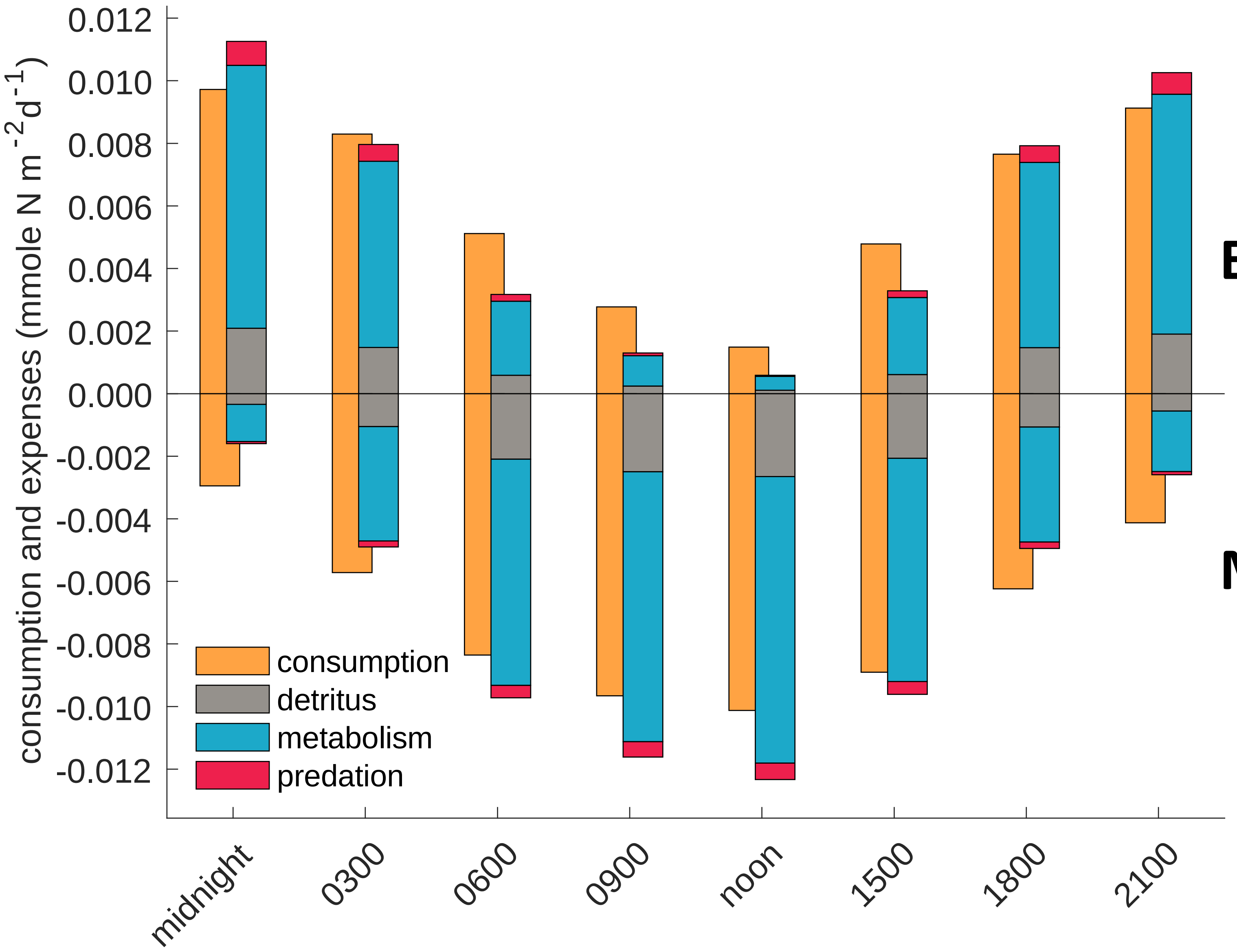
Hidalgo-Gonzalez et al. (2005) *f-ratio* at least 0.21

