Climate, biomass, and the trophic role of midwater fishes in the southern California Current

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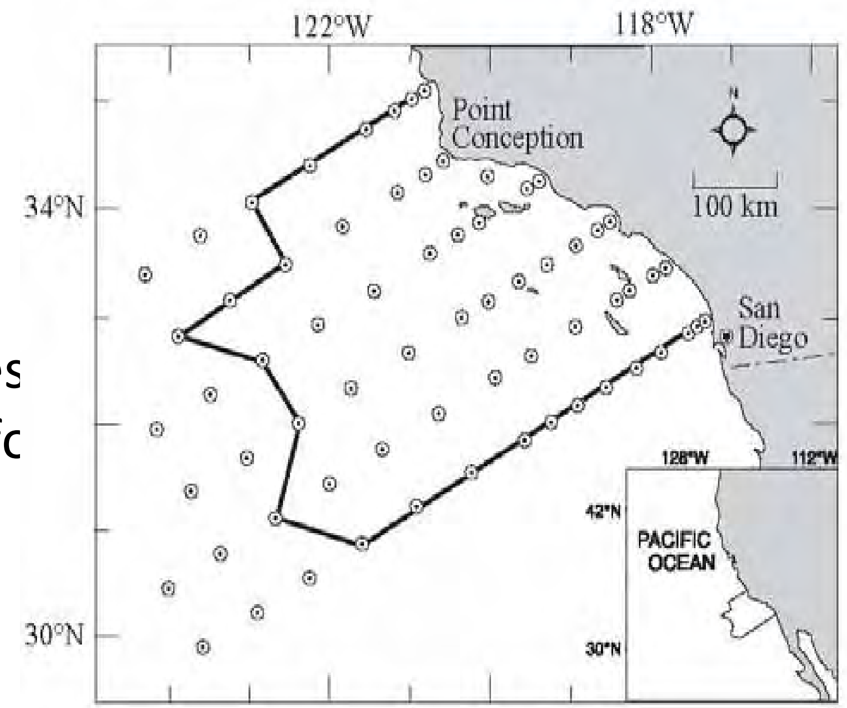
Outline

- Decadal scale variability of mesopelagic fishes in California Current (Koslow et al 2011)
- What is its influence on and relation to the pelagic food web?
  - Bottom-up forcing, related to climate variability (ENSO, PDO, NPGO) & climate change on key pelagic & mesopelagic fish groups?
  - Evidence of competitive replacement?
- What is the biomass and trophic impact of midwater fishes in the California Current relative to epipelagic planktivores, e.g. sardine, anchovy, mackerels?
  - Are productive ecosystems (e.g. upwelling systems) ‘wasp-waisted’? (Cury et al 2000)
    - Sardines & anchovy as a choke-point control the flow of plankton production to higher trophic levels

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 species
  - CTD casts to 525 m; water samples fc 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



Dominant pattern based on PCA

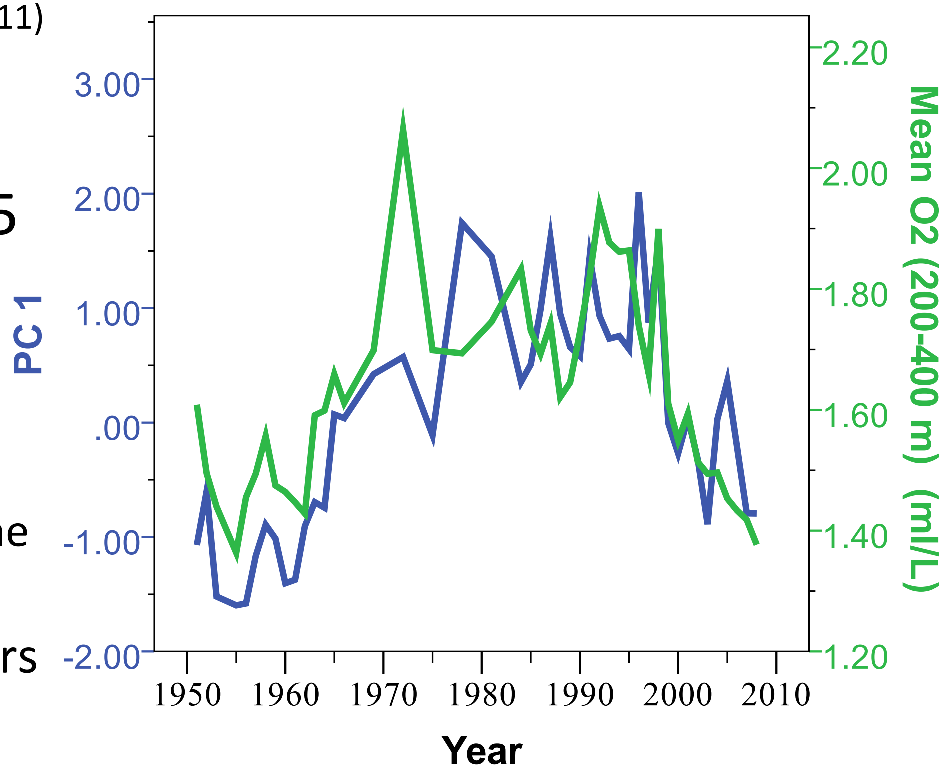
(Koslow et al 2011)

