The influence of declining oxygen and mesopelagic fish biomass on ecosystem structure and carbon export in the California Current

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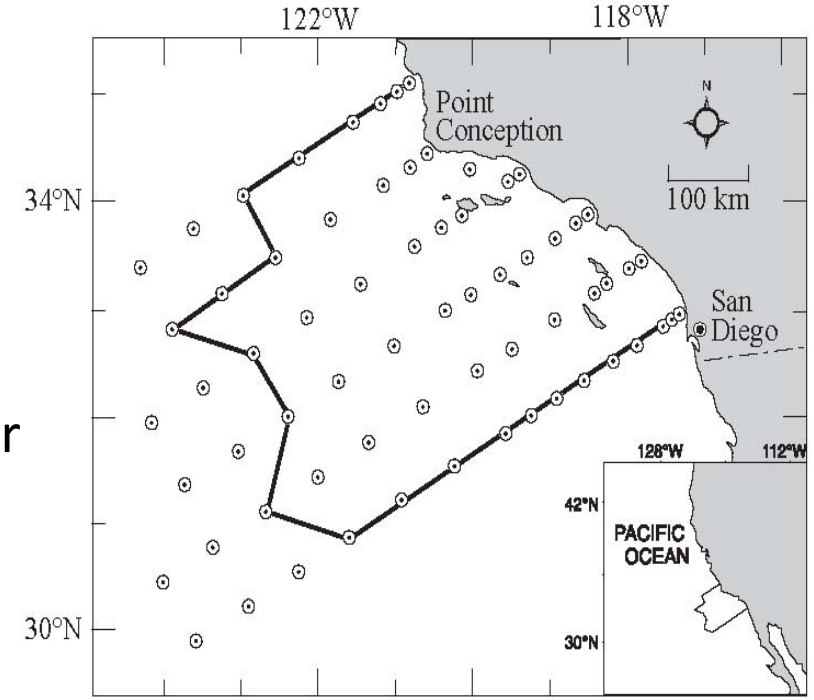
Outline

- Decadal scale variability of mesopelagic fishes in California Current (Koslow et al 2011)
- Midwater fishes in regional food webs
  - biomass and trophic role of midwater fishes relative to epipelagic planktivores
  - Do we need to expand the 'wasp-waist' of EBC food webs to include mesopelagics?
- Role of midwater fishes in the carbon flux:
  - Should we continue to neglect the active C flux by fish?

Data & background

- CalCOFI ichthyoplankton time series, 1951-present
  - Monthly/quarterly sampling
  - Oblique net tows to 210 m depth
  - All fish eggs/larvae removed, identified, enumerated (~500 taxa)
  - CTD casts to 500 m; water samples for nutrients, O_2, chl, salinity
- Method
  - Annual means estimated for each taxon over consistently sampled portion of grid
  - Rare species removed (0 > 50% of years)
  - 86 taxa consistently sampled, 1951-2008



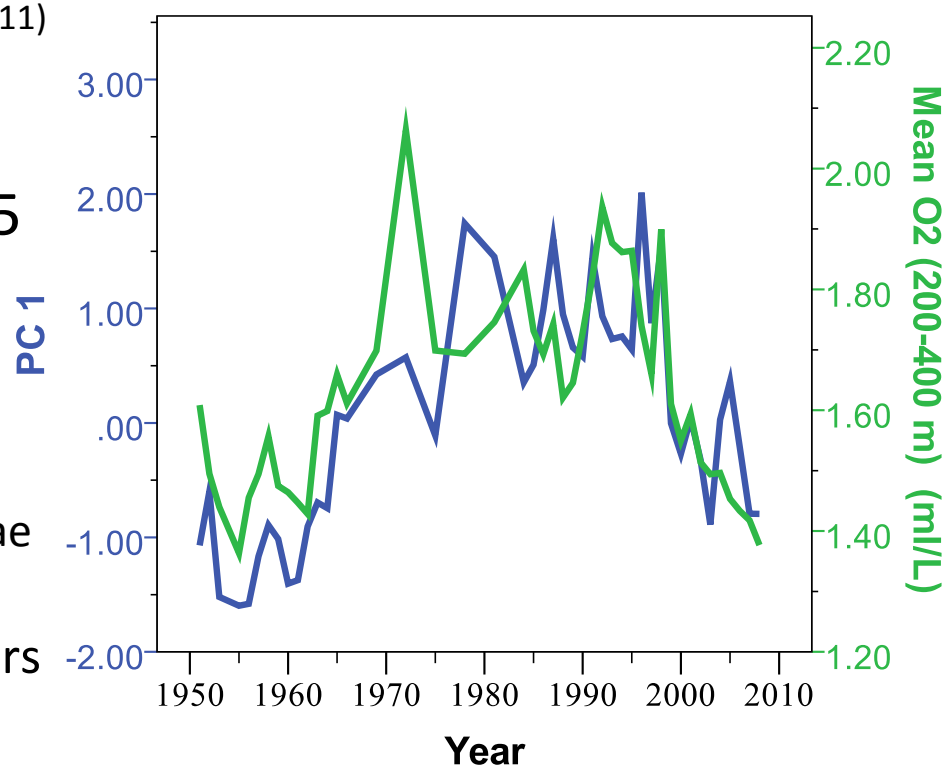
Since 2010, CalCOFI supplemented with multifrequency acoustic & pelagic trawl sampling to estimate micronekton biomass

