Importance of Forage Fish in the California Current

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Overview

- Definitions
- Forage species ecology
  - Population dynamics
  - Climate and other effects
  - Fisheries effects
  - Predators & their needs

Definitions

CCS forage species

- Small pelagics *(anchovy, sardine, herring, myctophid)*
- Juveniles of predatory fishes *(rockfish, hake)*
- Invertebrates *(krill, shrimp, squid)*

Comprehensive definition

1. Holds key role in the ecosystem
   (is important in predator diet)
2. Feeds predominantly on plankton
3. Forms dense schools
4. Small size (<30cm)

Forage Species' Ecology

Population dynamics

- Small pelagics' natural population fluctuations
  (known, although mechanisms not fully understood)

- Invertebrates are "bugs"
  - *some live <1yr, some longer*
  - *can "shrink & sink"*

- Juveniles depend on adult populations

Climate & Other Effects

-Climate effects
- ENSO, PDO *(warm/cool regimes)*
- Climate change *(trending temperatures, increasing variability)*
-Ocean acidification
-Disease, red-tide outbreaks
-Ecosystem degradation *(pelagic, tidal/subtidal)*

- Species' interactions *(competition, predation, non-natives)*

-Other non-fisheries human influences
- Direct destruction of habitat
- Increased pollution/runoff
- Wave energy generation, desalinization, etc.

Effects of Fishing

- Ecological and population "viability“
  - Forage population declines are due much to climate and some to harvest but causes not separable
  - Fishing makes populations more susceptible to climate (*Hsieh et al. 2006*)

Ultimately, the question is whether fishing has resulted in populations visiting ecological states that would not have occurred naturally.

Who are the Predators?

- Whales & dolphins
- Seals & sea lions
- Seabirds & sea turtles
- Sharks & rays
- Predatory fishes like salmon & tuna





Predator Needs

-Diverse forage base

-Spatio-temporal availability

(predator-prey mis-match more frequent w/ climate change)

- How much food? *(combo of quantification approaches)*
  - Bio-energetic modeling
  - Functional & numerical responses
  - Ecosystem modeling

Top 10 CCS Forage Groups

Forage species	presence in predator diet
Pacific herring (*Clupea pallasi*)	35%
Lantern fish (Myctophidae)	33%
Codfishes juvenile (Gadidae)	30%
Northern anchovy (*Engraulis mordax*)	29%
Rockfishes juvenile (*Sebastes* spp.)	29%
Shrimp (Crangon & Mysid)	25%
Market squid (*Loligo opalescens*)	24%
Sanddabs, juv. halibuts (Paralichthyidae)	20%
Krill (Euphausiidae)	19%
Pacific sardine (*Sardinops sagax*)	14%

Forage species	>10%
Anchovy	20%
Rockfishes juv.	19%
Codfishes juv.	19%
Krill	16%
Squid	15%
Lantern fish	15%
Shrimp	10%
Herring	8%
Sardine	7%
Sanddabs	6%

