A Novel Approach to Estimating Active Carbon Flux Using the Biomass Size Spectra

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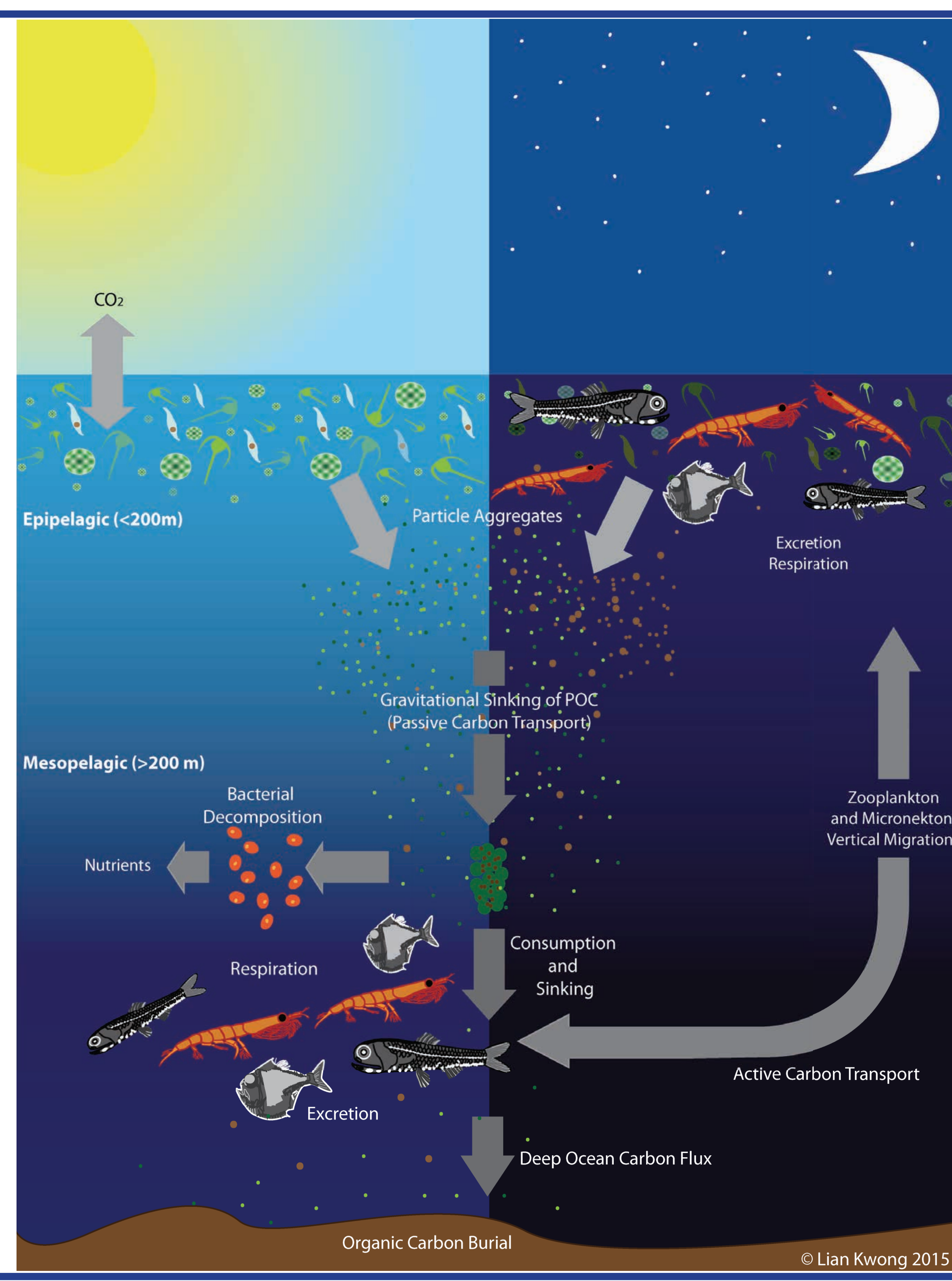
Oceans play a critical role in global carbon cycling.
The process known as the **biological carbon pump** involves the synthesis of organic matter by phytoplankton at the ocean's surface and its subsequent transport to the deep ocean via:

1. **Passive carbon transport** via gravitational settling of organic particles, and
2. **Active carbon transport** via vertical migrations of zooplankton and micronekton feeding in the epipelagic at night and residing in the mesopelagic during the day.



