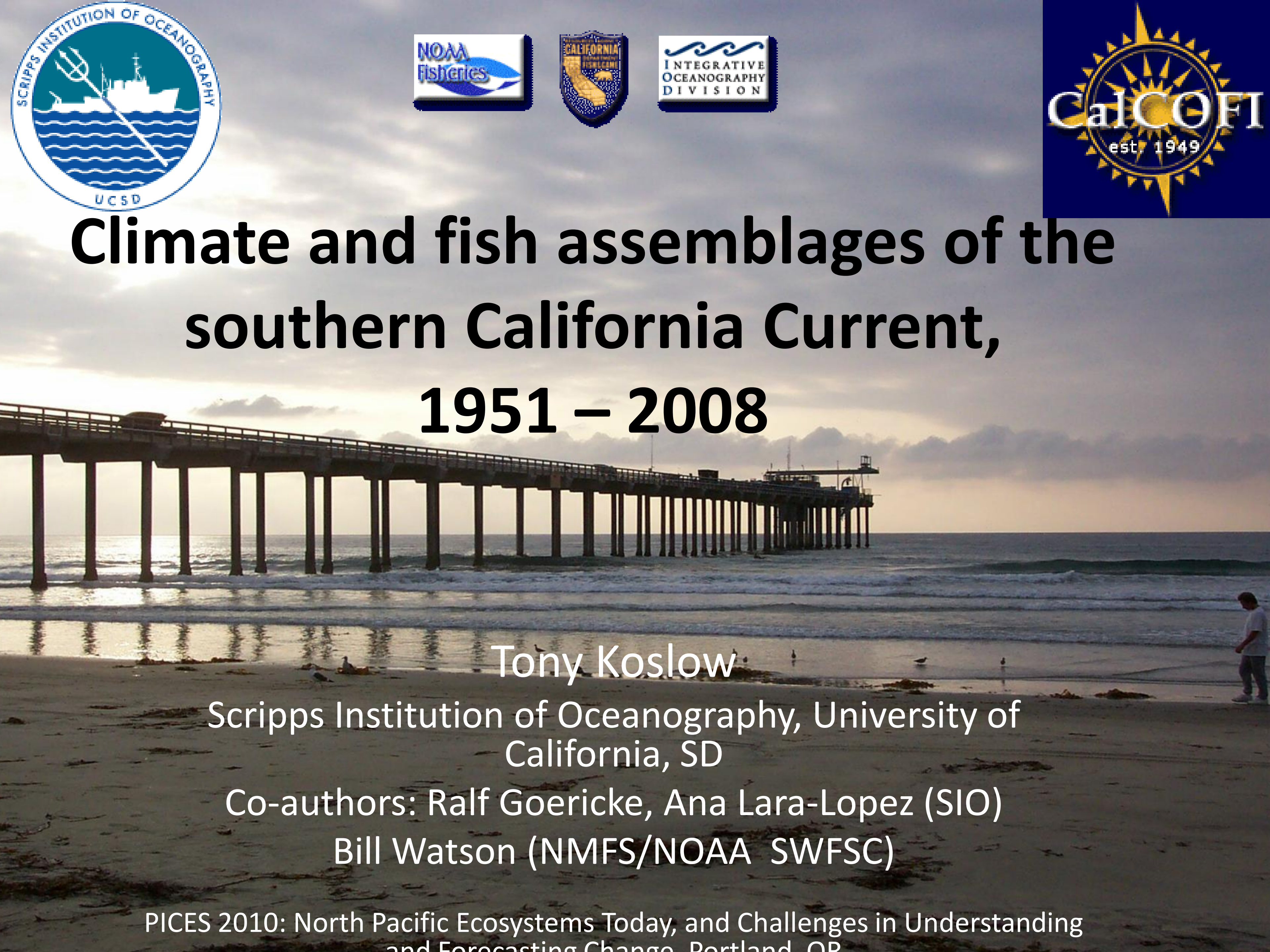

Climate and fish assemblages of the southern California Current, 1951 – 2008

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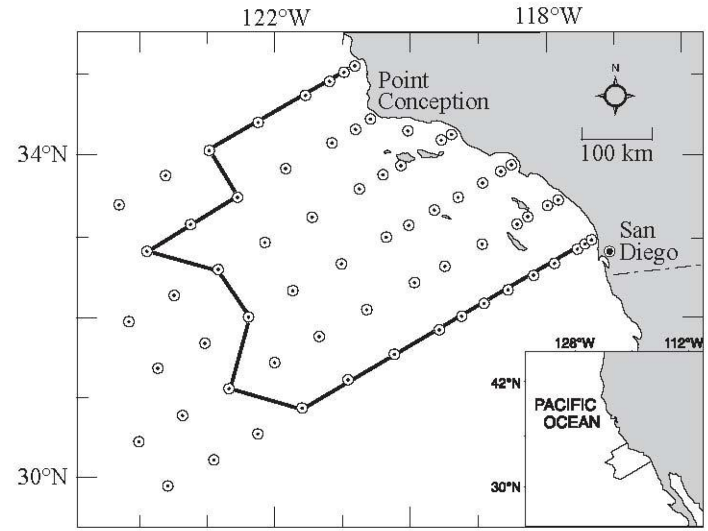
Purpose & Outline

- Examine
  - structure of fish assemblages in the southern California Current
  - relationships of assemblage time series with climate forcing
  - impacts of declining O_2 in the deep ocean
- Reconsider some paradigms & questions:
  - Climate impacts: species-specific or assemblage-level?
  - The variability of mid-water assemblages & their relationship with climate variability/change
    - Is there anything interesting going on down there?
    - Should they be included in 'end-to-end' ecosystem models?

