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

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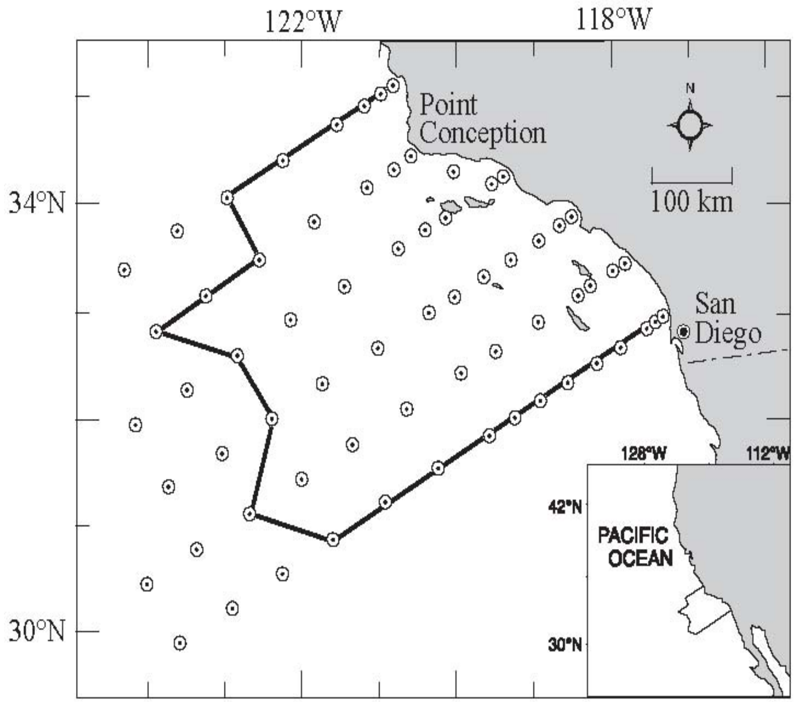
Outline

- Decadal scale variability of mesopelagic fishes in California Current, relationship with O_2 (Koslow et al 2011)
- Implications of climate change & growing hypoxia for mesopelagic fauna
- Midwater fishes in regional food webs
  - biomass and trophic impact of midwater fishes relative to epipelagic planktivores
  - Zooplankton/planktivore/climate interactions