Kelly et al. (2021) *f-ratio in situ* 0.07-0.14



# Migratory Mesopelagic Fish: hourly consumption gains and expenses

DVM: 3 flux pathways
- feces & senescence
- metabolism
- predation

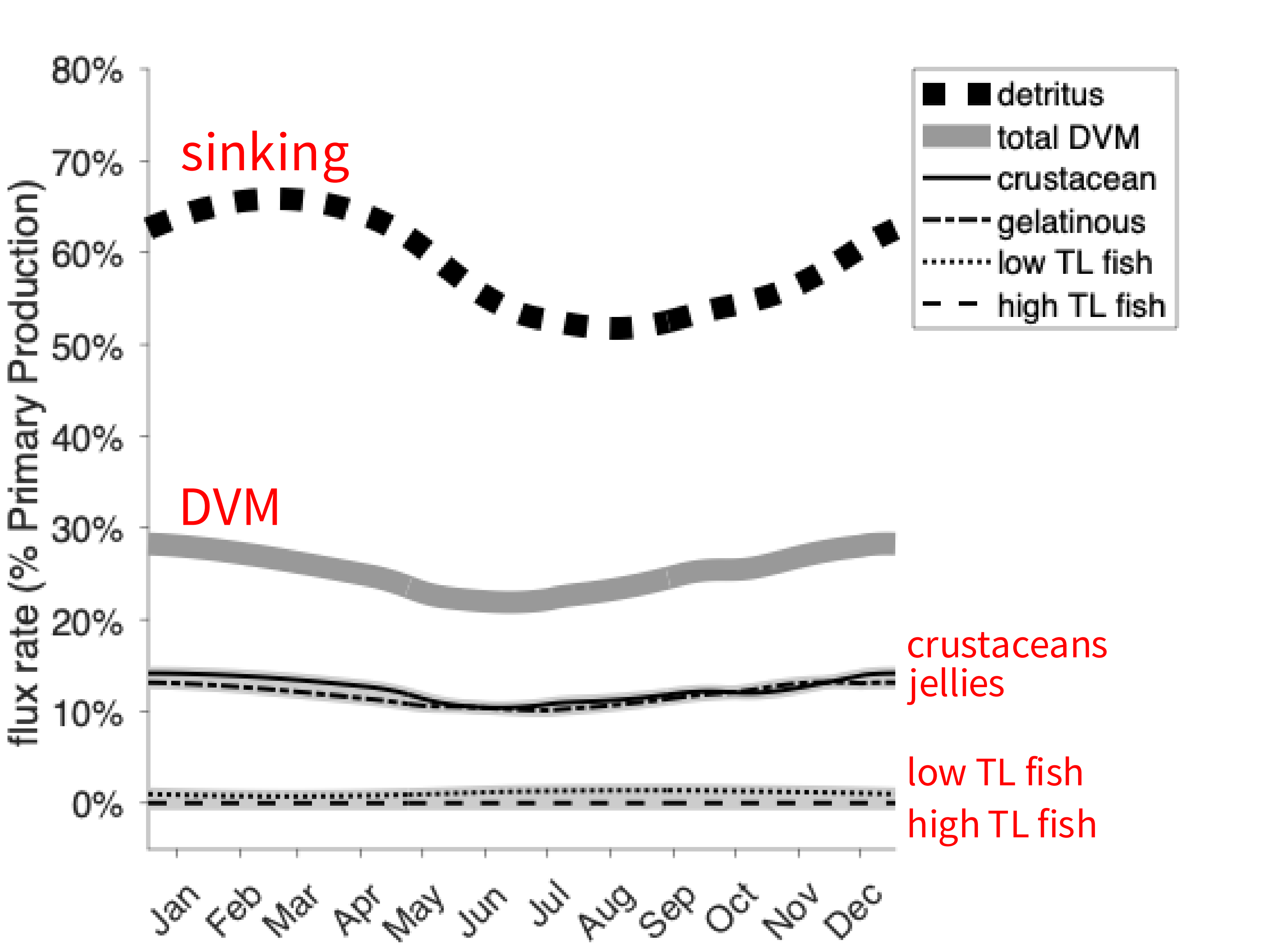



**EPIpelagic**

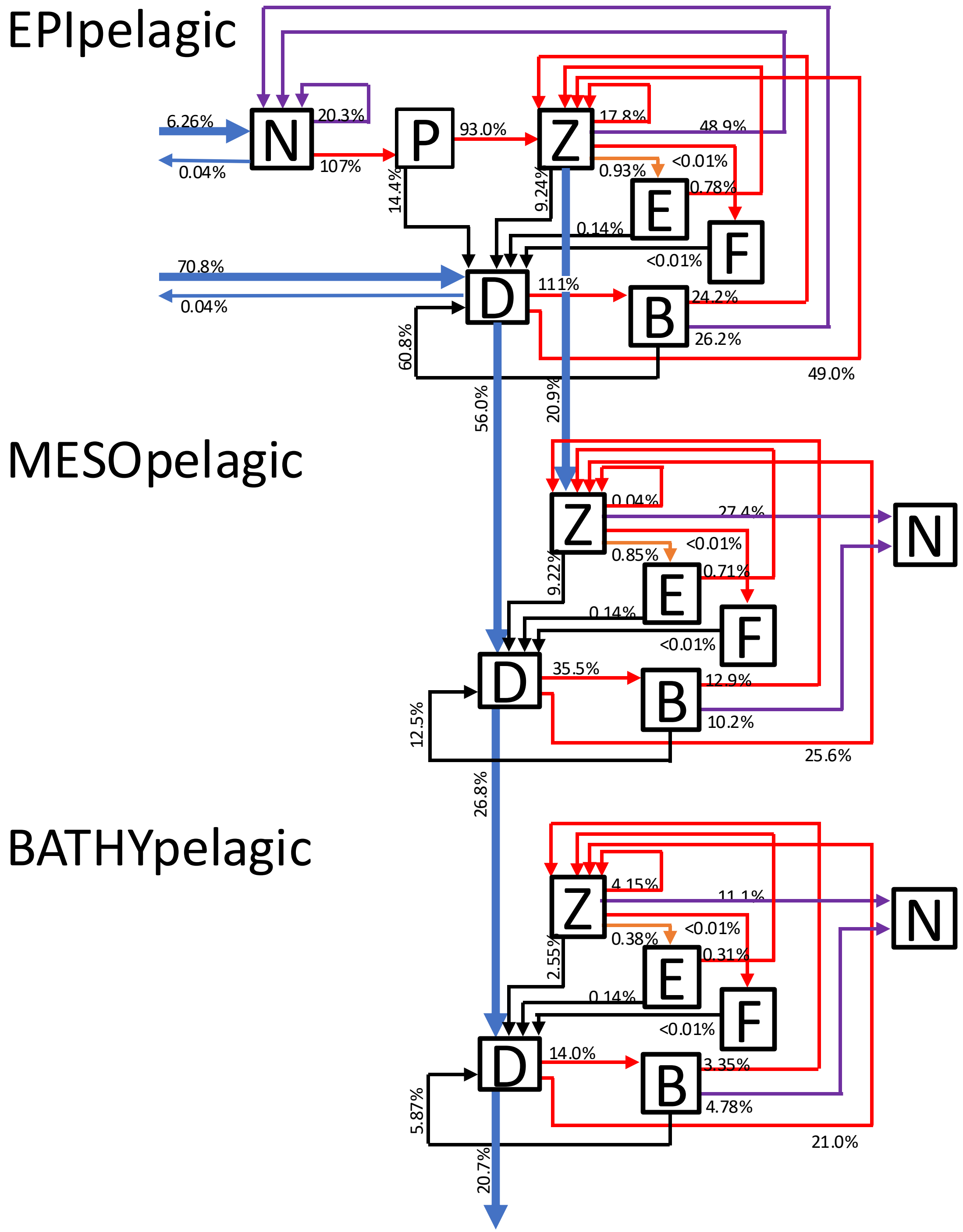
**MESOpelagic**

# Net Daily Vertical Flux Rates

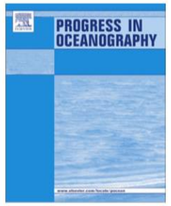
DVM is 30% of total biological pump




Fish are a minimal contributor (<5% sinking) can reverse the pump




Maximum Biomass Conservation Error: 0.14% of consumer input




Progress in Oceanography 116 (2013) 14–30

# Carbon export mediated by mesopelagic fishes in the northeast Pacific Ocean

P.C. Davison [a,*], D.M. Checkley Jr. [a], J.A. Koslow [a], J. Barlow [a,b]

## Our Model: Total DVM is 30% of BCP

| Author | Location | Taxa | DVM % total flux |
|---|---|---|---|
| Al-Mutairi and Landry (2001) | Hawaii | DVM zooplankton | 23% |
| Dam et al. (1995) | Bermuda | DVM zooplankton | 27% |
| Hernandez-Leon et al. (2001) | Canary Is. | DVM zooplankton | 25%-30% |
| Hidaka et al. (2001) | W. Eq. Pac. | DVM zooplankton | 16%-31% |
| Kobari et al. (2008) | N.W. Pac. | OVM, DVM copepods | 29%-27% |
| Le Borgne and Rodier (1997) | E. Eq. Pac. | DVM zooplankton | 3% |
| Le Borgne and Rodier (1997) | W. Eq. Pac. | DVM zooplankton | 6% |
| Longhurst et al. (1990) | Sargasso Sea, E. Trop. Pac. | DVM zooplankton | 4% |
| Longhurst and Williams (1992) | Bermuda | OVM copepods | 2% |
| Morales (1999) | Bermuda | OVM, DVM copepods | 27%-30% |
| Putzeys and Hernandez-Leon (2005) | Canary Is. | DVM zooplankton | 30%-37% |
| Schnetzer and Steinberg (2002) | Bermuda | DVM zooplankton | 3% |
| Steinberg et al. (2000) | Bermuda | DVM zooplankton | 7% |
| Steinberg et al. (2008b) | Hawaii | DVM zooplankton | 15% |
| Steinberg et al. (2008b) | N.W. Pac. | DVM zooplankton | 57%-60% |
| Takahashi et al. (2009) | N.W. Pac. | DVM copepods | 26% |
| Zhang and Dam (1997) | Eq. Pac. | DVM zooplankton | 24%-31% |
| Yebra et al. (2005) | Canary Is. | DVM zooplankton | 13%-35% |
| Hidaka et al. (2001) | W. Eq. Pac. | DVM fishes | 13%-30% |

LIMNOLOGY and OCEANOGRAPHY

*Limnol. Oceanogr.* 66, 2021, 1639–1664

# Toward a better understanding of fish-based contribution to ocean carbon flux

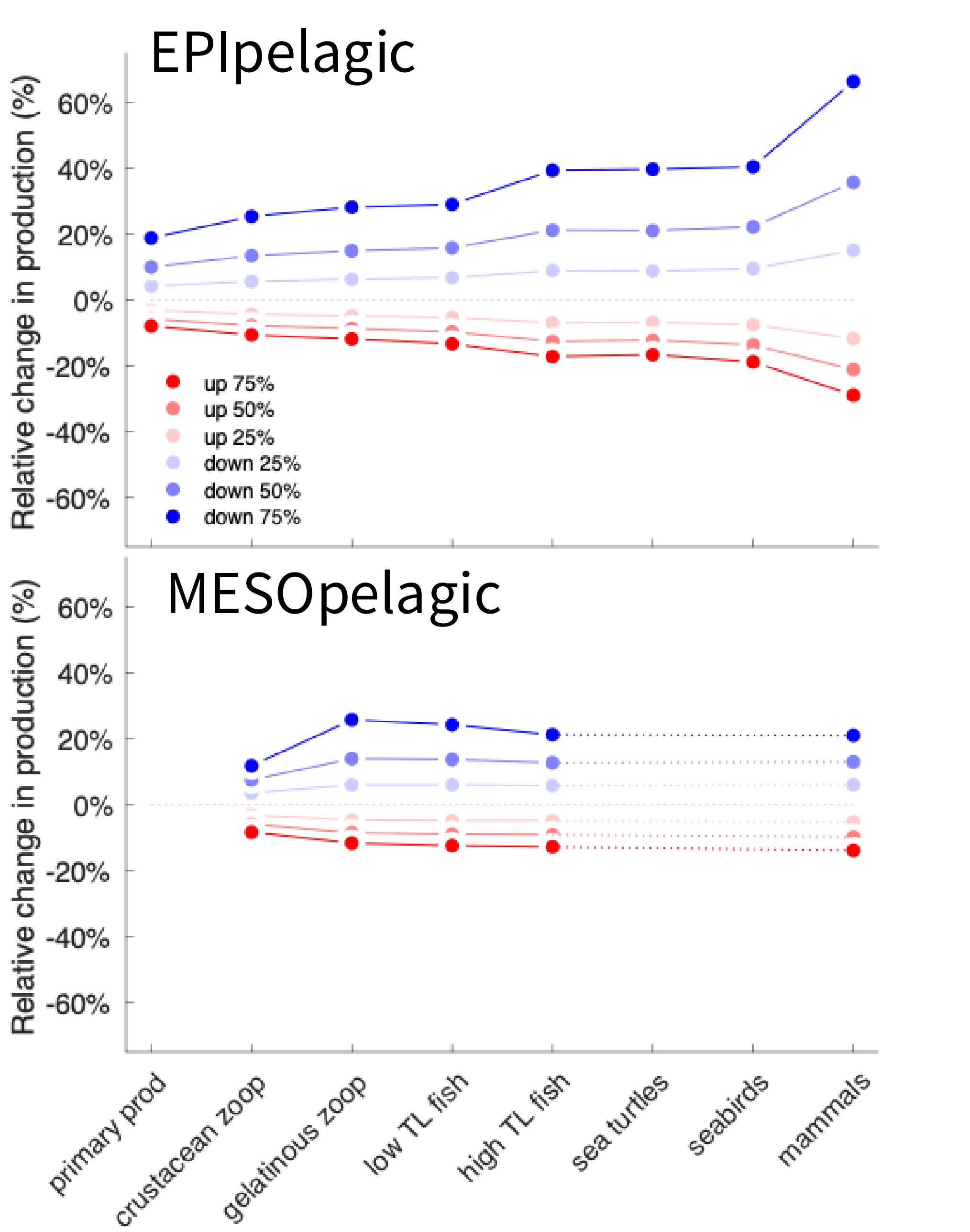
Grace K. Saba,[1*] Adrian B. Burd,[2] John P. Dunne,[3] Santiago Hernández-León,[4] Angela H. Martin,[5] Kenneth A. Rose,[6] Joseph Salisbury,[7] Deborah K. Steinberg,[8] Clive N. Trueman,[9] Rod W. Wilson,[10] Stephanie E. Wilson[11]