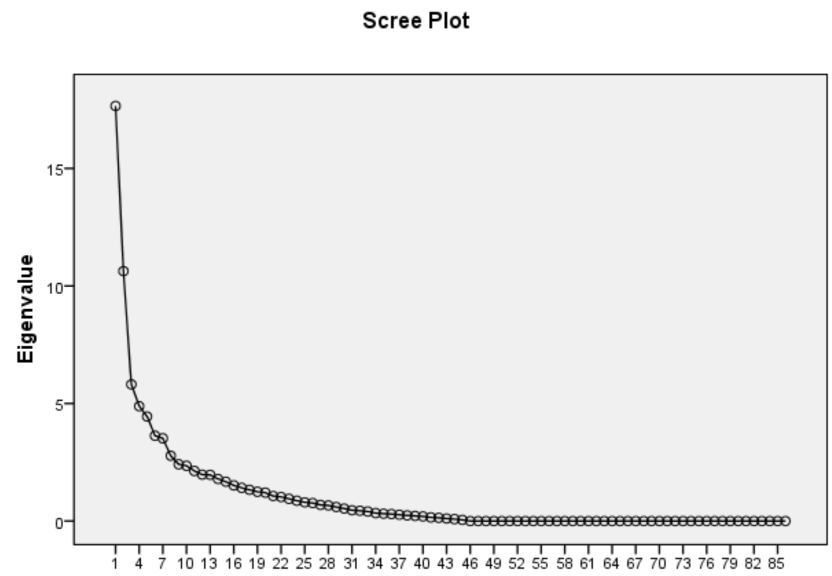
Starting point

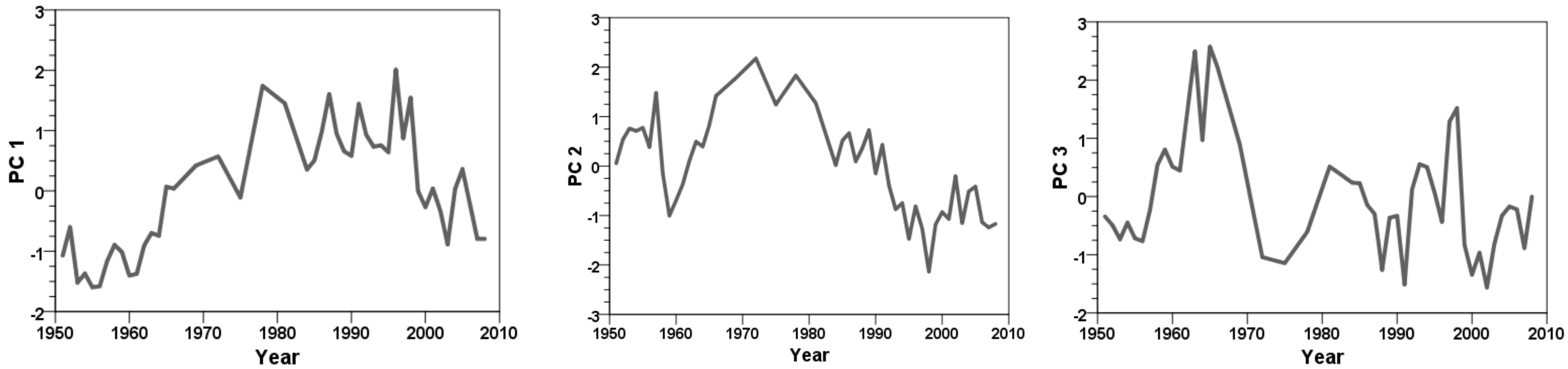
- CalCOFI ichthyoplankton time series, 1951-present
  - Monthly/quarterly sampling (triennial, 1966-84)
  - Oblique net tows to (140) 210 m depth
  - All fish eggs/larvae removed, id.ed, enumerated
  - Community-wide indices of abundance (not just of selected commercial species)
  - CTD casts to 525 m; water samples for nutrients, O_2, chl, salinity
- Method