Dominant pattern based on PCA

(Koslow et al 2011)

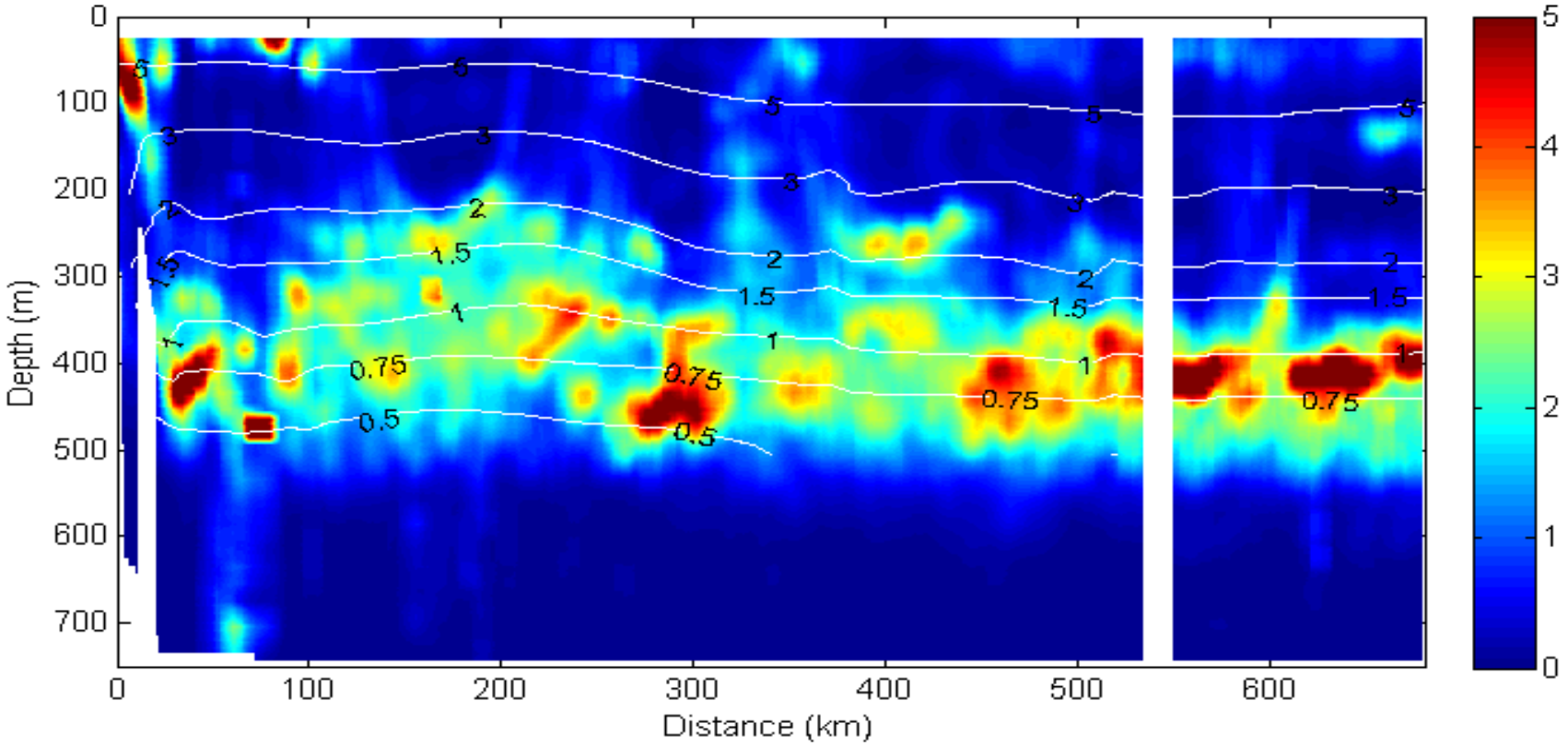
PC 1 (20.5% var explained):