**Our Model: Fish DVM is <5% BCP**

**Globally, "...fishes contribute an average (+/- standard deviation) of about 16.1% ( 13%) to total carbon flux out of the euphotic zone." – Saba et al. 2021**

| Author | Location | Taxa | fish DVM % sinking |
|---|---|---|---|
| Staresinic et al. (1983) | Peru upwelling | Peruvian anchovy | 7.3% |
| Ariza et al. (2015) | Canary Islands | Myctophids | 23.0% |
| Belcher et al. (2019) | Scotia Sea, Southern Ocean | Myctophids | 6.9% |
| Belcher et al. (2020) | Scotia Sea, Southern Ocean | Myctophids | 21.1% |
| Hernández-León et al. (2019) | tropical/subtropical Atlantic | Myctophids | 3.6% |
| Hidaka et al. (2001) | west equatrorial Pacific | Myctophids | 20.7% |
| Davison et al. (2013) | Northeast Pacific | Myctophids | 22.0% |
| Hudson et al. (2014) | Mid-Atlantic Ridge (North Azores) | Myctophids | 0.3% |

# Sensitivity to detritus sinking rates



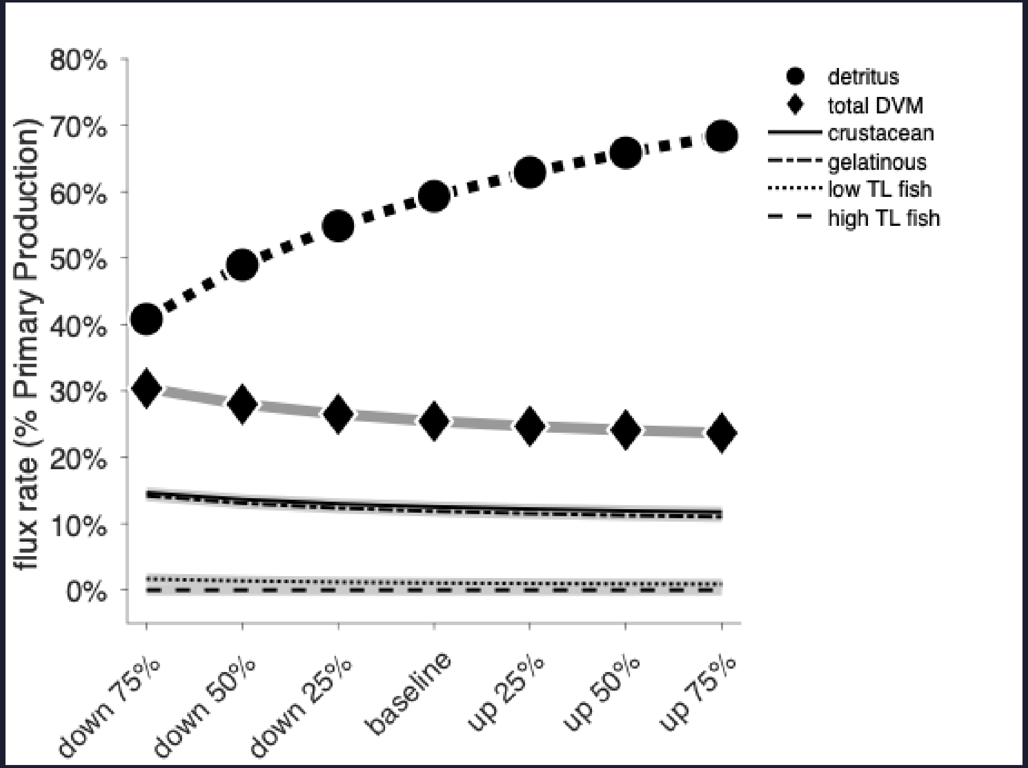

down 75%

down 50%

down 25%

up 25%
up 50%
up 75%

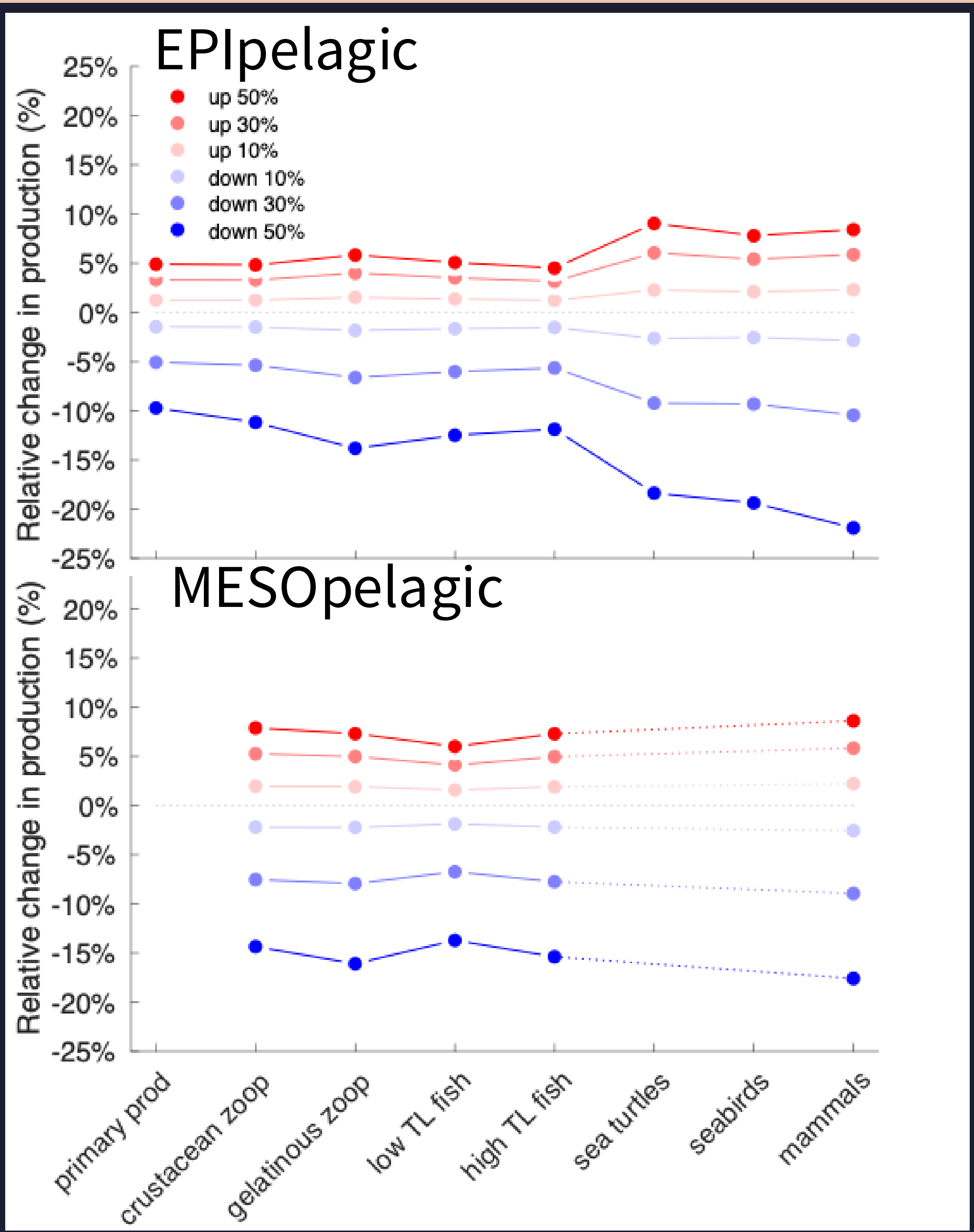
Detritus A: 5 m/d * X
Detritus B: 200 m/d * X
Detritus C: 1500 m/d




| EPI | sinking | DVM |
|---|---|---|
| UP 50% | 4.7% | -12.6% |
| DOWN 50% | -9.8% | 26.3% |