  - Seasonal -> annual means estimated for each taxa over consistently sampled portion of grid
  - Rare species removed (0 > 50% of years)
  - 86 taxa consistently sampled, 1951-2008
  - $Log_{10}(x+1)$ transformed
  - PCA based on correlation matrix to standardize variables to anomalies from mean/sd



PCA results

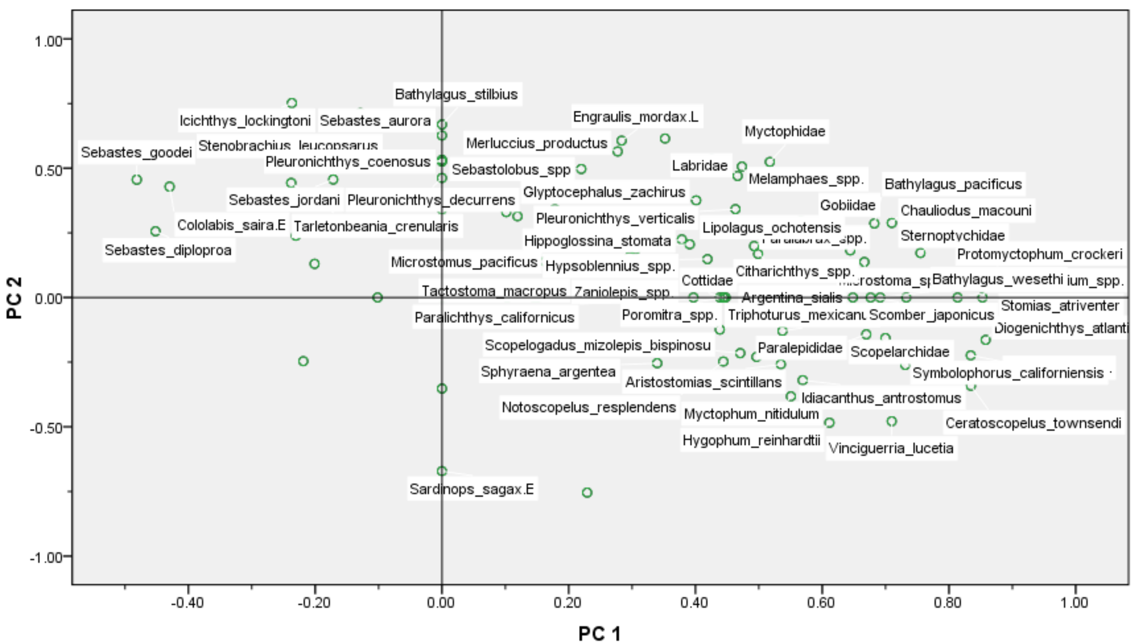
- PC 1-3 of significant interest
  - Explained 20.5, 12.4, 6.8% of the variance : 40% total
  - All displayed significant low-frequency variability