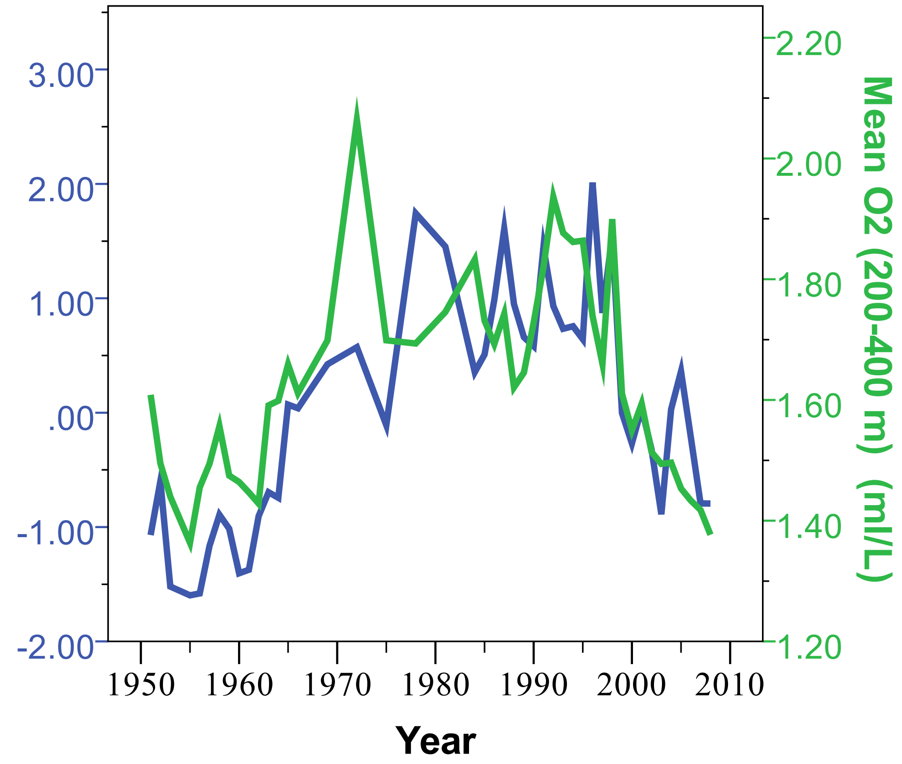
Data & background

- CalCOFI ichthyoplankton time series, 1951-2008
  - Monthly/quarterly sampling
  - Oblique net tows to 210 m depth
  - All fish eggs/larvae removed, identified, enumerated (~500 taxa), mostly pre-flexion, very early – proxies for spawning biomass
  - 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



Dominant pattern based on PCA

(Koslow et al 2011)



PC 1 (20.5% var explained):

24/27 taxa with loadings ≥ 0.5 mesopelagic from 10 families:

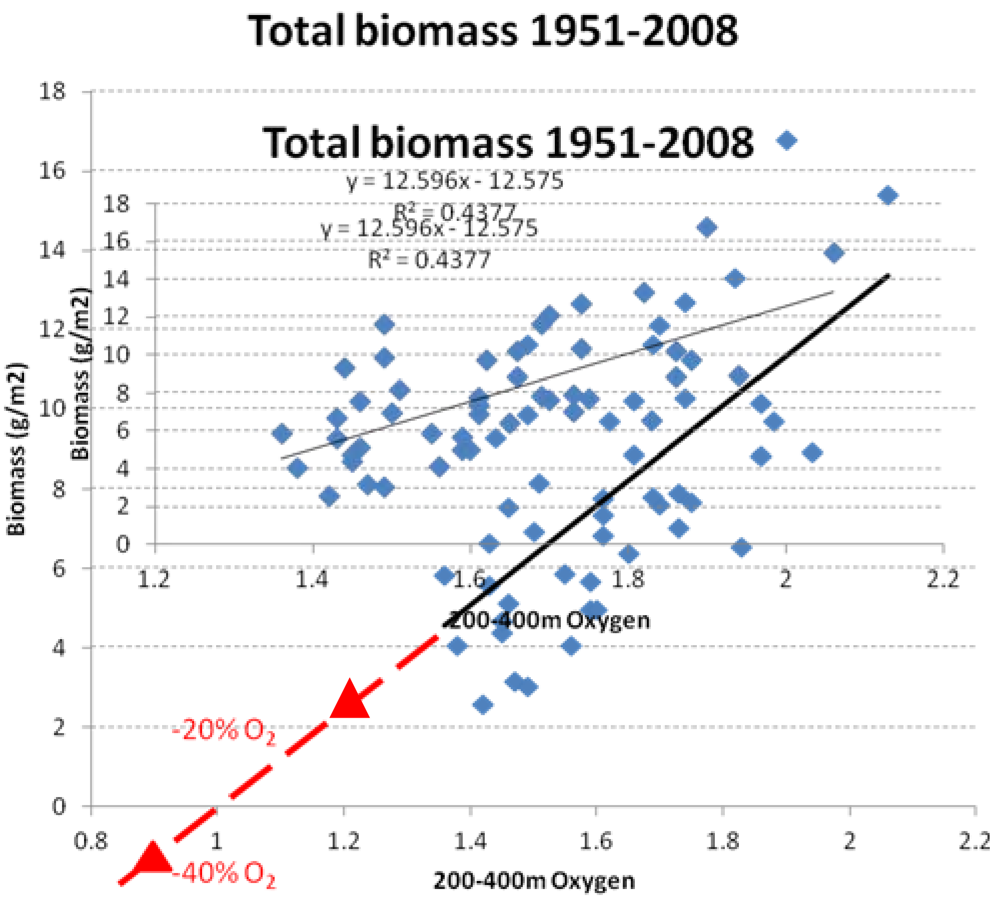
Myctophidae, Gonostomatidae, Sternoptychidae, Stomiidae, Phosichthyidae, Scopelarchidae, Argentinidae, and Microstomatidae, Paralepididae, Bathylagidae