- 24/27 taxa with loadings ≥ 0.5
- mesopelagic from 8 families:
  - Myctophidae, Gonostomatidae, Sternoptychidae, Stomiidae, Phosichthyidae, Scopelarchidae, Argentinidae, and Microstomatidae
  - Includes vertical migrators & non-migrators, plankton feeders & predators



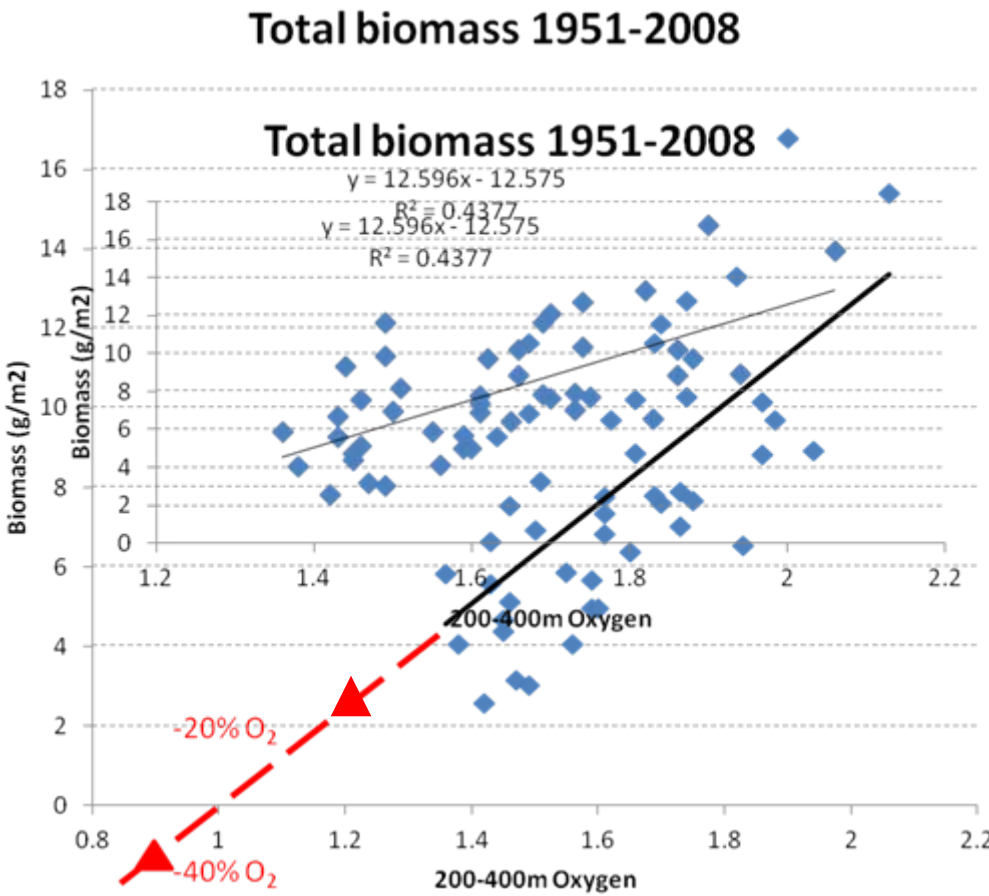
PC 1	O_2 (200-400 m)	PDO	MEI	NPGO	SST	Upwelling
R	0.75*	0.56**	0.47*	-0.23	0.45?	-0.25
N* (corrected for autocorrelation)	8	26	30		20	