PC composition

- PC 1 (20.5% variance explained):
  - 49/86 taxa loaded nominally significantly + ($r > 0.29$)
  - 24/27 taxa with loadings $\geq$ 0.5 were mesopelagic from 8 families:
    - Myctophidae, Gonostomatidae, Sternoptychidae, Stomiidae, Phosichthyidae, Scopelarchidae, Argentinidae, and Microstomatidae
    - Of 22 other taxa with $r > 0.29$, 6 mesopelagic & 9 shelf/slope demersal
  - 3/86 taxa loaded nominally significantly -
    - *Sebastes goodei, S. diploproa:* krill, micronekton predators
    - *S. diploproa:* depth range to 600 m

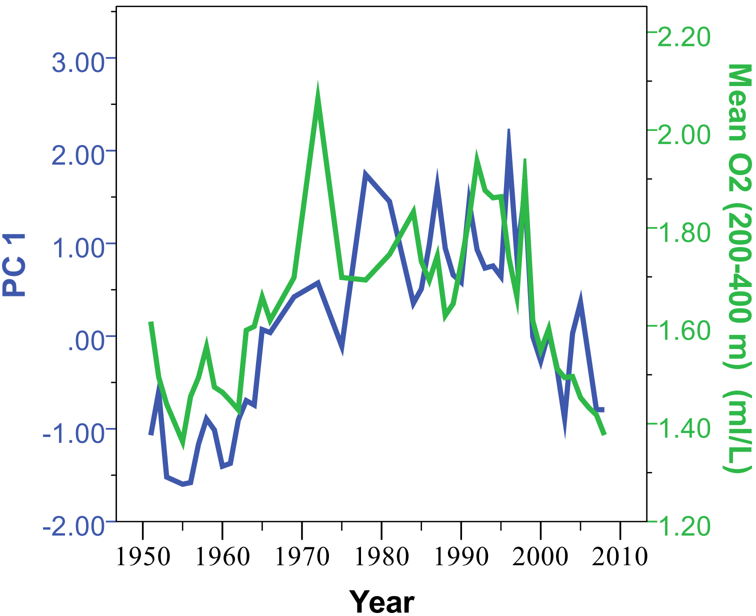


PC composition (cont)

- PC 2 (12.4% variance explained)
  - Dominated by pelagic fishes: medusafish, butterfish (pompano), anchovy, hake (-), sardine (+)
  - also several rockfish: *Sebastes spp., S. aurora,* boccacio
- PC 3 (6.8% variance explained)
  - Dominated by coastal species: tonguefish (*Symphurus atricaudus*), blacksmith (*Chromis punctipinnis*), Pacific barracuda (*Sphyraena argentea*), cuskeels (*Ophidion scrippsae, Chilara taylori*), blennies, (*Hypsoblennius* spp.), sciaenids, anchovy, sand dabs (*Citharichthys* spp.), cabezon (*Scorpaenichthys marmoratus*)