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	

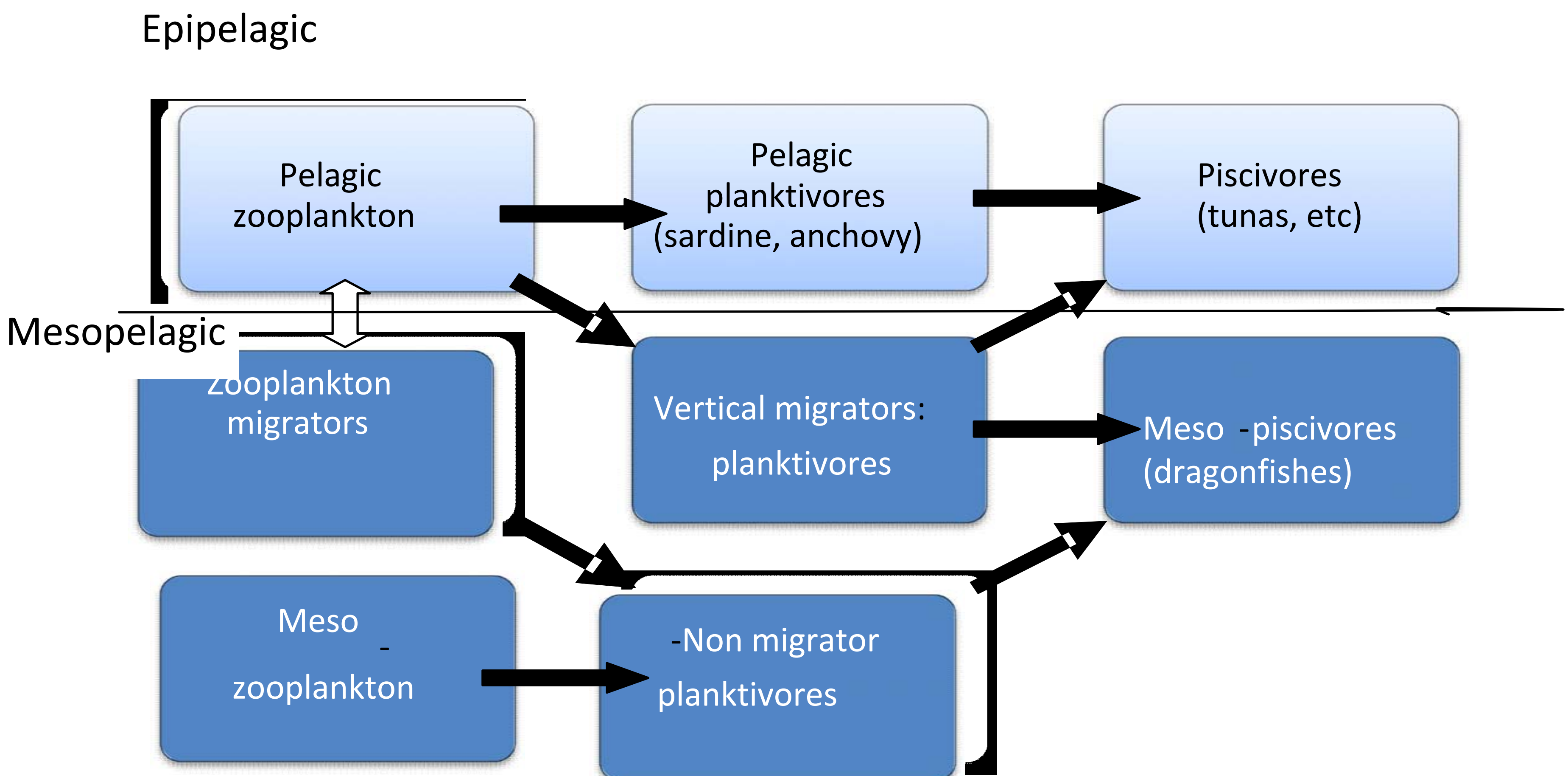
Implications of climate change & deoxygenation