- DSL in California Current resides above OMZ
- Shoaling OMZ causes DSL to shoal, where more vulnerable to visual predators
- + PDO & MEI, - upwelling: depressed thermocline, deeper OMZ



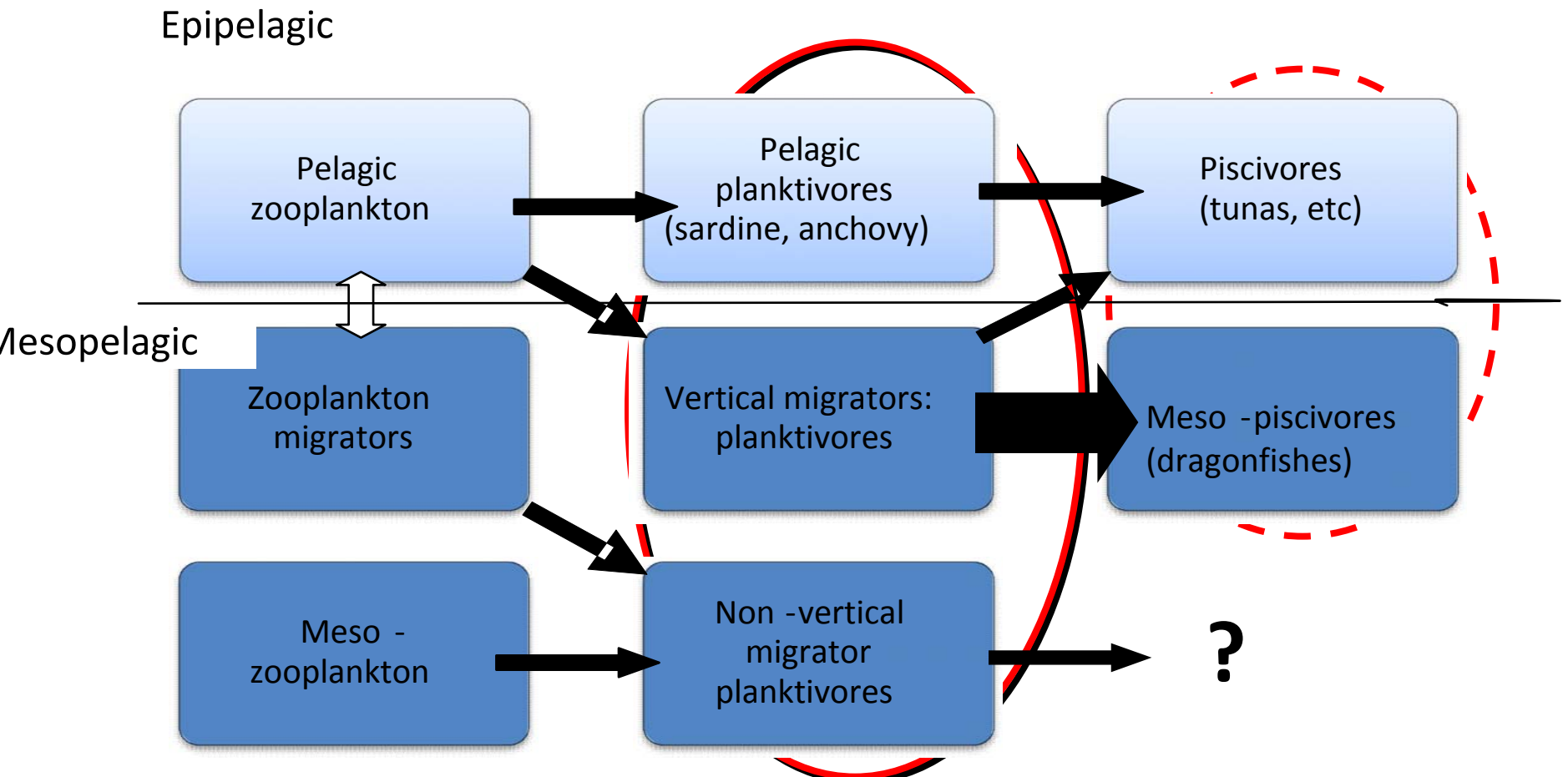
Implications of climate change & deoxygenation