PC 1 (20.5% var explained):

24/27 taxa with loadings $\geq$ 0.5 mesopelagic from 8 families:

Myctophidae, Gonostomatidae, Sternoptychidae, Stomiidae, Phosichthyidae, Scopelarchidae, Argentinidae, and Microstomatidae

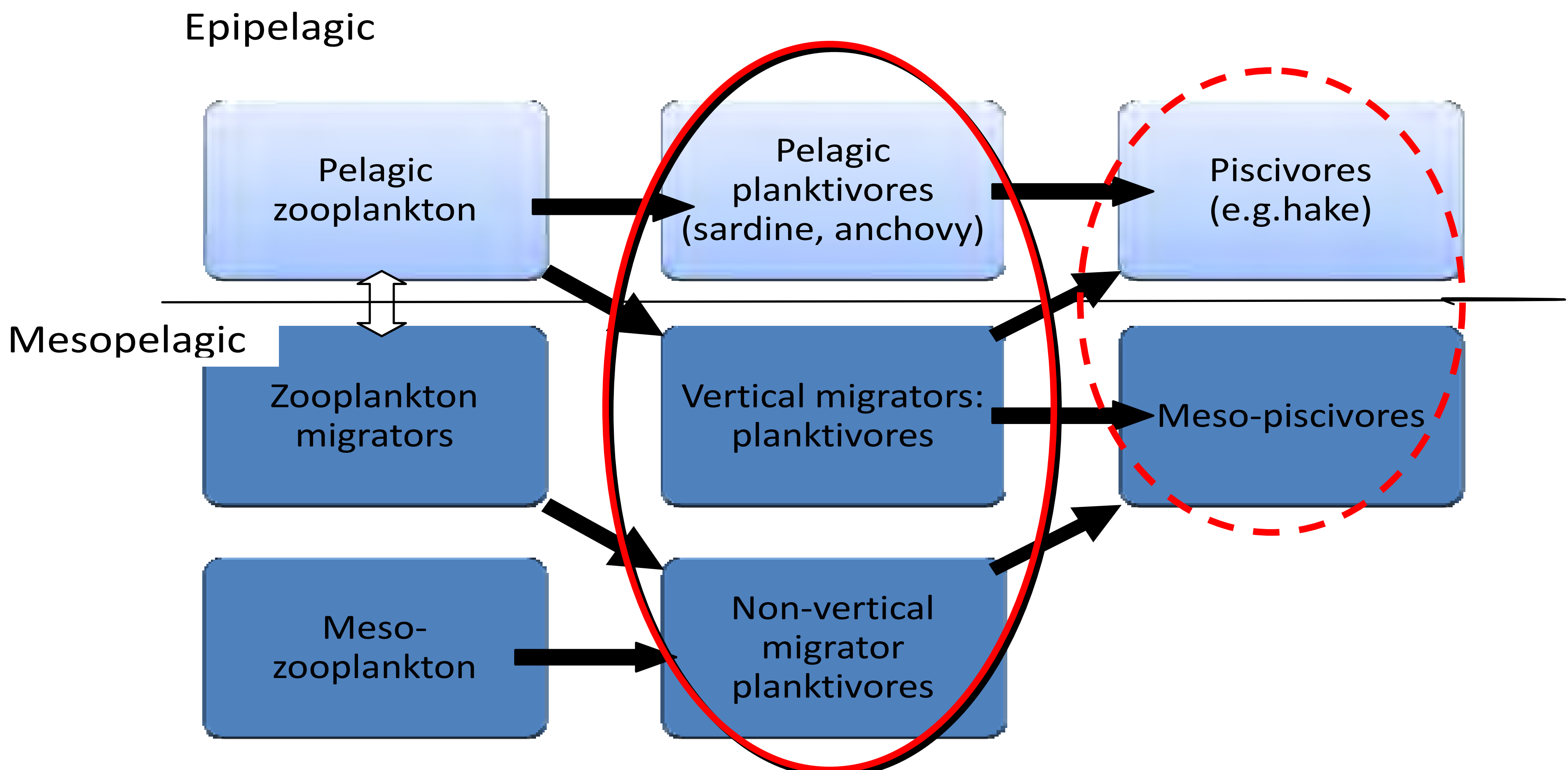
Includes vertical migrators & non-migrators, plankton feeders & predators