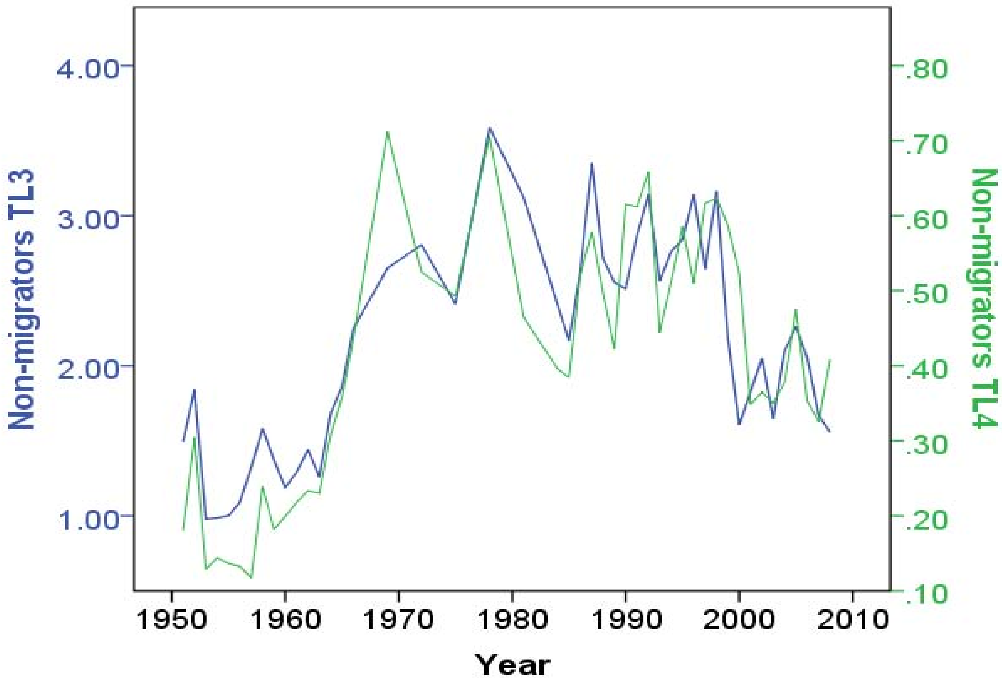
- Mesopelagic fish biomass estimated from recent acoustic/trawl studies in CalCOFI area; past values estimated from relative abundance of total mesopelagic fish larvae
- 3.5-fold range in estimated biomass of mesopelagic fish, 1951-2008
- Extrapolation of a further 20-40% decline in O_2 concentration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