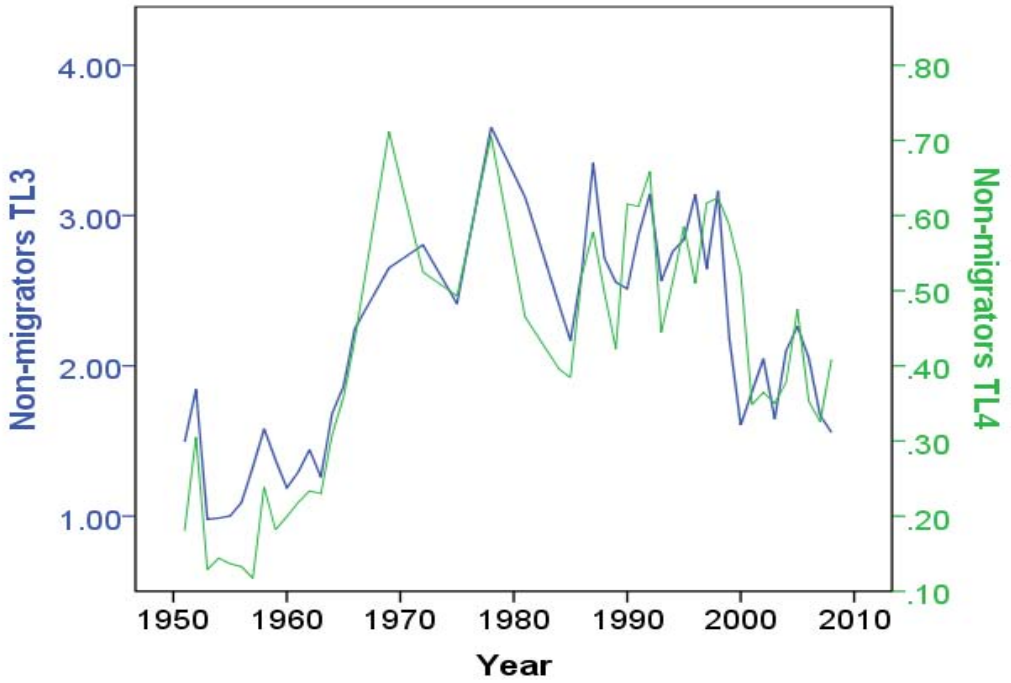
- Mesopelagic fish biomass estimated from recent acoustic/trawl studies in CalCOFI area; past values estimated from relative abundance of total mesopelagic fish larvae
- 3.5-fold range in estimated biomass of mesopelagic fish, 1951-2008
- Extrapolation of a further 20-40% decline in O_2 concentration from GCMs implies disappearance, if linear trend continues!

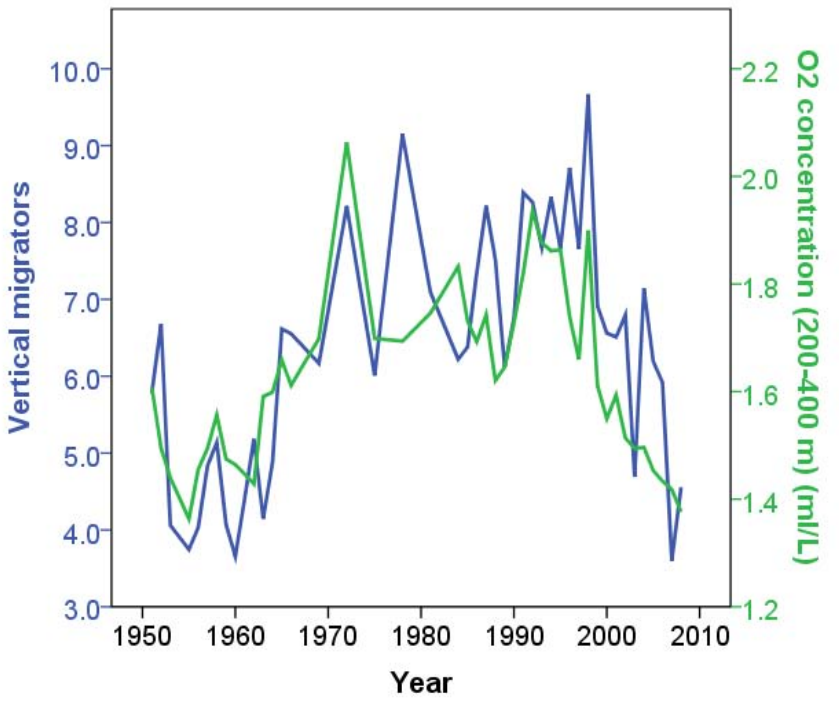


What are the ecosystem impacts of changing midwater fish populations?