| MESO | sinking |
|---|---|
| UP 50% | 8.5% |
| DOWN 50% | -8.2% |

# Sensitivity to temperature response




Exponential $Q_{10}$ scaling term affects both metabolic costs & feeding rate

$Q_{10} = 3.0$

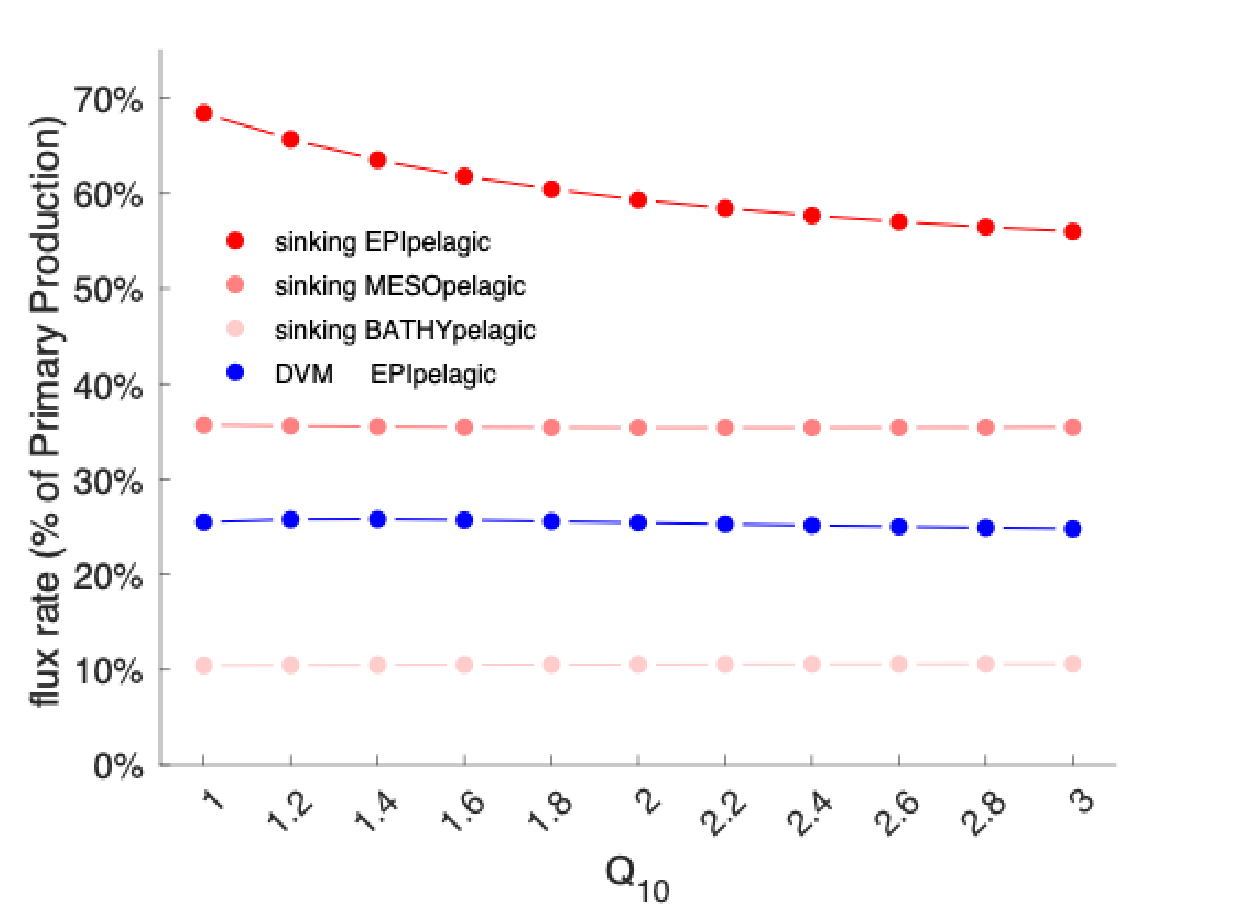
$Q_{10} = 2.6$

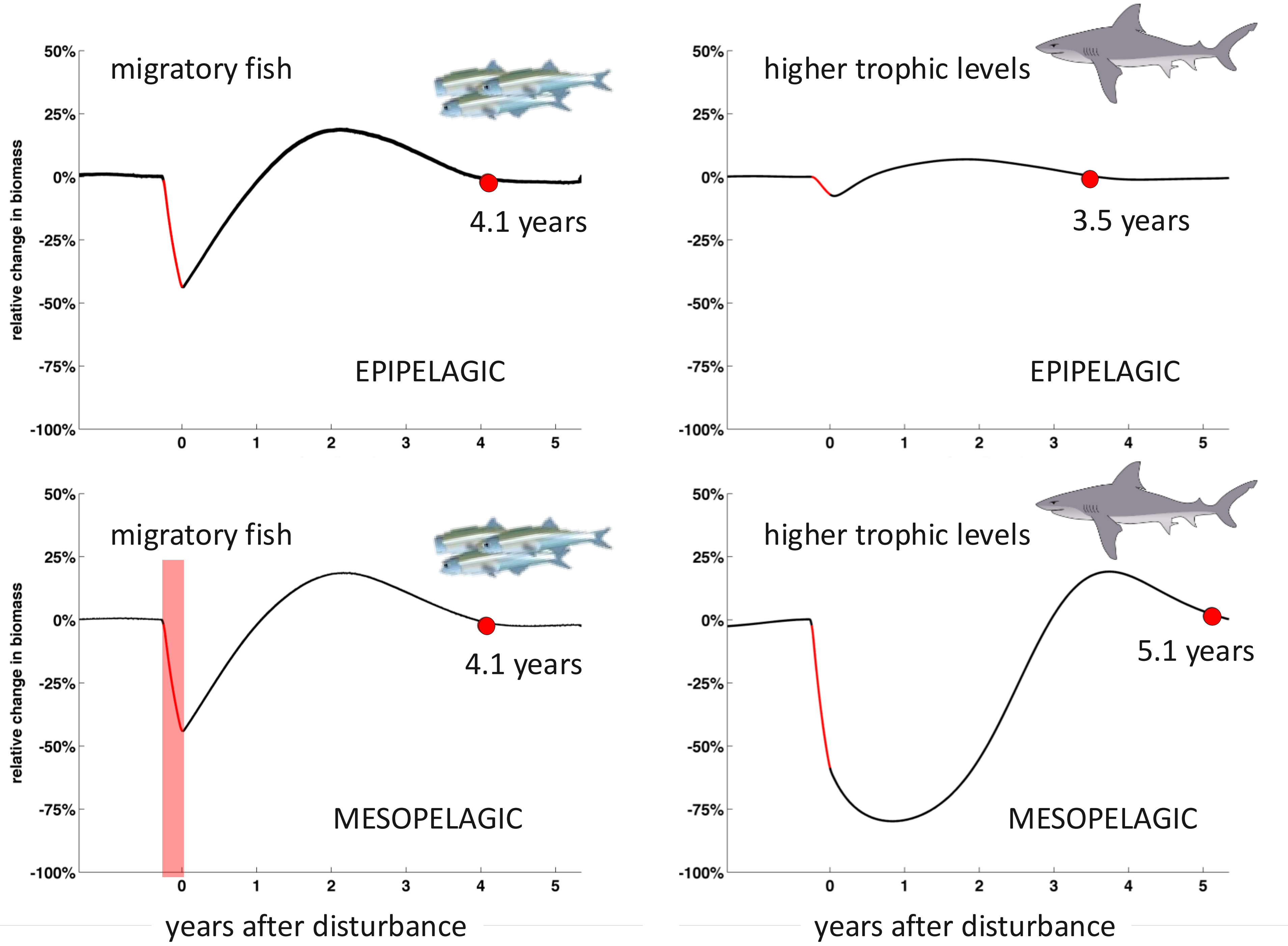
$Q_{10} = 2.2$

$Q_{10} = 1.8$

$Q_{10} = 1.4$

$Q_{10} = 1.0$



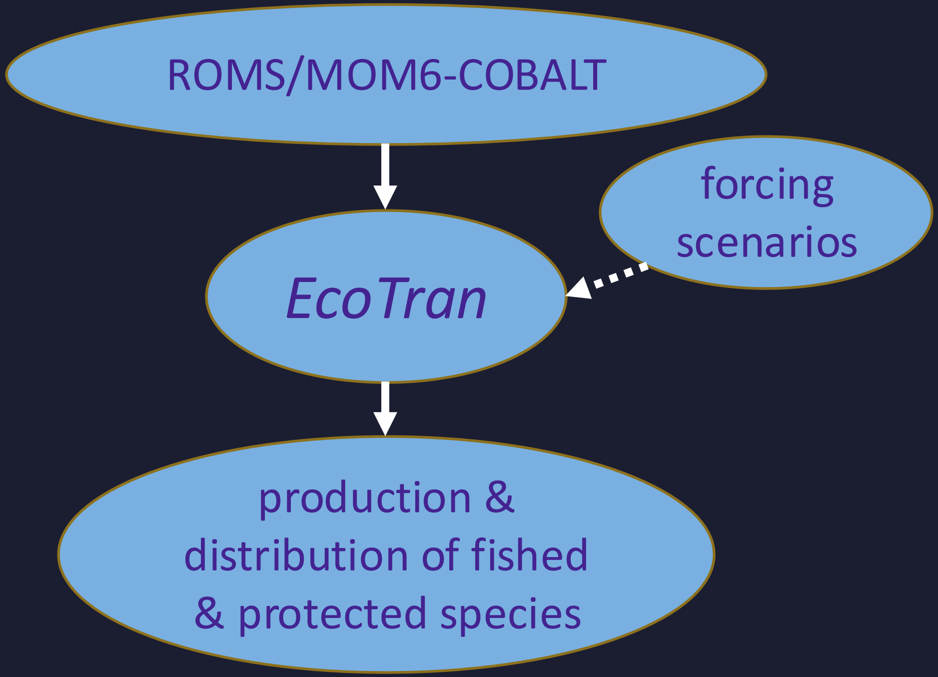


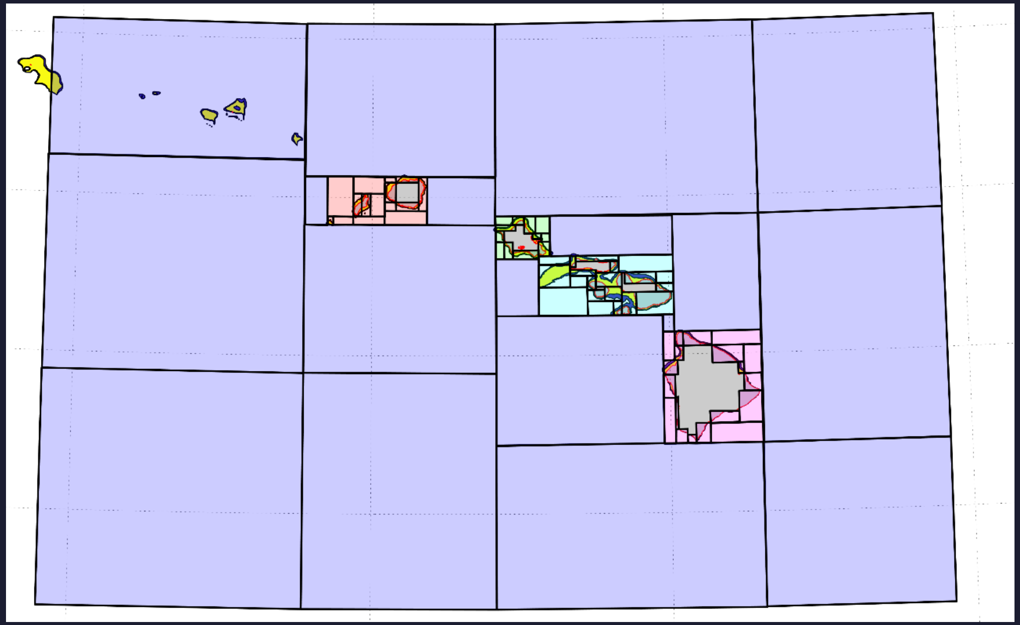
migratory fish
4.1 years
EPIPELAGIC
higher trophic levels
3.5 years
EPIPELAGIC
migratory fish
4.1 years
MESOPELAGIC
higher trophic levels
5.1 years
MESOPELAGIC
relative change in biomass
50%
25%
0%
-25%
-50%
-75%
-100%
0
1
2
3
4
5
years after disturbance
years after disturbance