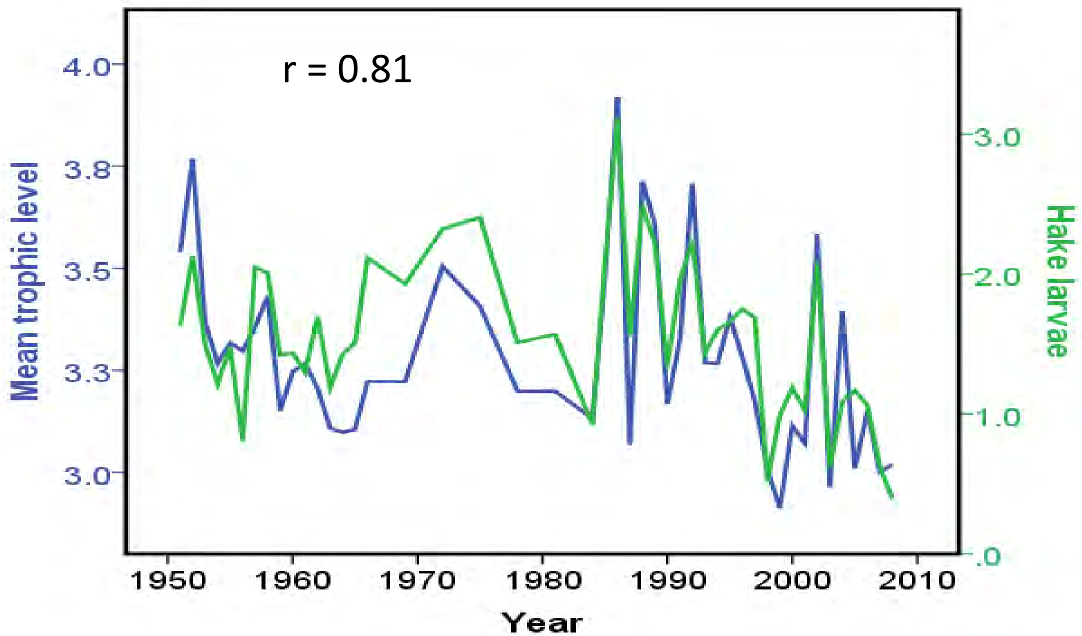
PC 1		O_2 (200-400 m)	PDO	MEI	NPGO	SST	Upwelling
	R	0.75*	0.56**	0.47*	-0.23	0.45?	-0.25
	N* (corrected for autocorrelation)	8	26	30		20	

What are the ecosystem impacts of changing midwater fish populations?