- What are the biomass levels?
- What are the trophic interactions and their relative importance?







	VM	NM-3	NM-4
NM-3	.88*** (15)		
NM-4	.76*** (16)	.85*** (13)	
O_2	.75*** (16)	.77** (13)	.68* (13)

Consistent very strong + correlations between midwater groups (migrators, non-migrators, plankton feeders & predators): r = 0.76 – 0.88.

	Vertical migrators	Non-migrators TL3	Non-migrators TL4
Hake	0.48* (26)	0.51* (22)	0.43* (23)
Anchovy	0.41? (19)	0.57* (16)	0.53* (16)
Jack mackerel	0.37* (45)	0.30 ns (16)	0.21 ns (46)
Pacific mackerel	0.47* (25)	0.62** (21)	0.38* (22)

Consistent + correlations among most potential predators, prey & competitors: r = 0.4 – 0.6
Anchovy & sardine: r = -0.41*

Little evidence for compensatory changes due to +/- changes in competitors (mesopelagic v epipelagic planktivores/piscivores)

Relationships with environmental variables

(N*): # independent data points, corrected for autocorrelation

?: 0.10<p<0.05; *: p<0.05; **: p<0.01; ***: p < 0.001

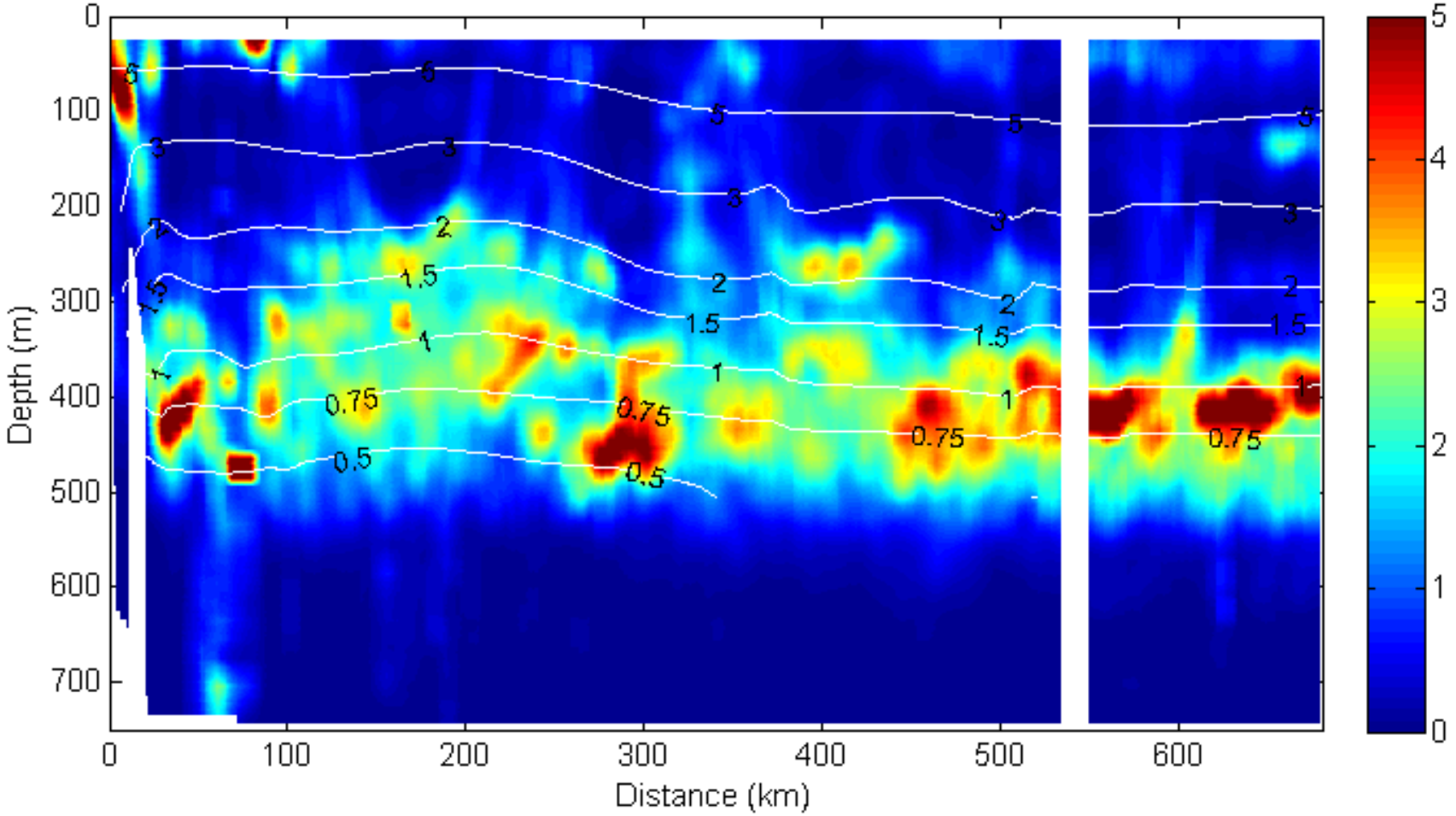
	$DeepO_2$	SST	T_{200}	Upwelling	MEI	PDO	NPGO
Vertical migrators	0.75*** (16)	0.10 ns	0.20 ns	-0.35* (46)	0.47** (36)	0.33* (46)	-0.39* (26)
Non-migrators TL3	0.77** (13)	0.13 ns	0.22 ns	-0.14 ns	0.42* (35)	0.43** (46)	-0.41* (25)
Non-migrators TL4	0.68* (13)	-0.02 ns	0.28? (45)	-0.20 ns	0.34* (36)	-.21 ns	-0.27 ns (24)
Hake	0.32 ns (21)	-0.06 ns	0.02 ns	0.06 ns	0.18 ns	0.32* (46)	-0.36* (38)
Anchovy		0.00 ns		0.25 ns	0.22 ns	0.32* (42)	0.17 ns
Jack mackerel		0.29* (38)		-0.25 ns	0.26? (45)	0.28? (37)	-0.37* (30)
Pacific mackerel		0.25 ns (36)		-0.12 ns	0.30ns (37)	0.59*** (29)	-0.11 ns