Current estimates of active carbon transport focus primarily on individual species/ groups or certain fluxes. Whole communities and all four fluxes (respiration [R], excretion [E], gut flux [G] and mortality[M]) are not often considered.

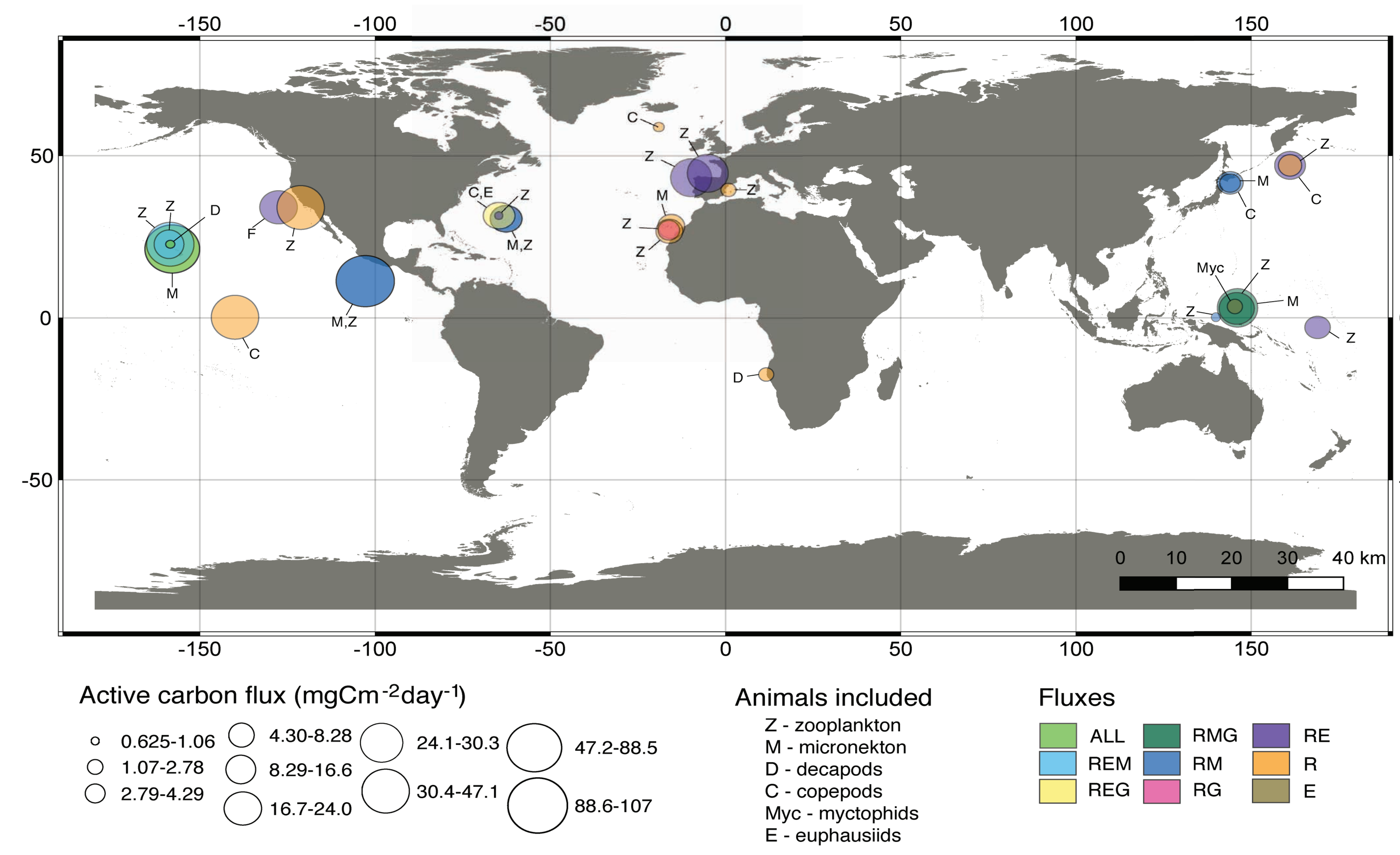


Fig 4. Locations of past studies assessing active carbon flux. It should be noted that the depth of export is not portrayed in this figure.