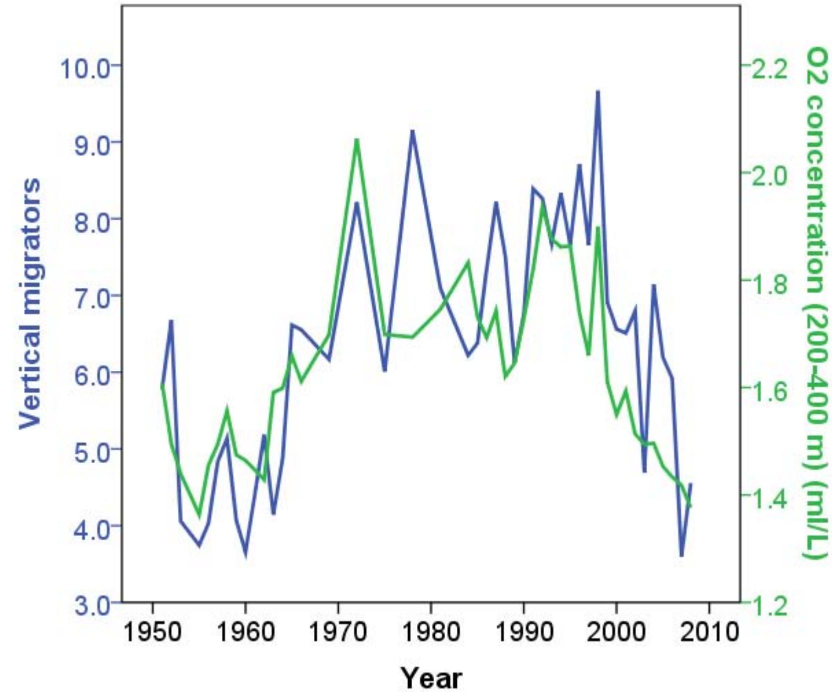


What are the ecosystem impacts of changing midwater fish populations?

- 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 potential meso- and epipelagic competitors & predators: 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

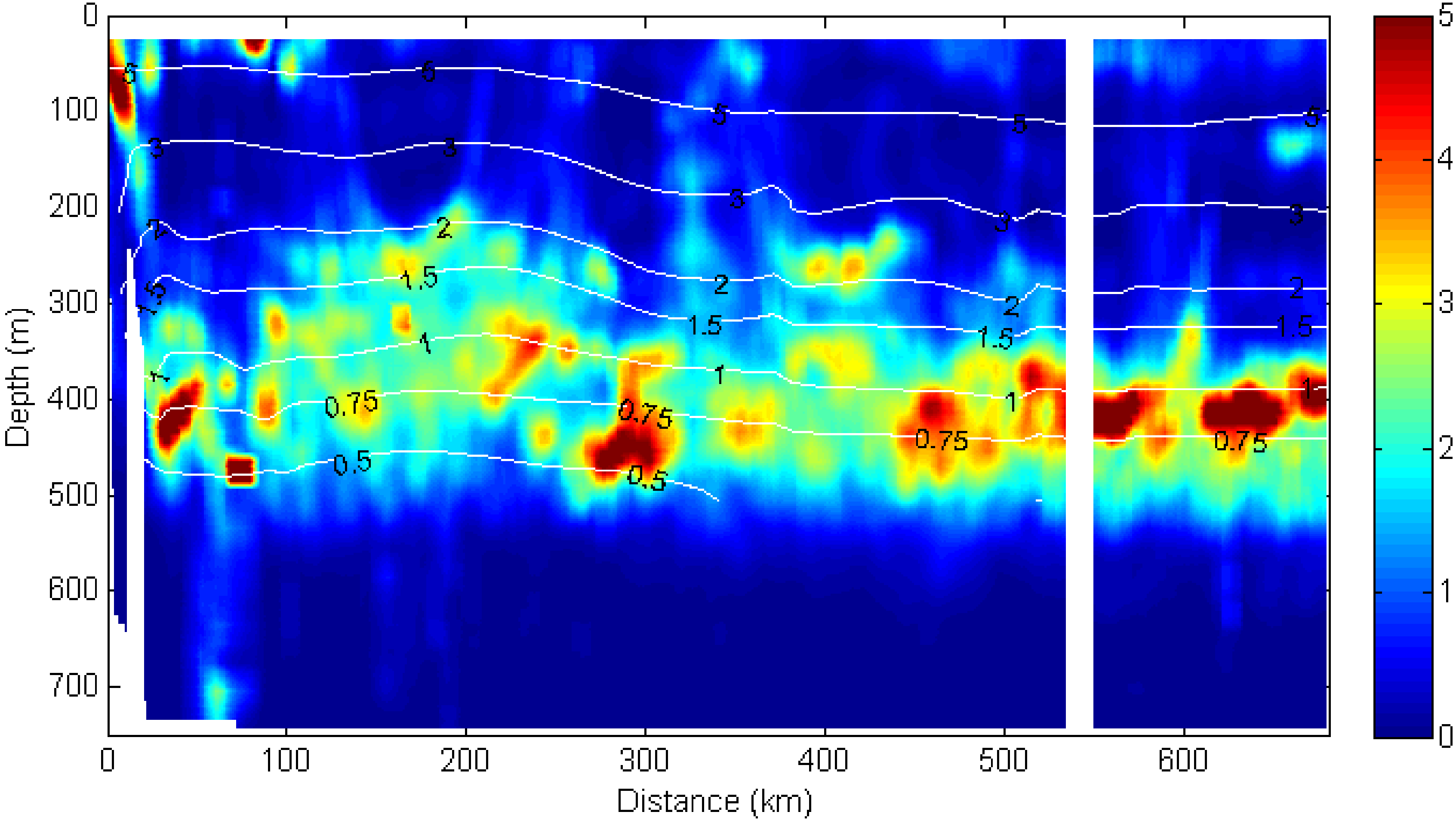
(N*): # independent data points, corrected for autocorrelation