Summary of correlations

- Mesopelagics & O_2: **Strongly** correlated (r = 0.7 – 0.8)
- Mesopelagics & MEI: Consistent correlations (r = 0.3 – 0.5)
  - NOTE: + correlation with El Nino events! – Downwelling isotherms & oxycline
- Mesopelagics & pelagics correlated
- Both correlated with PDO & NPGO, but less consistently (r=0.3 - 0.4.)
  - +PDO = warm phase, shallow upwelling in N CC
  - -NPGO = shallow upwelling, low salinity, nutrients & chl in the CalCOFI area

The relative importance of the mesopelagic fauna

- Relative acoustic backscatter per ping, daytime averaged over 6 CalCOFI transects, January 2010
- Pelagics dominant coastally, mesopelagics offshore



Mesopelagic biomass

Based on trawl/acoustic biomass data for California Current and relation to satellite primary production (Davison 2011; Behrenfeld & Falkowski 1997)

Vertical migration determined taxonomically from trawls

2008 Mean biomass (MT)

	Migrators	Non-migrators	Total
CalCOFI area	1.8	2.0	3.8
Calif Current (30° - 48°)	8.6 (11.1 g/m^2)	9.9 (12.9 g/m^2)	18.5 (24.0 g/m^2)

Previous estimates: 3.6 g/m^2 (Pearcy & Laurs 1966, using IKMT)