Environmental relationships: PC 1

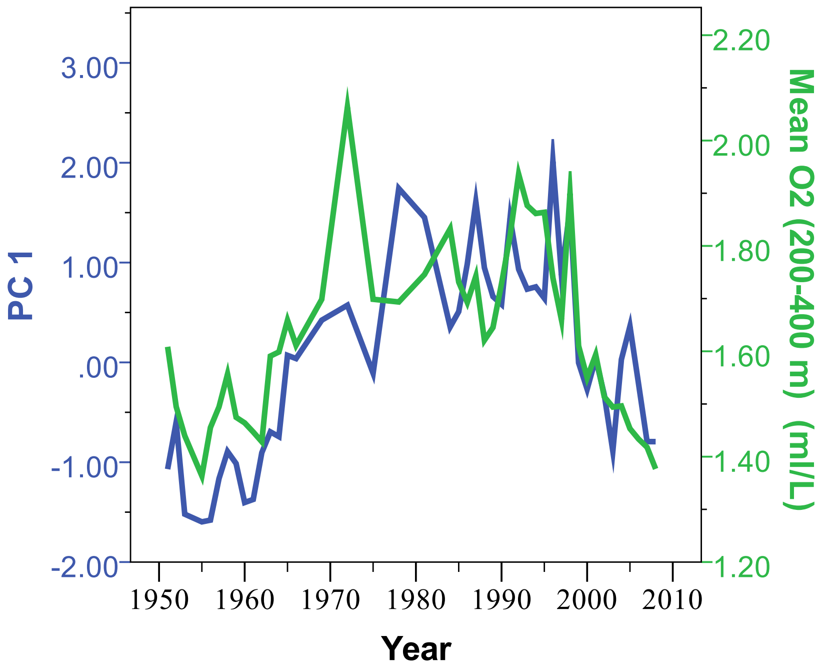
PC 1	O_2 (200-400 m)	PDO	MEI	NPGO	SST	Upwelling
R (nominal significance, N=46)	0.75***	0.56**	0.47**	-0.23	0.45**	-0.25?
N* (corrected for autocorrelation)	8	26	30		20	
Significance	*	**	*		?	
Differenced R & significance	0.35*	0.03	0.19	-0.28	0.07	-0.31*



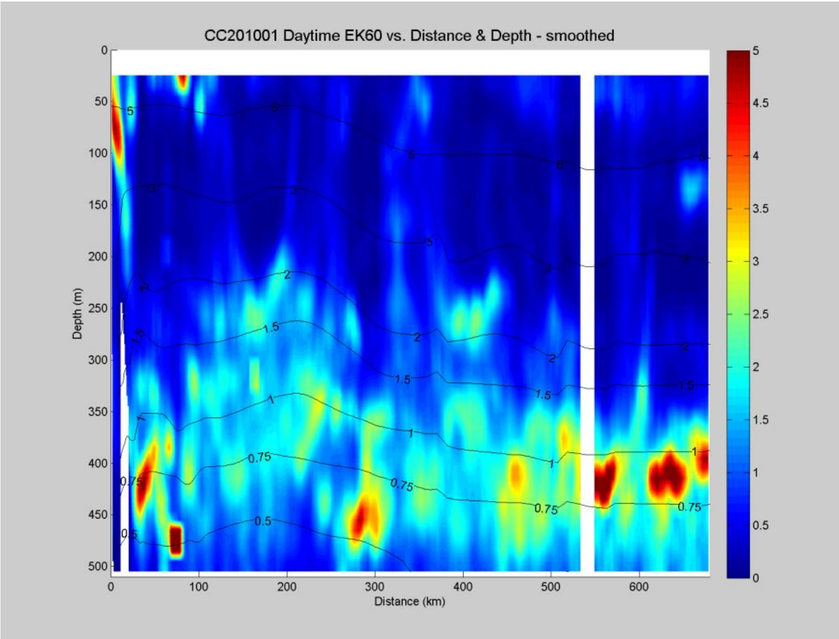
	Unstandardized Coefficients		Standardized Coefficients			
	B	Std. Error	Beta	t	Sig.	R^2
Constant	-5.94	.97		-6.16	.000	0.65
Mean O_2 (200-400m)	3.69	.59	.62	6.25	.000	
PDO	0.38	.12	.33	3.28	.002	