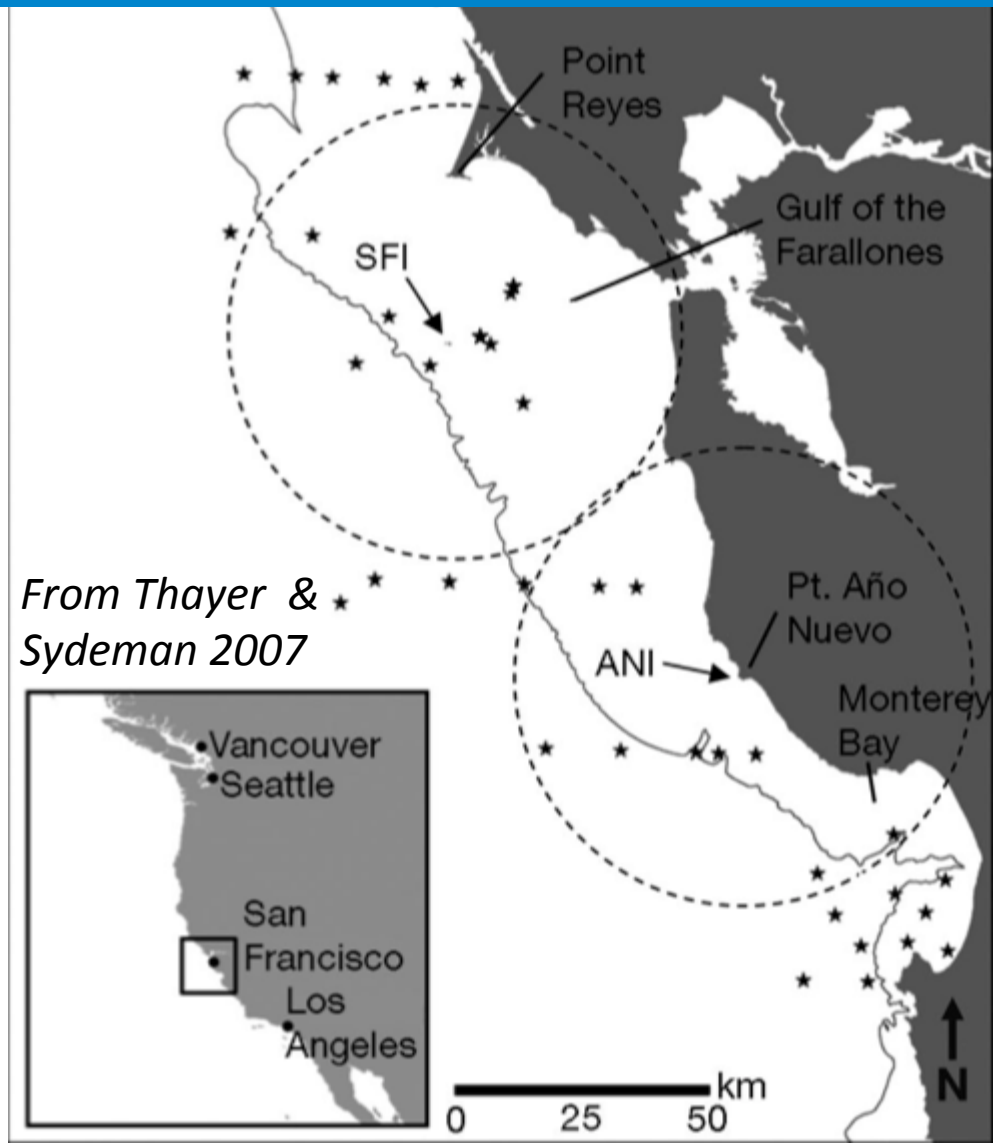
Forage species	>25%
Anchovy	11%
Squid	11%
Herring	10%
Krill	9%
Codfishes juv.	9%
Rockfishes juv.	8%
Lantern fish	5%
Shrimp	4%
Sardine	3%
Sanddabs	2%

Forage species	>50%
Squid	6%
Krill	6%
Anchovy	4%
Herring	3%
Codfishes juv.	3%
Rockfishes juv.	2%
Shrimp	1%
Lantern fish	0.6%
Sardine	0.6%
Sanddabs	0.6%

Local Prey Importance

Important breeding colonies in Central CA (13 seabird, 5 pinniped spp.):