Main Objectives

1. Develop biomass size spectra for the day and night in the mesopelagic zone and for the night in the epipelagic zone
2. Estimate total migratory micronekton biomass
3. Develop a biomass/production size dependent model based on the biomass spectra theory to quantify active carbon

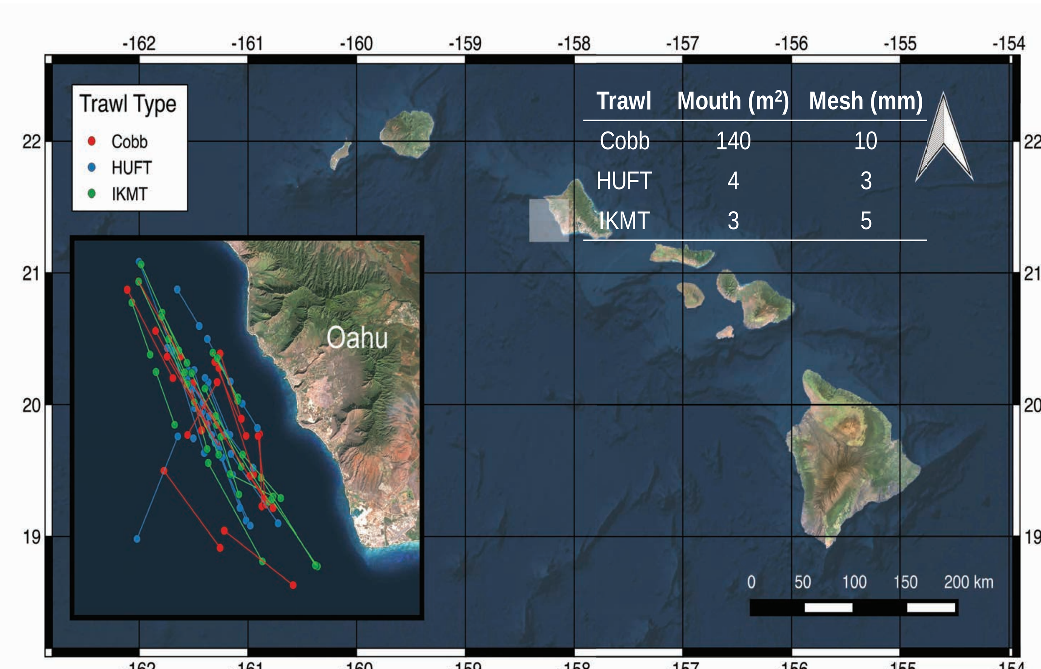
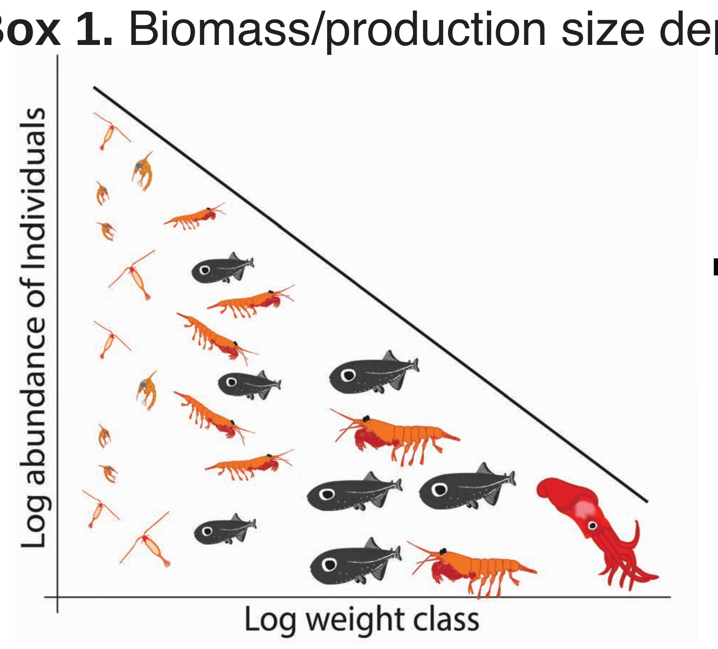


Fig 1. Sampling locations by trawl type on the southwest coast of Oahu, Hawaii.

Methodology

- Depth stratified (0-100 and 550-650 m) diel sampling using three different trawl types off the southwest coast of Oahu, Hawaii (**Fig. 1**)
- Size dependent equations obtained from the literature for respiration, mortality, excretion and gut flux to be used in biomass/production size dependent model (**Box 1**).

Box 1. Biomass/production size dependent modelling.