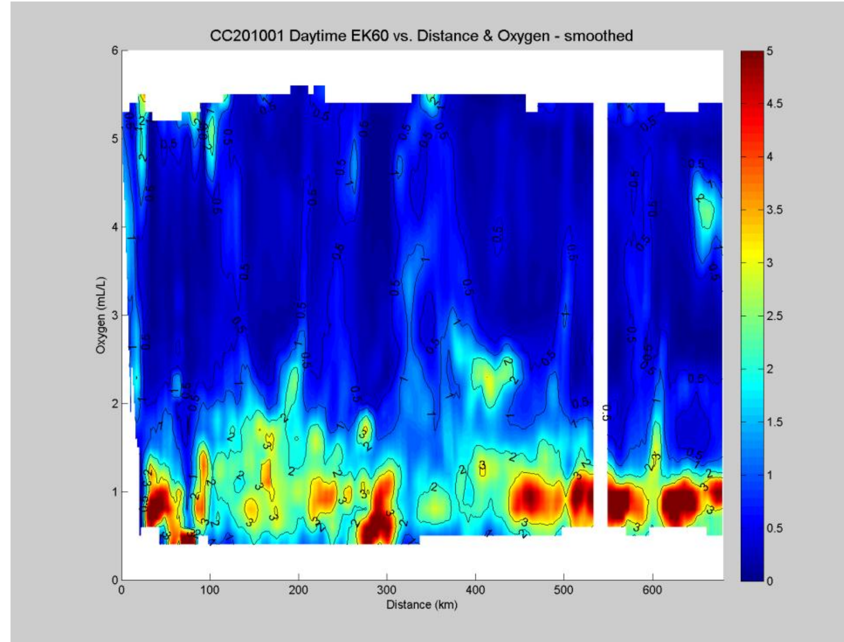
PC 1: 0_2 Relationship

- 15 - 20% lower 0_2 (200-400 m) 1951-64/1999-2008 vs 1965-98 (Bograd et al GRL 2008, McClatchie et al GRL 2010)
- 63% lower mesopelagics (24 taxa factor loadings $\geq$ 0.5) and mesopelagics + shelf/slope demersals (38 with loadings $\geq$ 0.3): decrease by a factor of 2.7
- Ocean climate models predict deepwater 0_2 will decline 20-40% over the coming century or so
- Declining 0_2 already observed in the tropical oceans and across the N Pacific
- First evidence of potential ecological impact of declining deepwater 0_2



What is the mechanism?





• Micronekton backscattering concentrates at the hypoxic boundary layer (HBL), where O_2 = ~0.5-1.5 ml/l

• A shoaling HBL when O_2 declines renders the micronekton more vulnerable to visually-orienting predators:

  •41 m avg shoaling, 1984-2006 implies 2.5-fold greater light at HBL

•Note: only 3 species with significant – factor loadings on PC 1 (i.e. increased during low-O_2 periods)