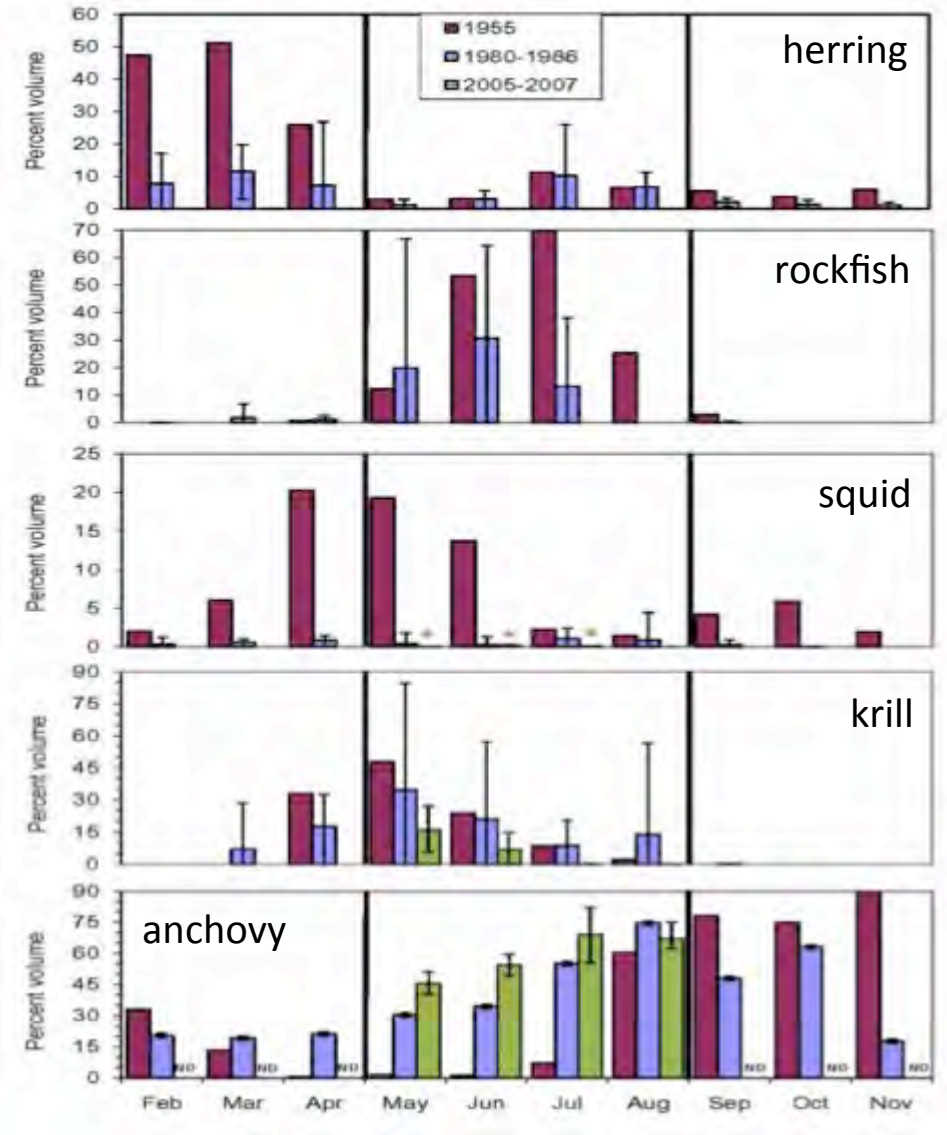
- Southeast Farallon Island *(~100,000 birds & 6,000 pinnipeds)*
- Año Nuevo Island *(~9,000 birds & 18,000 pinnipeds)*



From Thayer & Sydeman 2007

Seasonal Prey Importance

Central CA
Chinook salmon diet



From Thayer et al. submitted

Inter-Annual Prey Importance

			Percent of prey in diet between years								
Predator	**N (years)**	**Source**	**Krill**	**Market squid**	**Anchovy**	**Sardine**	**Herring**	**Rockfish (juv.)**	**Gadid (juv.)**	**Myctophid**	**Sanddab**
Brandt's cormorant	9	Ainley et al. 1981		0-0.2	0-28		0-73	0-91	0-15		
California sea lion	3	Weise and Harvey 2008		5-19	7-13	61-68	0.2	3-6	2-6		0-2
Chinook salmon	11	Thayer et al. submitted	0-48	0-20	1-90	0-28	0-51	0-70	0-7		0-1
Common murre	4	Matthews 1983	0-36	0-15	0-47		1-24	1-43	9-30		0-11
Elegant tern	8	Velarde et al. 1994			35-98	2-59					
Pacific hake	2	Livingston 1983	0-93		0-16		0-67	0-4	0-1.3		0-1
Rhinoceros auklet	17	Thayer & Sydeman 2007		0-27	8-100	0-18	0-8	0-61	0-1	0-12	
Sooty shearwater	2	Gould et al. 2000	0-1	0-2	36					1-40	
Yellowtail rockfish	2	Brodeur and Pearcy 1984	0-28	2-15			0-18	0-0.4		0-3	

Bio-energetic modeling

Seabird prey needs – *Common Murre*

-Pt. Conception, CA to Cape Blanco, OR

-Estimated prey consumption (2004) = **225,235t**

- Included consumption of:
  - ~58,000t market squid
  - ~55,000t juvenile hake
  - ~23,000t anchovy
  - ~21,000t juvenile rockfish