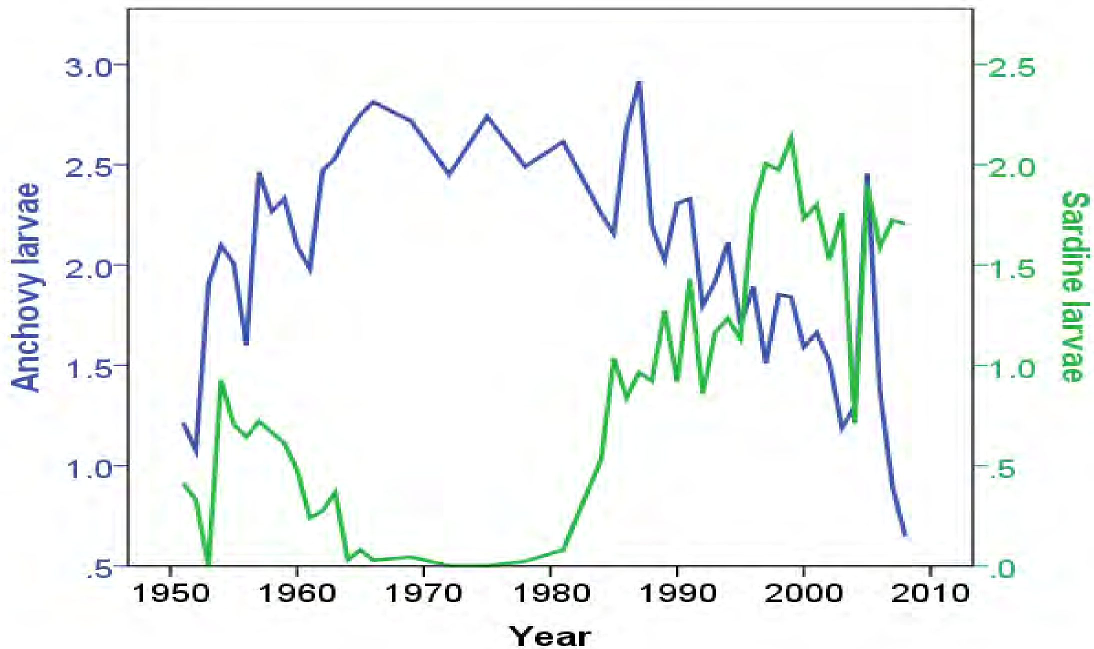
- What are the biomass levels?
- What are the trophic interactions and their relative importance?