# *Hawai'i-EcoTran*

## End-to-end ecosystem modeling for nearshore & oceanic regions

- *MECHANISTIC multi-species ecosystem* model for nearshore & oceanic regions driven with ROMS & MOM6 output
  - OUTPUT: group productivities & spatial distributions under variable environment & effort by longline & small-boat fleets
  - dynamics evolve from interaction of trophic, physiological, and behavioral rules defining multiple functional groups

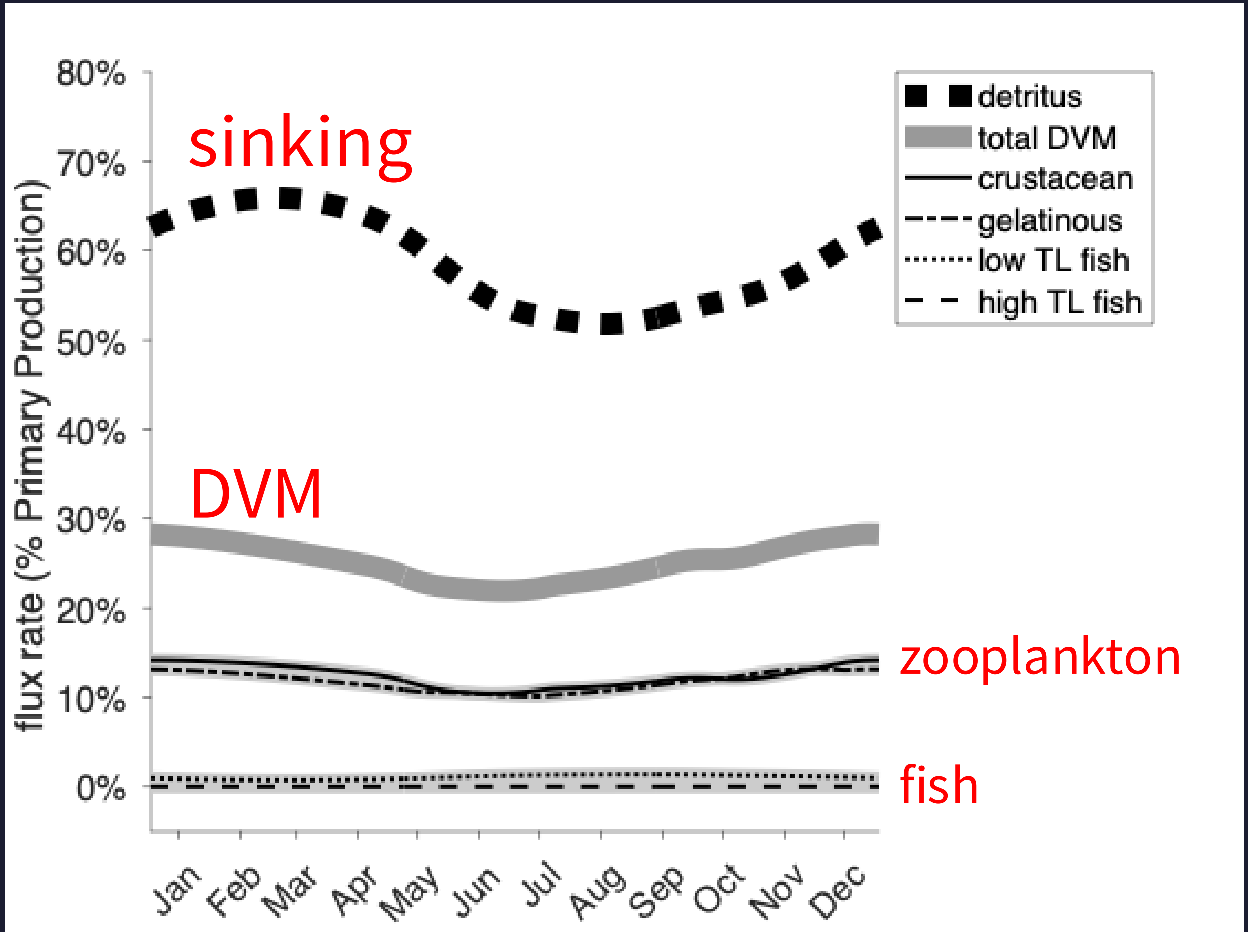


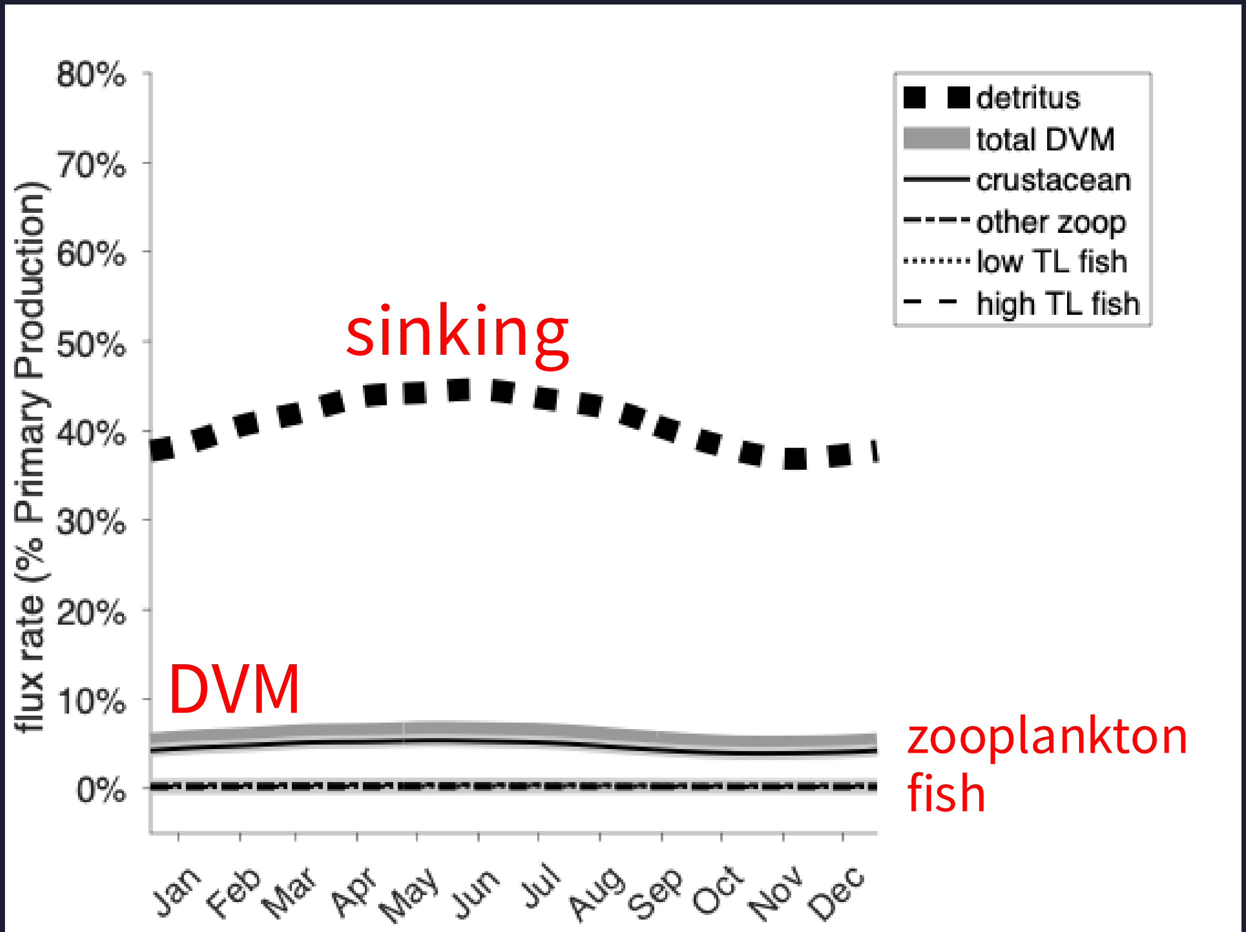
- Grid: 84 oceanic & nearshore regions, 4 depth zones
  - Physical model drivers w/ Dax Matthews
- Food web: builds from Weijerman & Choy models
  - 54 nearshore groups
  - 40 oceanic groups