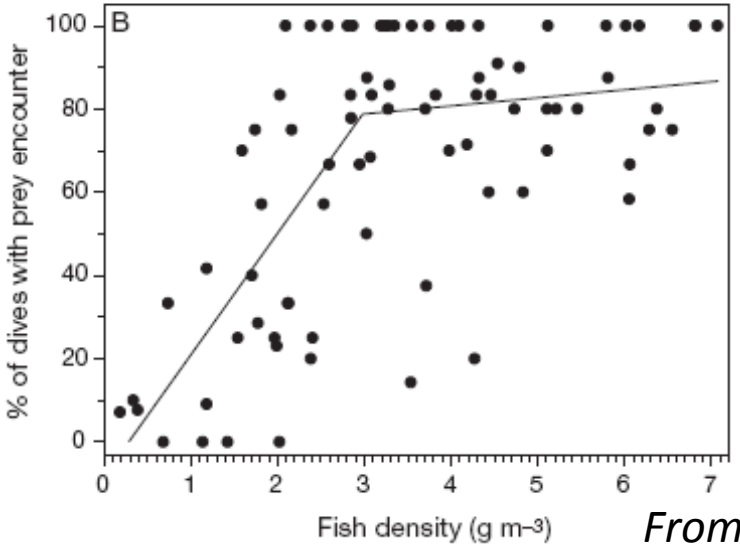
From Roth et al. 2008

Functional Responses

- Single predator parameter vs. forage parameters

Double-crested cormorants and juvenile rainbow trout

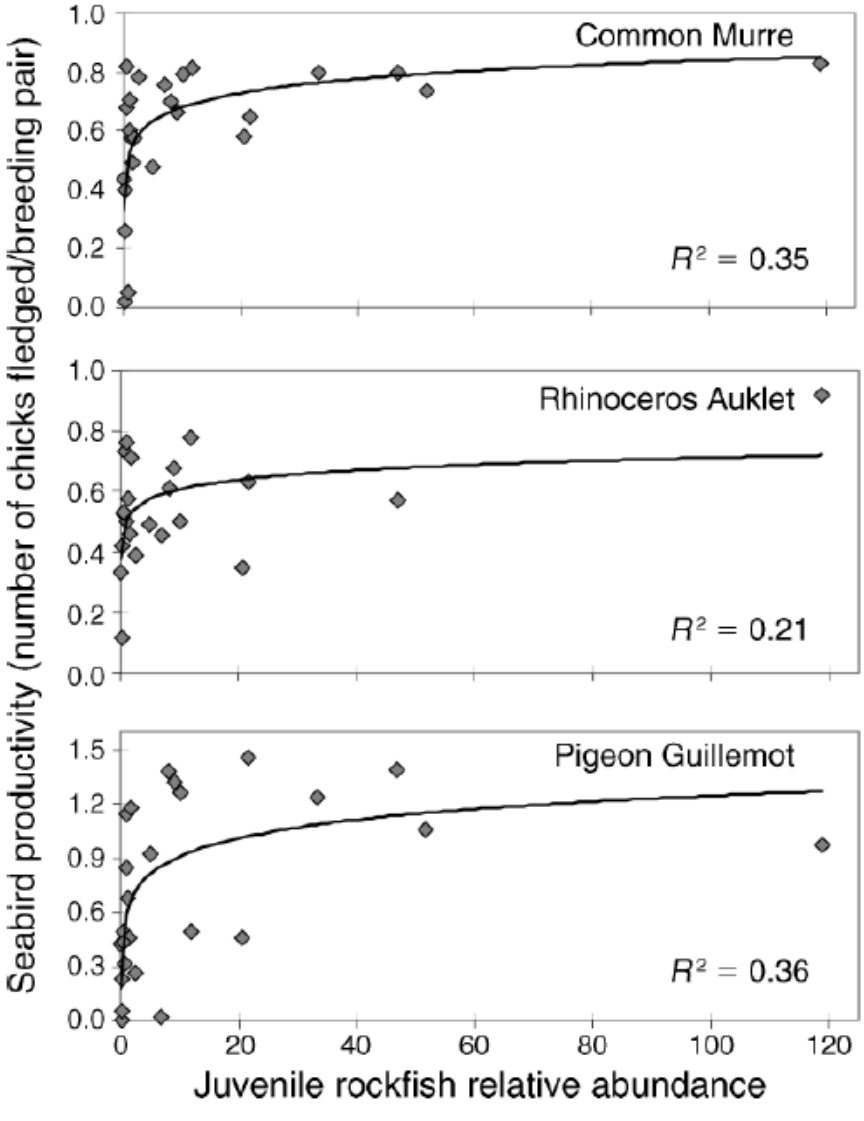
- Determines threshold at which predator parameters are compromised