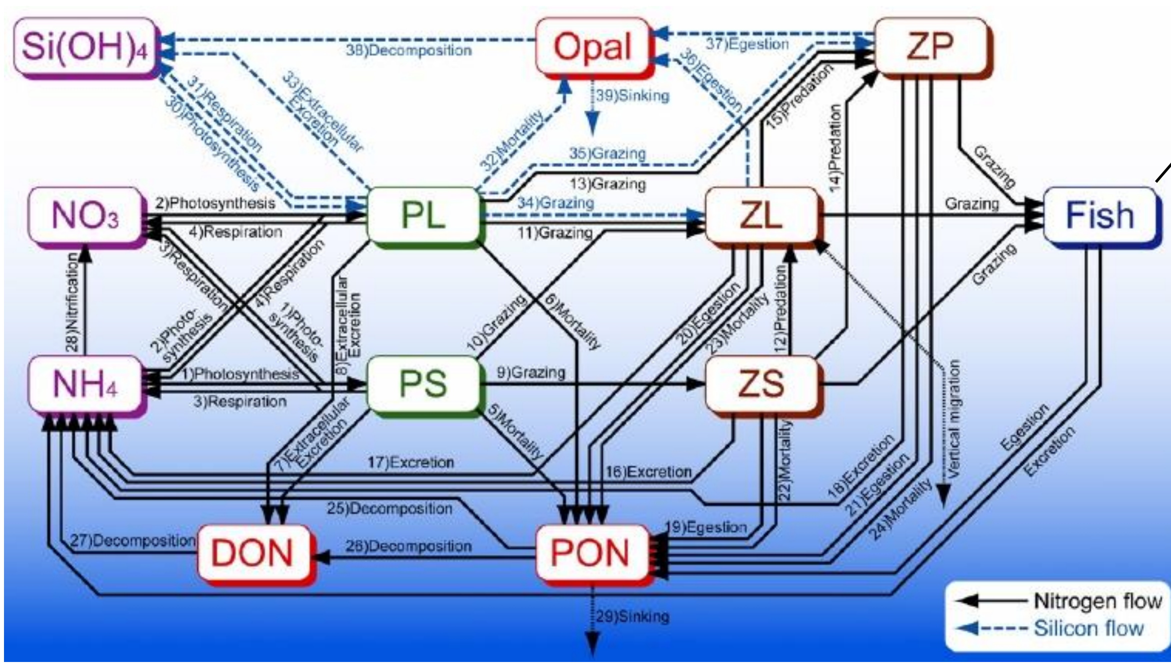
  •Two were *Sebastes (S. goodei, S. diploproa)*, krill & micronekton predators. *S. diploproa* (splitnose rockfish) extends to HBL.

  •Increased 1.7-fold when O_2 low

Conclusions & Implications for Future Research

- Analysis of California Current assemblage indicates broad community coherence in environmental responses based on common habitats
  - Most reported fish-environment relationships with single species
  - Artifact of fish data mostly limited to commercial species?
  - *Need for community-based fisheries research*
- – Dominant pattern: mesopelagic fauna, not anchovy/sardines
  - Higher diversity in midwater
  - Common response to major environmental driver, changing deepwater O_2
  - Myth buster: deepwater fauna highly stable, buffered from environmental influences
  - What are the implications?
    - – Midwater fauna key prey of squids, certain seabirds, marine mammals and predatory fishes (bigeye, swordfish, *Sebastes*)
    - – But what is their biomass??? – Unknown, but apparently second only to small pelagics in eastern boundary currents based on egg/larval abundance
      - » Global mesopelagic biomass ~10^9 tonnes (Gjosaeter 1980: based mostly on research trawl catches!)
  - *Need to assess biomass of mesopelagic fauna as baseline for climate/O_2 impacts, ecosystem models, and Integrated Ecosystem Assessments*

The future:
Ecosystem-based management of Large Marine Ecosystems



Typically a small epipelagic planktivore (herring, sardine, saury)

Nemuro.Fish

Megrey et al. 2007, Ecol. Model.

But where are the mesopelagics?
(At least 10^9 tonnes of them!)

And where are the squids, fish predators, seabirds & marine mammals that feed on them?

Summary

- Analysis of the 60-year CalCOFI ichthyoplankton data indicates the diverse fish assemblage of the southern California Current exhibits coherent community/habitat-wide patterns with low- and high-frequency variability
- The dominant pattern (PC 1) was exhibited by a diverse range of mesopelagic (and shelf/slope demersal) fishes and was significantly linked to fluctuations in deepwater oxygen
  - In response to a 15 - 20% decadal-scale decline in deepwater oxygen, deepwater fishes have declined > 60%
  - Indication of a global-scale response of deepwater fishes to declining O_2 due to climate change?
- Findings highlight how little is known about deepwater fishes (what is their biomass, what is their role in marine food webs?) and the need to systematically monitor them and include them in ecosystem models, assessments and management plans

Thank you for your attention!

Questions?