# Comparison: Net Daily Vertical Flux Rates

**Gulf of Mexico**: DVM is 30% of total Biological Carbon Pump

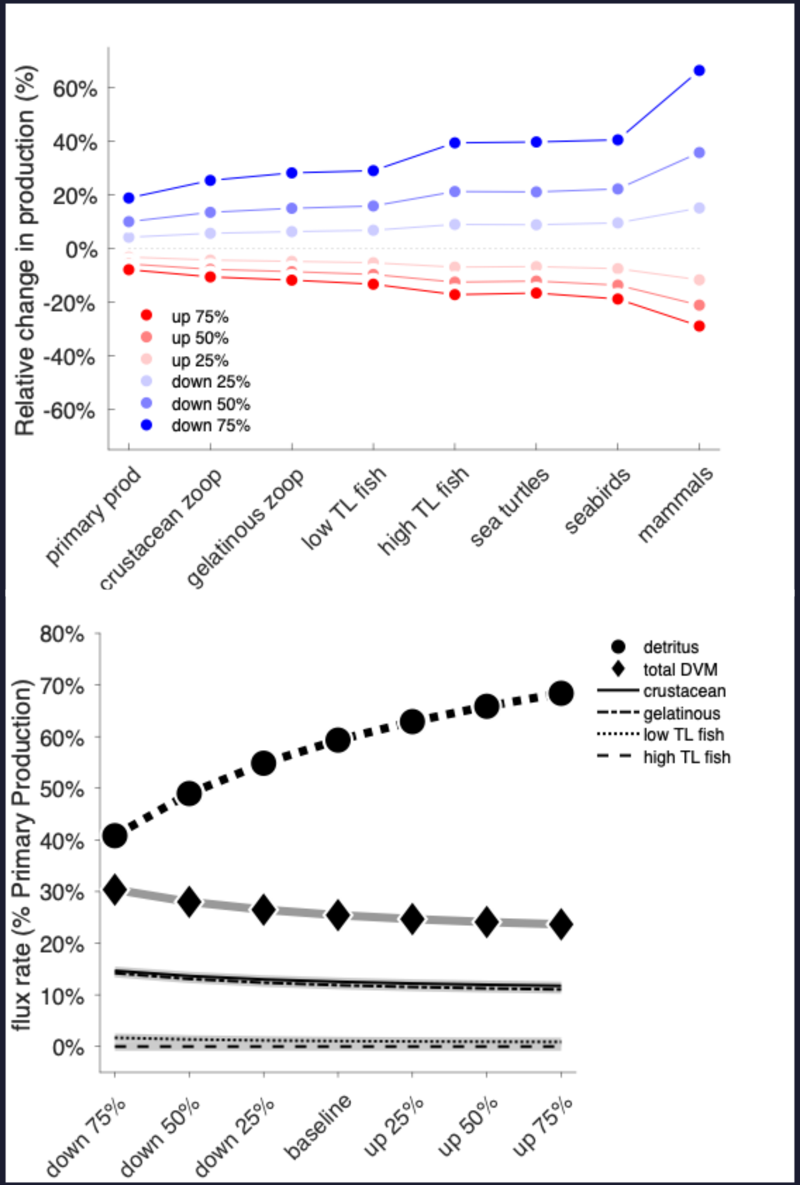



**Central North Pacific**: DVM is 12% of total Biological Carbon Pump

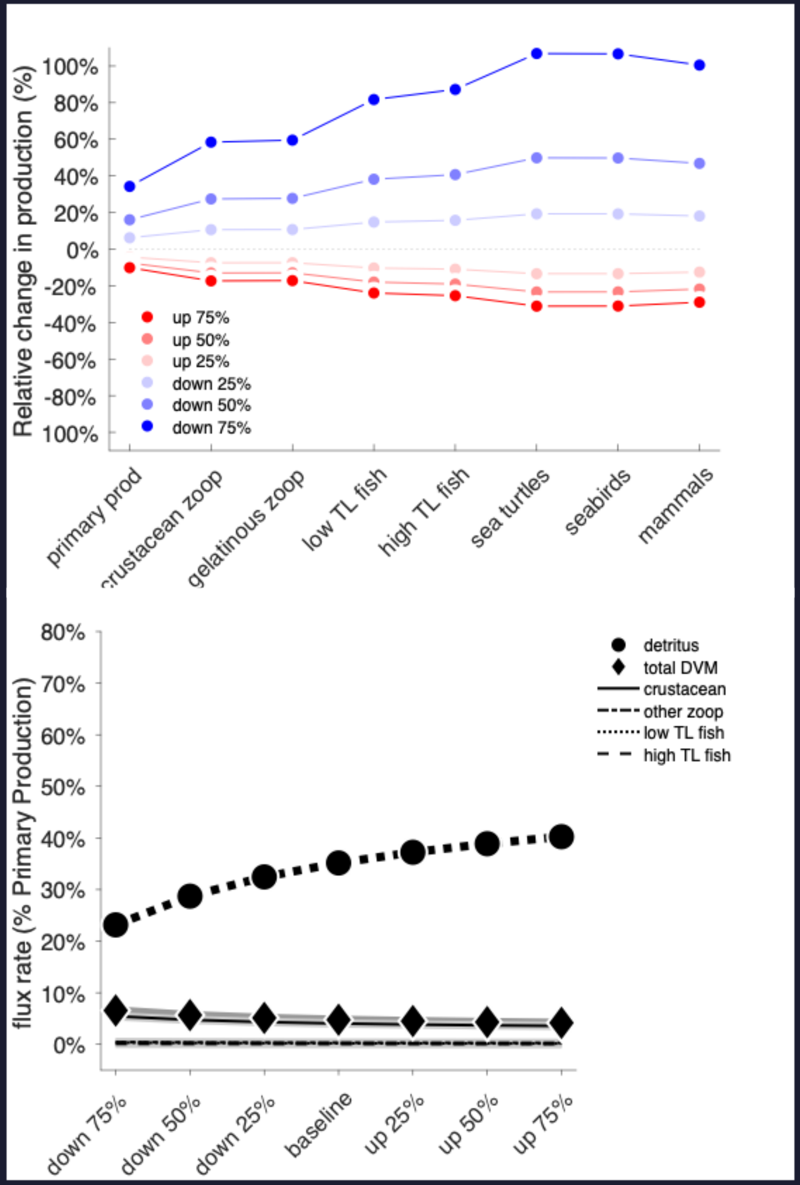


# Comparison: Sinking Rate Response

## Gulf of Mexico

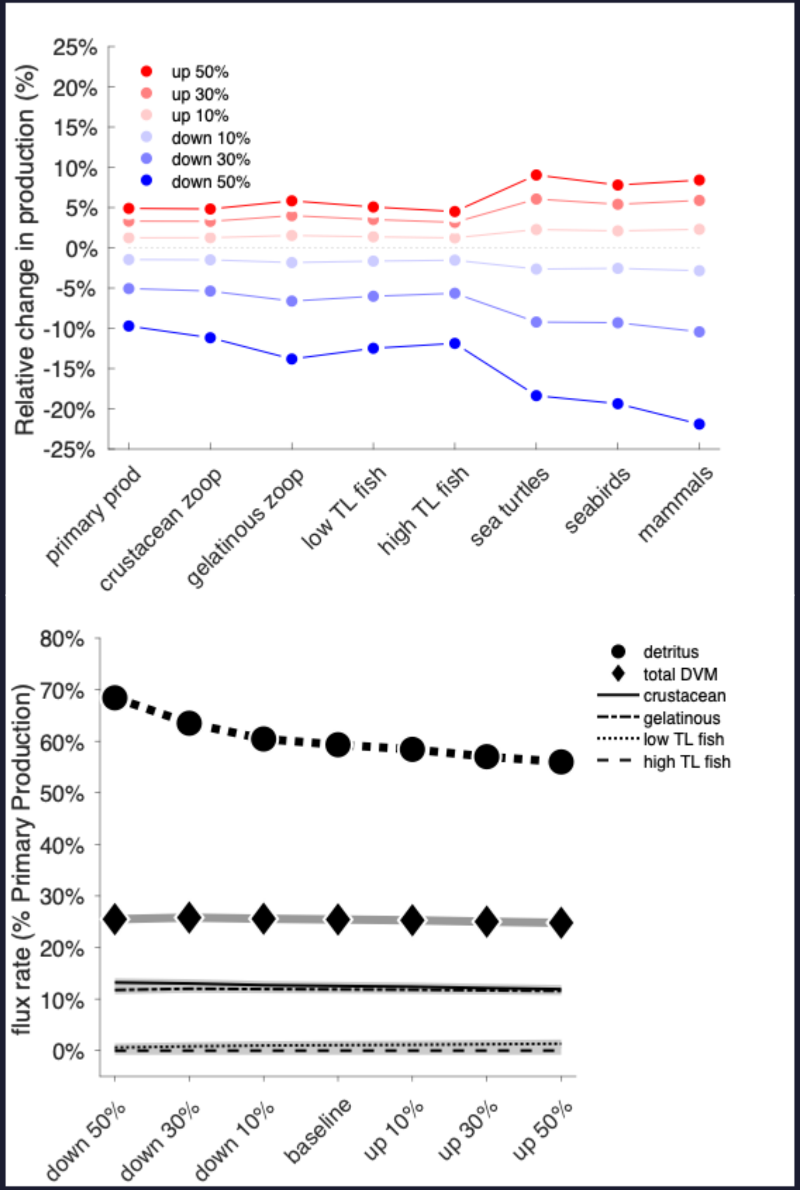