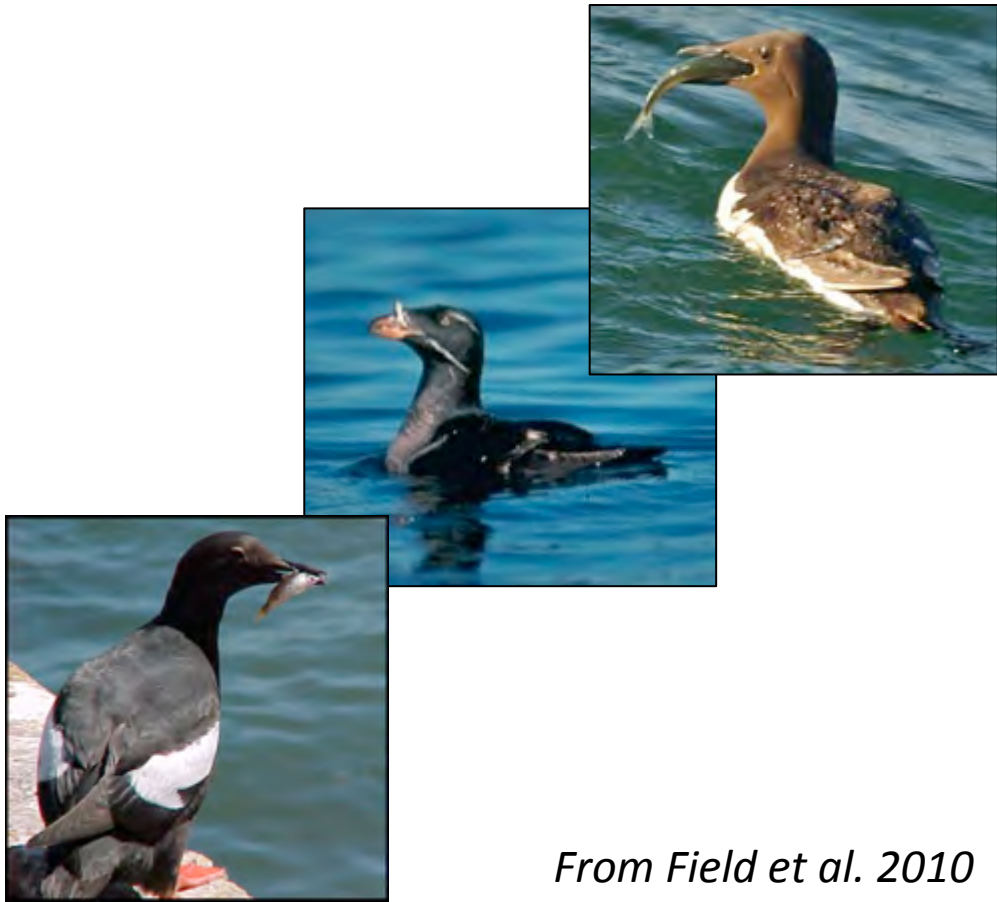
Below threshold, likelihood of bird encountering fish decreased