Mesopelagic biomass 39% less in the last decade than 1966-99, when

~ 6 MT in CalCOFI area

~30 MT in California Current

Trophic impact with current (and 1966-99) mesopelagic biomass

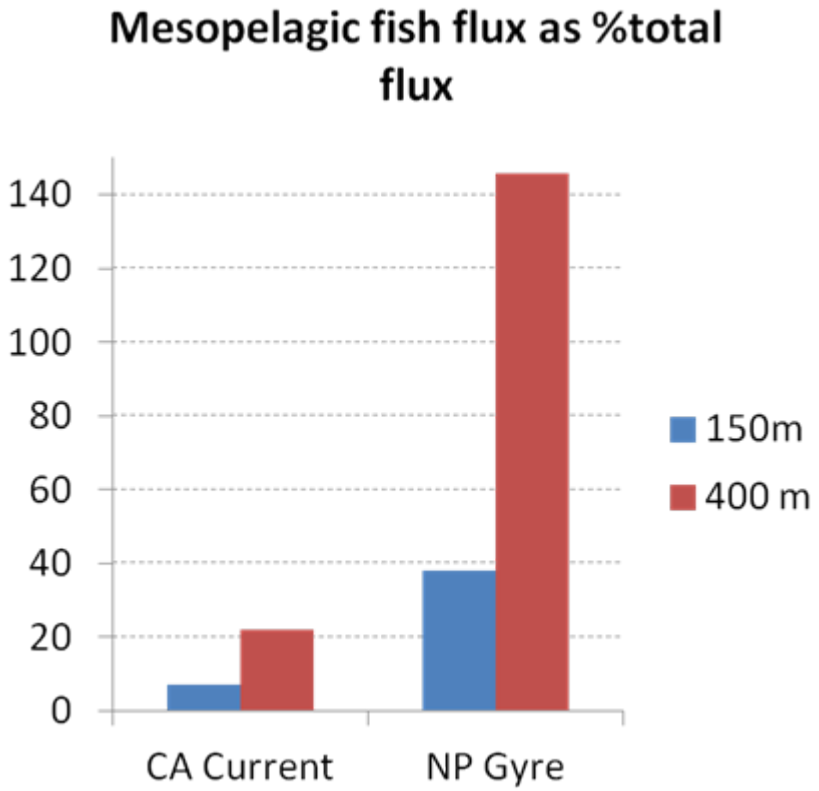
	Sardine + anchovy*	Migrators 2010 (1966-99)	Non-migrators	Total mesopelagic
B (Calif Current) (10^6 t)	1.7	8.6 (14)	9.9 (16)	18.5 (30)
(M+G)/(yr g)** (kcal)	13.3	4.1	0.96	
M+G (10^6 t)***	22.6	35.3 (58)	9.5 (16)	44.8 (74)

*Sardine biomass (2000-09): Md 1.2 million t (Hill et al 2009)
Anchovy biomass (1963-91): 0.2 – 1.5 million t, Md ~ 0.5 million t (Jacobson et al 1994)
**Childress et al 1980
***1 kcal/g wet wt

Migrators: 1.6x trophic impact of small epipelagics now; 1966-99: 2.6x
Total mesopelagics: 2.0x trophic impact of small epipelagics now; 1966-99: 3.3x

Active mesopelagic fish C flux relative to total C flux

- Most models of C flux are based on the passive sinking of particles & ignore active transport, particularly by mesopelagic fishes due to underestimation of their biomass
- However, the passive sinking flux (e.g. from sediment traps) seems to underestimate total flux, estimated from nutrient balancing & O_2 utilization
- Total C flux estimated from Laws et al (2000): C flux below euphotic zone balances new primary production
- C flux through mesopelagic follows Martin et al (1987) curve from sediment traps
- Active mesopelagic fish flux: M+G+defecation at depth



Summary

- Mesopelagic fishes (migrators/non-migrators, planktivores/piscivores) have fluctuated coherently since 1951, highly correlated with deepwater O_2; also ENSO, PDO, upwelling, temperature
- Changes among mesopelagic groups highly + correlated, also correlated with key epipelagic planktivores
- Acoustic biomass estimates of mesopelagics ~7x greater than small trawl estimates
  - Mesopelagic biomass ~10x small epipelagic planktivore biomass
  - Trophic role 2-3x greater
  - The concept of 'wasp-waisted' ecosystems should be abandoned
- Active C transport by mesopelagics accounts for a significant fraction of the global C flux to the deep ocean
- Mesopelagics need to be realistically assessed
- incorporated into ecosystem & biogeochemical models
- time series maintained to assess impacts of climate change, particularly hypoxia impacts


Thank you -
Questions?