Biomass Size Spectra[1]

$$W_{Ni} = W_i\left(\frac{2^{b+1}-1}{(2-1)(b+1)}\right)^{\frac{1}{b}}$$

Standing Stock Abundance

$$N_{W_{Ni}} = \int_{i+1}^{i} N(w)dw$$

Respiration[2]

$$lnRO_{CW_{Ni}} = 0.5254 + 0.8354 * lnCW_{Ni} + 0.0601T$$

$$R(CW_{Ni}) = RO_{CW_{Ni}} * RQ * \left(\frac{12}{22.4}\right)$$

$$\widehat{\boldsymbol{R}} = \sum_{i=1}^{N}(N_{W_{Ni}} * R(CW_{Ni}))$$

Excretion[3]

$$E(CW_{Ni}) = R_{Ni} * 0.31$$

$$\widehat{\boldsymbol{E}} = \sum_{i=1}^{N}(N_{W_{Ni}} * E(CW_{Ni}))$$

Gut Flux[4]

$$G(CW_{Ni}) = CW_{Ni} * 0.15 * \frac{\left(ISF_{Ni} * \frac{10}{GPT_{Ni}^{-1}}\right)}{100}$$

$$\widehat{\boldsymbol{G}} = \sum_{i=1}^{N} N_{W_{Ni}} * G(CW_{Ni})$$

Mortality[5]

$$HM(DW_{Ni}) = \frac{(5.26 * 10^{-3}day^{-1}) * DW_{Ni}{}^{-0.25}}{24\ hours}$$

$$M(CW_{Ni}) = B(CW_{Ni}) * HM(DW_{Ni}) * TD * CR$$

$$\widehat{\boldsymbol{M}} = \sum_{i=1}^{N} M(DW_{Ni})$$

$$\textit{Active Carbon Flux} = \widehat{\boldsymbol{R}} + \widehat{\boldsymbol{M}} + \widehat{\boldsymbol{E}} + \widehat{\boldsymbol{G}}$$

- b = Slope of the biomass size spectra
- W_{Ni} = Nominal size class (carbon (CW_{Ni}) or dry (DW_{Ni}) weight) representing each size bin
- W_i = Lower limit of the size class
- $N_{W_{Ni}}$ = Abundance of individuals in a given nominal size class
- $N(w)$ = Abundance of individuals by carbon or dry weight
- $B(CW_{Ni})$ = Biomass in a given nominal size class
- T = Environmental temperature (°C)
- $RO_{CW_{Ni}}$ = Respiratory rate of oxygen uptake for a given nominal size class
- RQ = Respiratory quotient (0.97)
- $R(CW_{Ni})$ = Respiratory carbon equivalent for a given nominal size class
- ISF_{Ni} = Index of stomach fullness
- GPT_{Ni} = Gut passage time for a given nominal size class
- $G(CW_{Ni})$ = Gut flux for a given nominal size class
- $E(CW_{Ni})$ = Excretion rate for a given nominal size class
- TD = Time at depth (hours)
- CR = Carbon weight to dry weight ratio for data set
- $HM(DW_{Ni})$ = Hourly mortality rate for a given nominal size class
- $M(DW_{Ni})$ = Mortality rate for a given nominal size class
- $\widehat{R}$ = Total community respiration
- $\widehat{G}$ = Total community gut flux
- $\widehat{E}$ = Total community excretion
- $\widehat{M}$ = Total community mortality

References: 1. Blanco et al. 1994. *Scientia Marina 58*(1-2):17-29. **2.** Ikeda. 1985. *Mar. Biol. 85*:1-11. **3.** Pakhomov et al. 1996. *Mar. Ecol. Prog. Ser.134*(1-3):1-14. **4.** Peterson and Wroblewski. 1984. *Can. J. Fish. Aquat. Sci.* 41:1117-1120. **5.** Steinberg et al. 2000. *DSR 1 47*(1):137-158.