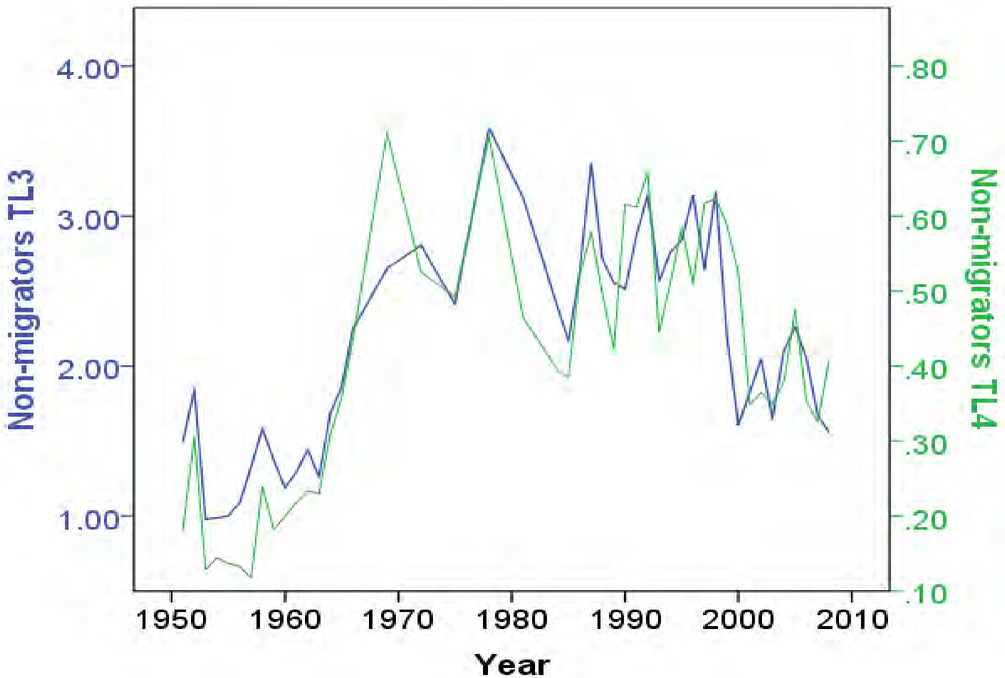
CalCOFI time series, 1951-2008

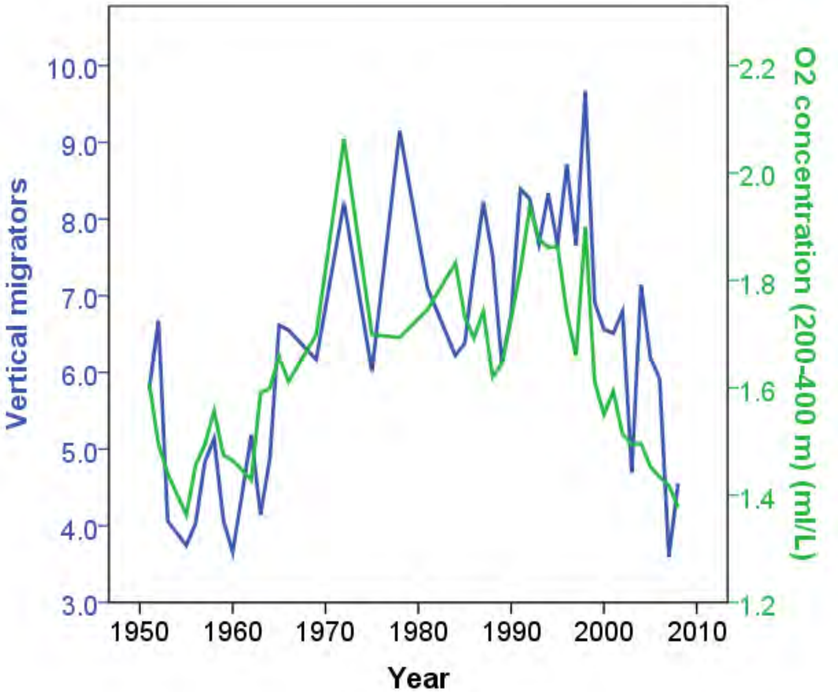


- Trophic level time series driven by hake
- Correlation with mesopelagics ns



- Sardine v anchovy:
  r = -0.41*, only
  negative correlation





	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 potential predators, prey & competitors: r = 0.4 – 0.6

Consistent with pattern of bottom-up forcing related to food availability, advection or other environmental forcing

No 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

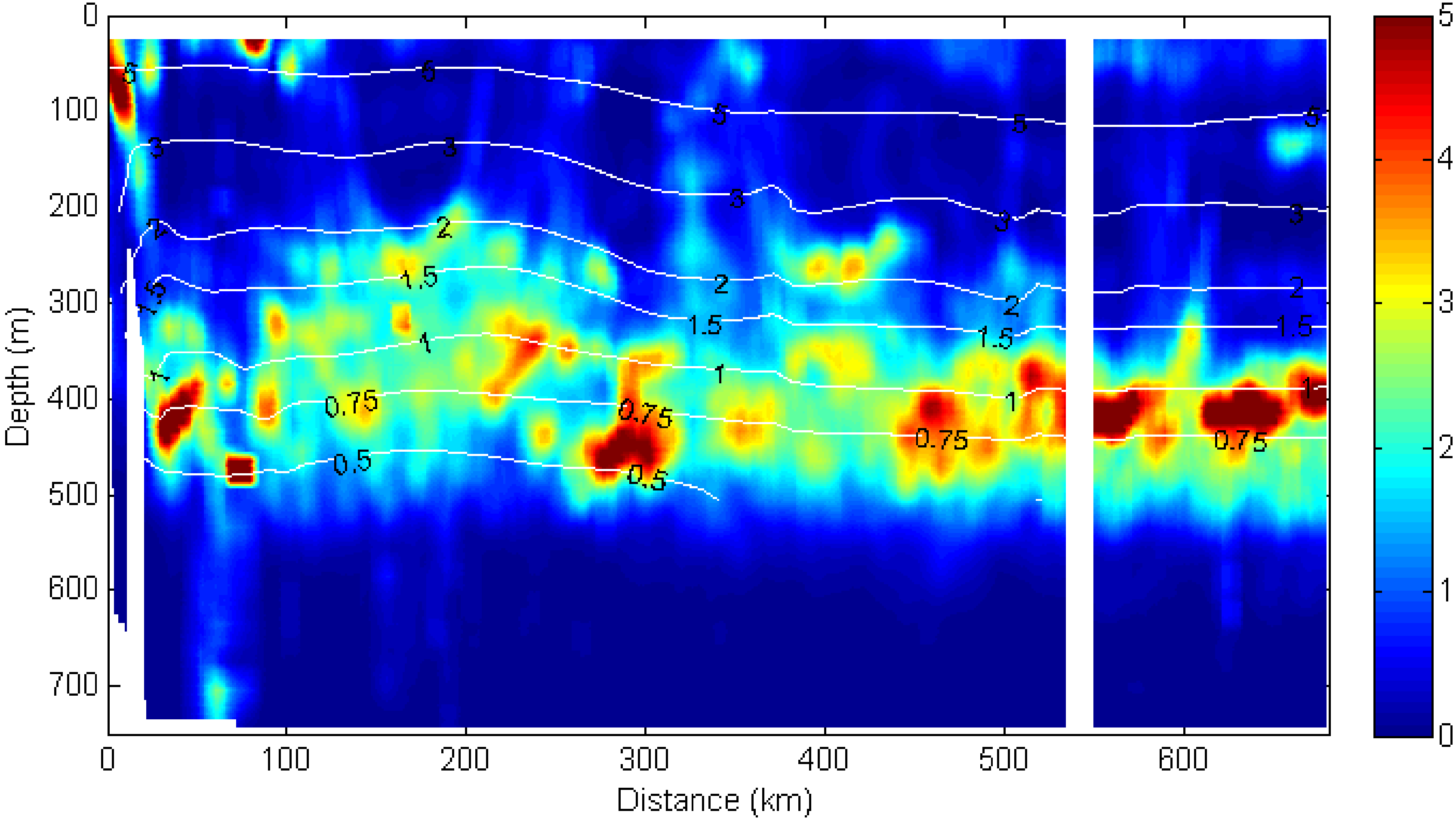
Does biogeography/advection play a role?