?: 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

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



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: 1.5x trophic impact of small epipelagics now; 1966-99: 2.5x
Total mesopelagics: 2x trophic impact of small epipelagics now; 1966-99: 3x

Relationships with prey?

Correlations (detrended variables)

	PC 1
Log(Sm Zoopl DV)	-0.059
Log (Calanids)	-0.37*
Log (*Euphausia pacifica*)	-0.31*
Log (*Thysanoessa spinifera*)	-0.35*
Log (*Nematoscelis difficilis*)	-0.23

Example of top-down impact?

	MEI	NPGO	PDO	SST	Upwelling	SF SL
Log Thysanoessa	-.29?	.34*	-.06	-.16	.10	-.45**
Log SmZooDV	-.36*	.34*	-.27?	-.51**	.18	-.44**
Log Epacifica	-.17	.25	-.07	-.15	.14	-.16
Log Calanids	-.34*	.37*	-.10	-.20	.29?	-.34*
Log Nematoscelis	-0.08	0.07	-.03	.20	.25?	.11

Or common negative correlations with environmental drivers?

Test of top-down vs environmental drivers

- To reduce dimensionality, PCA s of zooplankton and physical variables
  - Environmental PC 1 explained 51% of variance of SL, SST, PDO, MEI, NPGO, upwelling, deep O2 variables
  - Zooplankton PC1 explained 53% of variance of DV, Calanid, E euphausiid variables

Correlations of detrended variables

	Ichthyo PC1 (mesopelagic)	Epi + meso planktivores	Physical PC 1
Zoo PC 1	-0.38*	-0.34*	-0.42**

Regression of Zoo PC1 with Physical PC 1 & Ichthyo PC 1: R^2 = 0.21, p= 0.008

Regression, Zoo PC 1 with Physical PC 1 & Total epi+meso planktivores: : R^2 = 0.20, p= 0.01

For both, only Physical PC1 entered significantly.

Standardized regression coefficients (β) for regression of Zoo PC 1 with

Physical PC 1: β = -0.33, p = 0.05 ,

Total epi + mesopelagic planktivores: β = -0.18, p = 0.27

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 epipelagic planktivores
- Acoustic biomass estimates of mesopelagics ~7x greater than small trawl estimates
  - Mesopelagic biomass ~10x small epipelagic planktivore biomass
  - Trophic role ~1.5 – 3x greater
- Correlations between zooplankton & planktivores appear driven by common correlations with environmental drivers, not top-down impacts
- Mesopelagics need to be realistically assessed & incorporated into ecosystem models


Questions?