## Central North Pacific

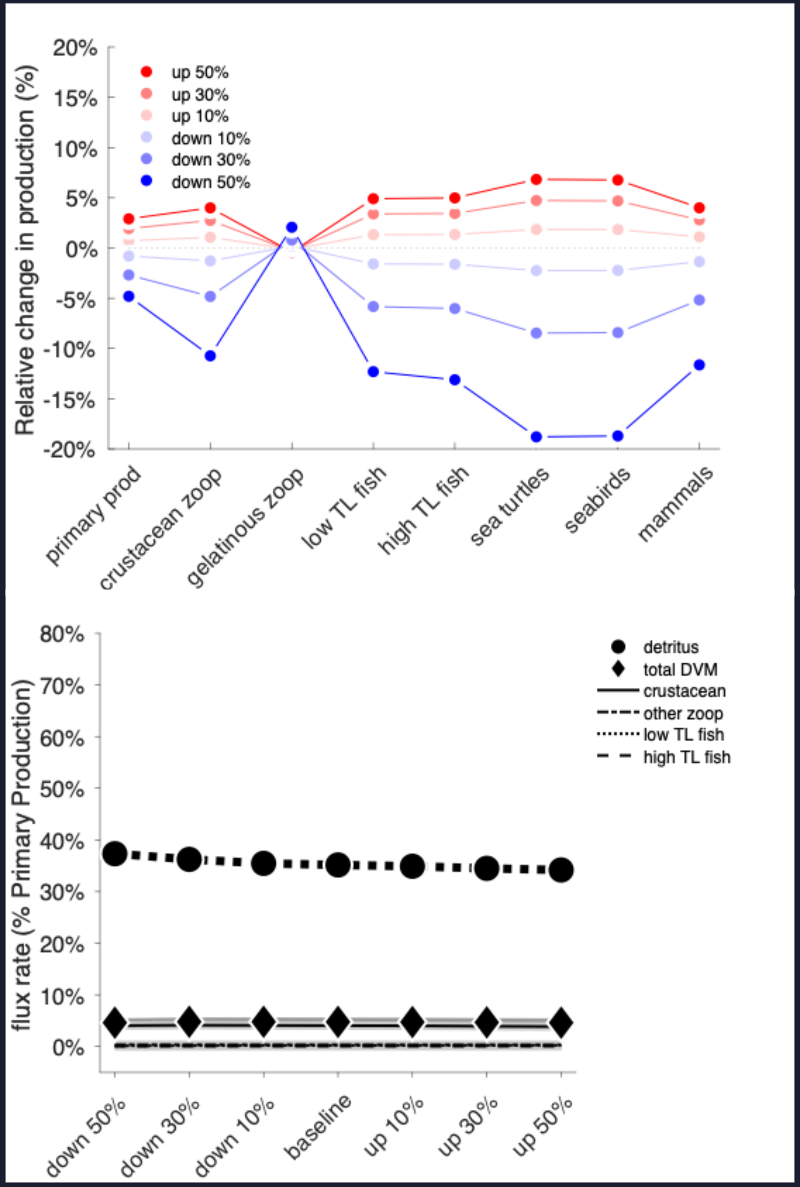


# Comparison: Temperature Response ($Q_{10}$)

## Gulf of Mexico

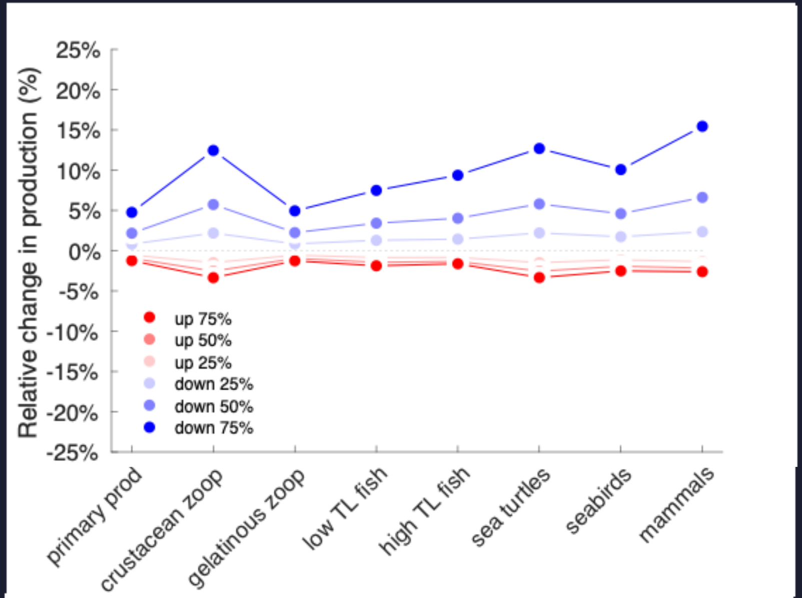


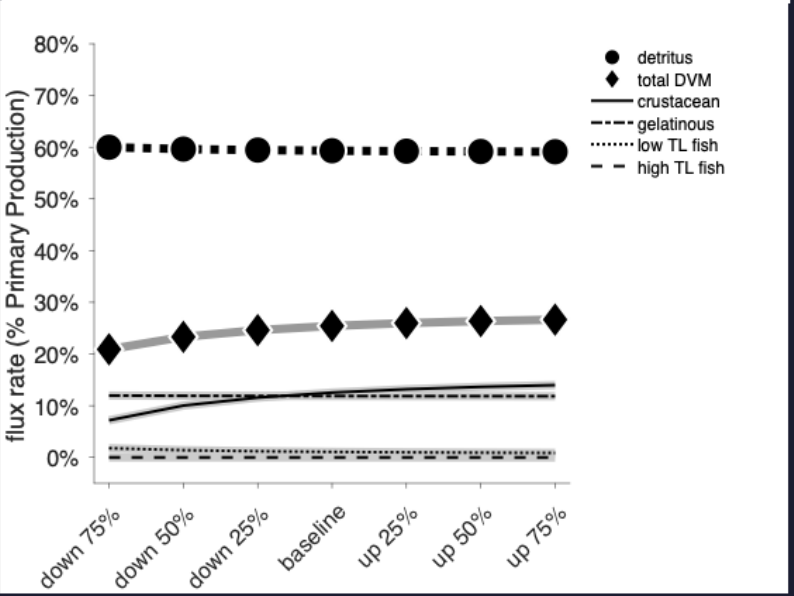

## Central North Pacific



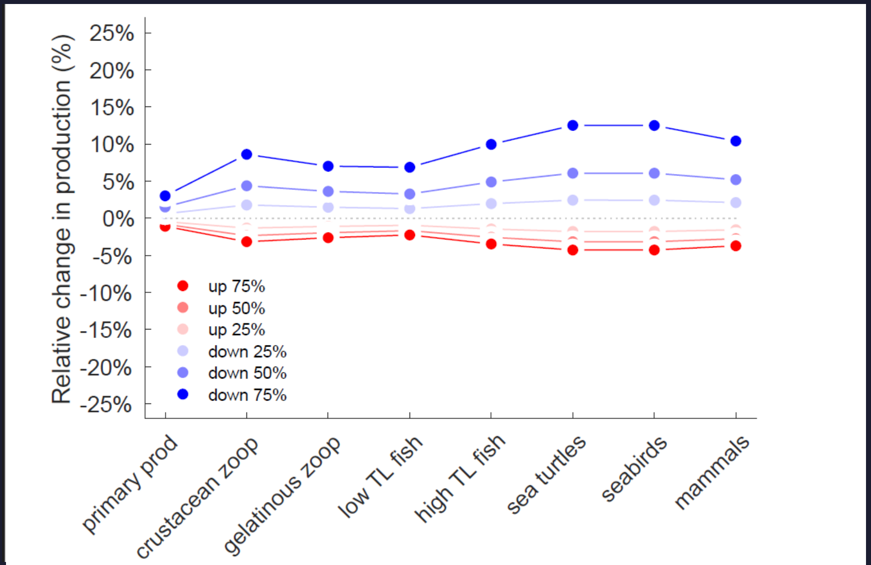
# Comparison: Crustacean Zooplankton DVM rate