From Enstipp et al. 2007

Numerical Responses – CCS Data

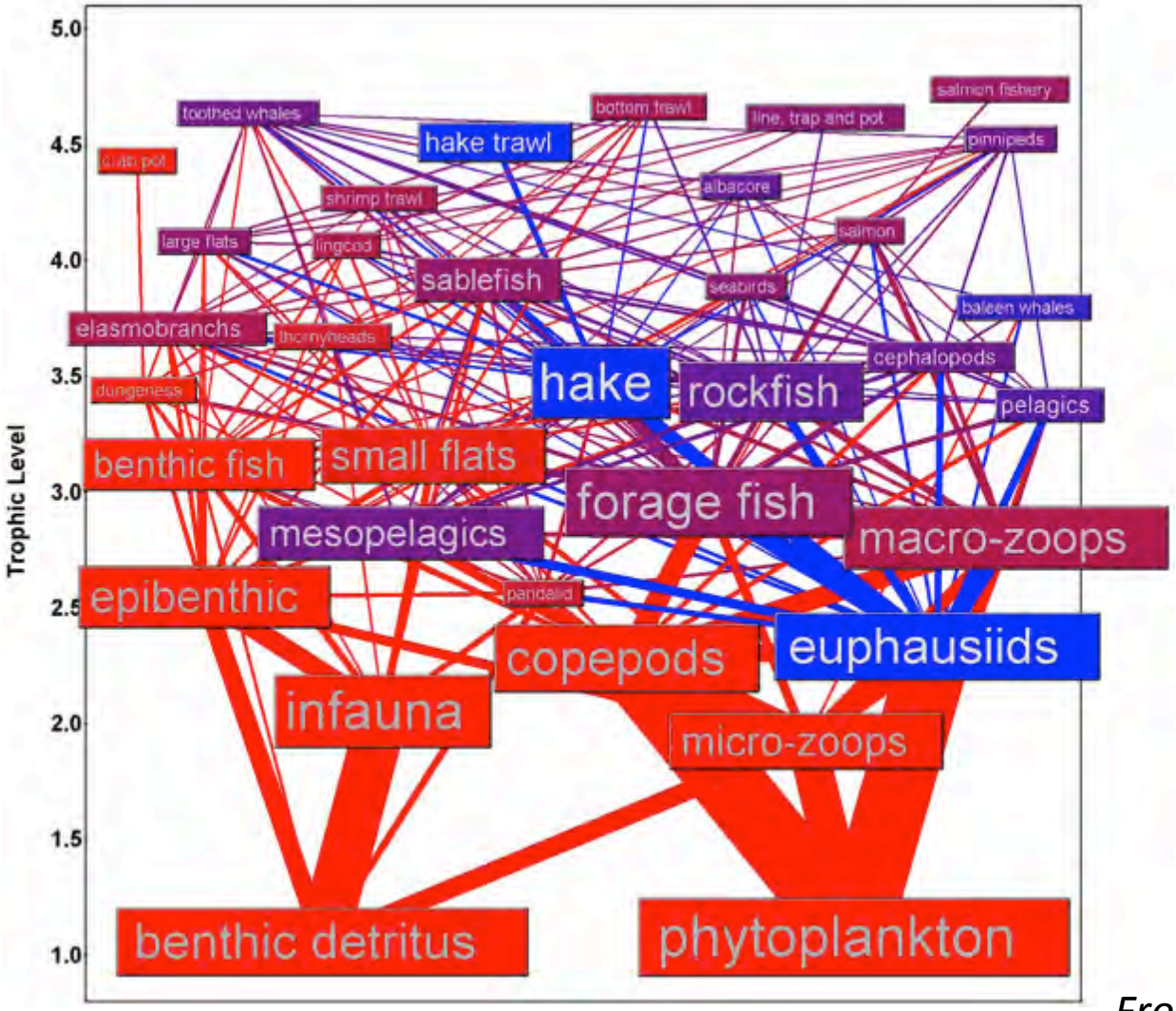


Seabird productivity and prey abundance



From Field et al. 2010

Ecosystem modeling – current



- Allows integration of multiple predators in a comprehensive ecosystem context
- ECOPATH w/ECOSIM, ATLANTIS
- But has NOT been able to replicate population cycling of coastal pelagics

From Field & Francis 2006

Ecosystem modeling - needs

- Stochastic models best represent predator use of prey (*which varies seasonally, inter-annually, spatially*) (e.g., End-to-End Models: ROHMS->NPZ->IBM)

- Get away from abundance as metric of predator response *(the LEAST responsive measure, may underestimate needs)*

- Incorporate variance *(averages do not accurately represent how predators respond to prey availability)*

Ecosystem-Based Approach

- Many of top 10 forage groups in the CCS are exploited
- Ecological importance of forage species is not new issue, but improved acknowledgement and explicit management guidance needed *(particularly in light of increasing climate variability)*
- First step - data does exist to quantify predator forage needs in the CCS – needs synthesis!

Summary

- Forage species are more than just small pelagics
- Forage species ecology affected by climate & fishing
- Whales to seabirds rely on these forage species
- Important to have diverse forage community *(species richness, space & time)*
- Data exist to quantify predator needs; *need to be synthesized*
- Ecosystem-Based Management