Results

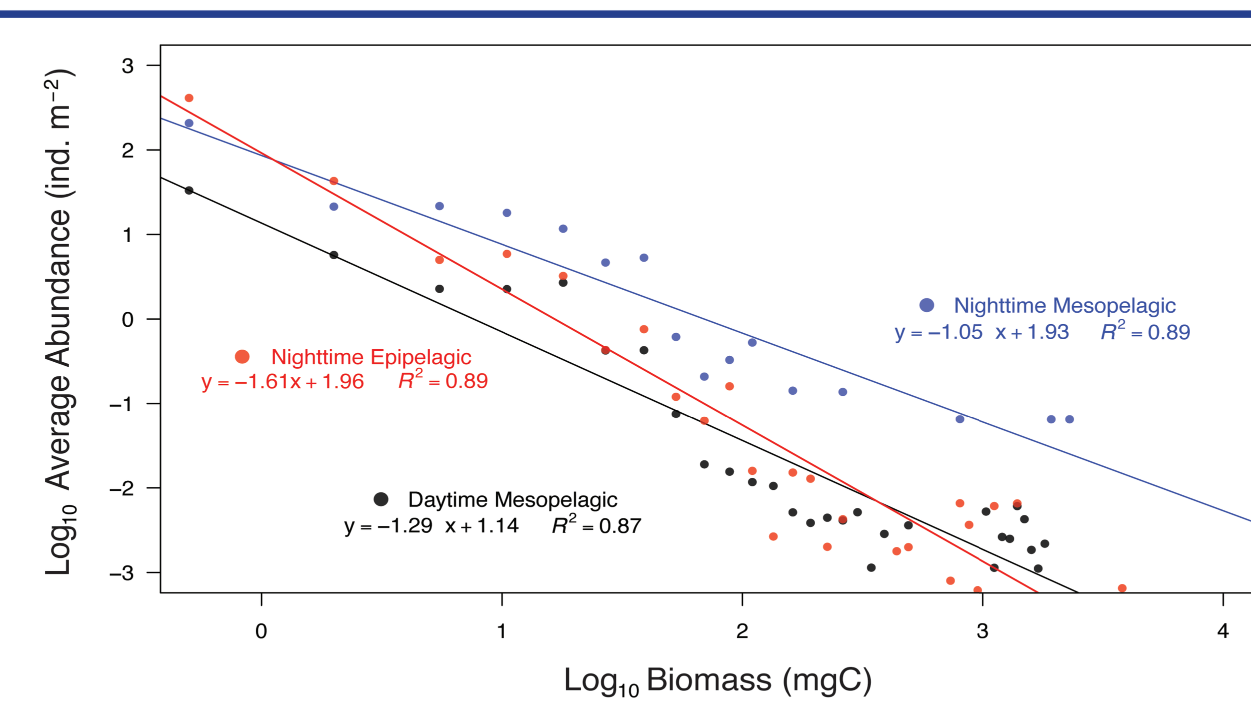


Fig 4. Biomass size spectra expressed as the log-transformed relationship between average abundance (individuals m^{-2}) of against carbon weight (mg) for organisms ranging from 20 to 100 mm in length.

Table 1. Results of the sensitivity analysis as percent change in the carbon flux rate from the epipelagic to mesopelagic for perturbation in individual parameters.

Parameter	Perturbation							
	-40%	-20%	-10%	-5%	5%	10%	20%	40%
Index of stomach fullness	17	9	4	2	-2	-4	-9	-17
Gut passage time	-29	-11	-5	-2	2	4	7	12
Gut flux	17	9	4	2	-2	-4	-9	-17
Respiratory oxygen	16	8	4	2	-2	-4	-8	-16
Respiratory carbon	16	8	4	2	-2	-4	-8	-16
Daily mortality	6	3	2	1	-1	-2	-3	-6
Mortality	6	3	2	1	-1	-2	-3	-6
Excretion	4	2	1	0	0	-1	-2	-4

Total micronekton migrant biomass:
- Based on the biomass size spectra model: **7796.5 mgC m^{-2}**
- Based on catch: **543.5 mgC m^{-2}** (7% of biomass spectra estimate)

Active carbon transport:
- Based on the biomass size spectra model: **105 mgC m^{-2} day^{-1}**
- Based on catch: **17.6 mgC m^{-2} day^{-1}** (17% of biomass spectra estimate)

Conclusions

- The biomass spectra approach provides a promising tool for predicting active carbon flux, particularly at the community level.
- In combination with the use of multiple gears, the biomass spectra may potentially reduce net sampling bias associated with avoidance by larger micronekton.
- Previous estimates of active carbon flux may have underestimated the contribution of zooplankton and micronekton to global carbon cycling by up to an order of magnitude.
- While time at depth can be estimated using global acoustic data sets, gut flux requires further investigation to decrease model uncertainty.
- Combining this model with acoustic methods may improve predictions of regional and global active carbon fluxes.

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