	Warm meso	T_{200}	SST	Deep O_2	Up-welling	PDO	NPGO	MEI
Cool-affinity mesopelagics	0.41 (12)	-0.13	-0.22	0.60* (13)	-.21	.03	.01	.27
Warm-affinity mesopelagics		.35* (45)	.35* (46)	.65* (13)	-.41* (39)	.42* (38)	-.28	.56*** (36)

Mesopelagics with warm-water affinities appear to be responding to warming (SST & T_{200}, warm PDO phase, El Ninos), but cool-water fauna unaffected

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

Analysis of winter, summer, fall 2010 CalCOFI acoustic data beyond the shelf, 200-600 m (above the OMZ)
Day-night acoustic data compared to assess (daytime) total mesopelagics, (night-time) non-migratory mesopelagics & (by difference) migratory mesopelagics

Mean biomass

	Migrators	Non-migrators	Total
g/m^2	7.15	10.37	17.51
CalCOFI area ($T*10^6$)	1.36	1.97	3.33
Calif Current (32° - 48°)	2.86	4.15	7.01

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

Mesopelagic biomass 63% (factor of 2.7) less in the last decade than 1966-99, when
Migrators ~3.7 million t & total mesopelagics ~ 9 million t in CalCOFI area (190,000 km^2)
Migrators ~7.7 million t and total mesopelagics ~19 million t in California Current (400,000 km^2)

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	2.9 (7.7)	4.2 (11.2)	7.0 (18.9)
(M+G)/(yr g)** (kcal)	13.3	4.1	0.96	
M+G (10^6 t)***	22.6	11.9 (31.6)	4.0 (10.8)	15.9 (42.4)

*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)
**From Childress et al 1980
***Assume 1 kcal/g wet wt

Comparable trophic impact of mesopelagics and small pelagic plankton feeders in the California Current

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 hake (piscivore) and pelagic planktivores
  - Consistent with bottom-up, not top-down, forcing
- Acoustic biomass estimates of mesopelagics ~5x greater than small trawl estimates
  - Mesopelagic biomass > small pelagic planktivore biomass
  - Trophic roles comparable
  - The concept of 'wasp-waisted' ecosystems should be abandoned
- Mesopelagics need to be realistically assessed,
- incorporated into ecosystem models,
- time series maintained to assess impacts of climate change, particularly hypoxia impacts