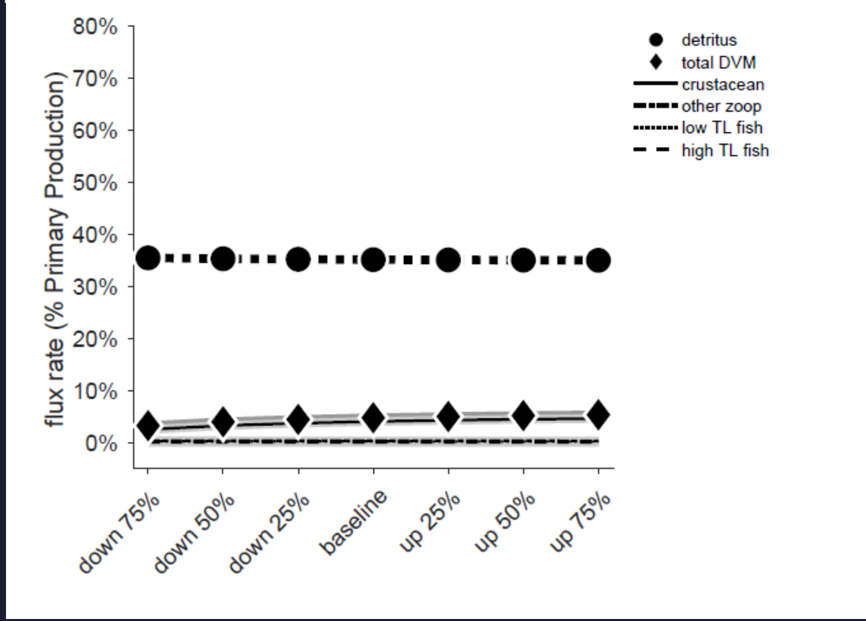
## Gulf of Mexico




## Central North Pacific



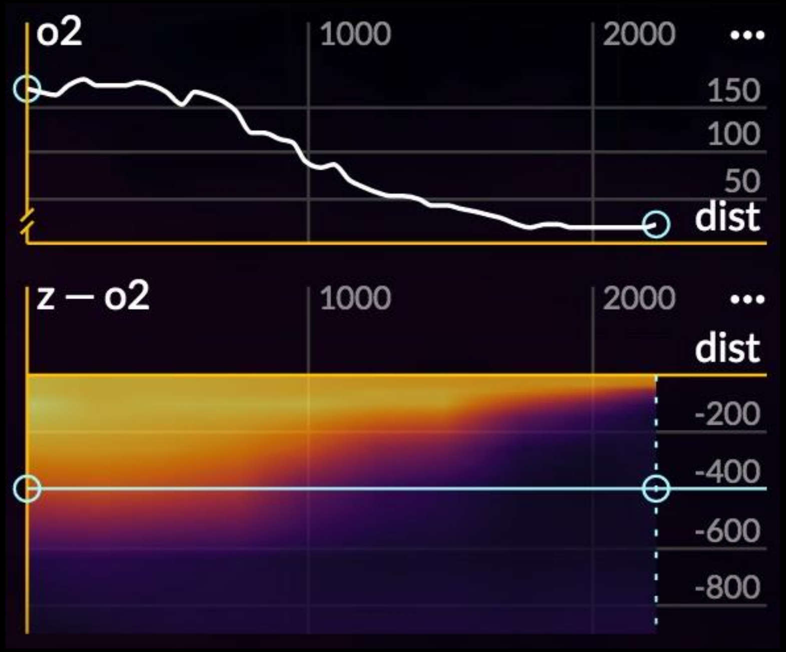



# *EcoTran* process modeling in the **Central North Pacific**

## Oxygen

effects on vertical migration & physiology

Oxygen profile @ 400m-longline target (150W, 30-10N)

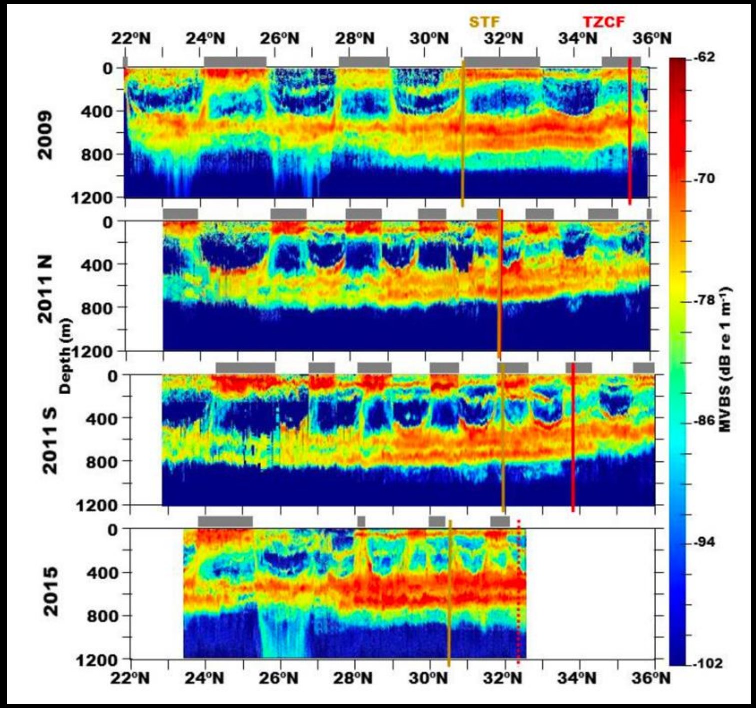



Copernicus: GLOBAL_MULTIYEAR_BGC_001_029

## Regional-Temporal changes in DVM

Acoustics: DVM

at ocean feature

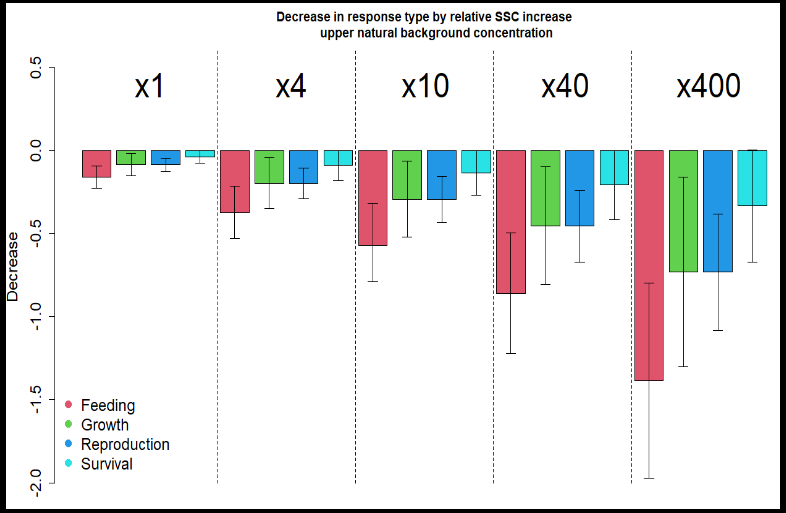


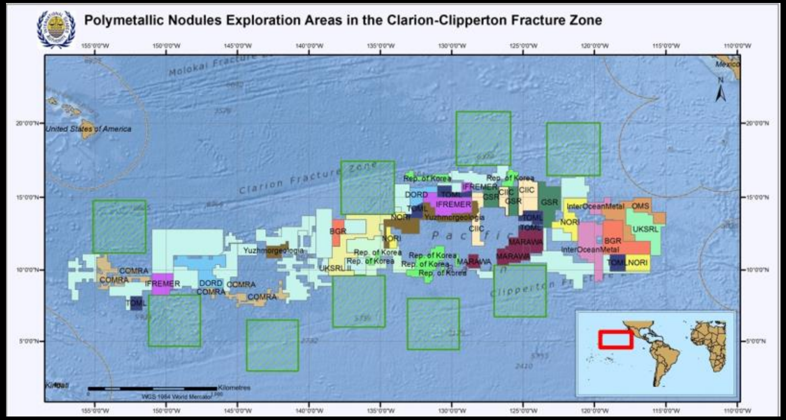

Domokos 2023 DeepSea Res I

## Deep-sea Mining Plumes

effects of plumes on physiology & trophic ecology

Jesse van der Grient Ph.D (UH SOEST)




ISA 2014