Environmental forcing on forage fish and apex predators in the California Current: Results from a fully coupled ecosystem model

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Ecosystem Variability in the California Current

Goal: use fully coupled model to characterize environmental forcing on population dynamics of fish and top predators.

Sardine & Anchovy (Schwartzlose et al., 1999)

Coho Salmon Survival (Peterson & Schwing, 2003)

California Sea Lion (Weise et al., 2006)
Fully Coupled Ecosystem Model using ROMS Framework

Regional Ocean Modeling System (ROMS)
- Ocean circulation
- Multi-decadal runs
- High-res. nesting
- Data assimilation
- Climate coupling

Biogeochemistry (NEMURO) Multi-species Individual-Based Model

Fish IBM
- Sardine
- Anchovy
- Juv. Salmon

Predator IBM
- Sea Lions
- Albacore

Fishing Fleet
Multi-species Individual-Based Model (IBM)

Individual-based Model
- Basic unit in nature; allows for complex life history/behavior.
- Main components: behavior, growth, mortality, reproduction.

Sardines and Anchovy (low frequency variability, 1964-2008)
- Dynamically feed on/compete for NEMURO zooplankton.
- Kinesis behavior combining temperature and food cues.

California Sea Lions (shifts in foraging patterns, 1989-2008)
- Dynamically feed on sardine and anchovy from fish IBM.
- Additional predation on market squid and mackerel.
- Kinesis behavior using temperature cue of upwelled waters.

Juvenile Salmon (growth following ocean entry, 1980-2008)
- Dynamically feed on NEMURO predatory zooplankton (krill).
- Bioenergetics (growth) from dynamic energy budget model.
- Neighborhood search behavior based on prey availability.
Sardine and Anchovy Population Dynamics

Adult Population Biomass

Model  Obs Data 1  Obs Data 2

Anchovy

Favorable Environmental Conditions

SST Anomaly  Zooplankton Anomaly

Rose et al., Prog. Ocean., 2015  Fiechter et al., Prog. Ocean., 2015
California Sea Lion Feeding Success (EOF Mode 1)

Sea Lion Mode 1 66%

Sardine Mode 2 14%

R = 0.75

Fiechter et al., MEPS, 2016
California Sea Lion Foraging Patterns (EOF Mode 2)

Sea Lion Mode 2 13%

SST Mode 2 8%

‘97-98 El Niño
‘05 delayed upwelling

Sea Lions SST

R = 0.73

R_{\text{ENSO}} = 0.21 \quad R_{\text{U136N}} = -0.20

Fiechter et al., MEPS, 2016
Onshore-Offshore Shift in Foraging Patterns (Mode 2)

February 2004  February 2005  February 2006
Environmental Forcing across Trophic Levels

Sea Lions
- Increased coastal foraging
- Increased feeding success

Anchovy
- Increased growth and population abundance

Sardine
- Increased survival and nearshore abundance

Regional Scale Forcing
- Coastal upwelling variability
- Cooler, more productive years

Basin Scale Forcing
- Positive SST anomalies
- Warm phase of PDO
Juvenile Salmon Growth and Early Upwelling Intensity

Growth Potential

Environmental Conditions

April Entry

Fiechter et al., GRL, 2015
Environmental Forcing across Trophic Levels

**Basin Scale Forcing**
- Positive SST anomalies
- Warm phase of PDO

**Local/Regional Scale Forcing**
- Coastal upwelling variability
- Cooler, more productive years
- Intensified upwelling in early spring

**Sardine**
- Increased survival and nearshore abundance

**Anchovy**
- Increased growth and population abundance

**Salmon**
- Increased growth during first year at sea

**Sea Lions**
- Increased coastal foraging
- Increased feeding success

**Basin Scale Forcing**
- Positive SST anomalies
- Warm phase of PDO
Summary

Proof of principle (it can be done)
- 3 days of CPU time for 20 years at 10km resolution.
- 20,000 fish super-individuals and 1,000 predator individuals.

Model calibration and evaluation
- Very challenging: physics, NPZ, fish, and predators.
- Behavior: must include realism without “overtuning”.

Is it useful?
- Low-frequency cycles in sardine and anchovy populations.
- Shifts in sea lion foraging patterns (e.g., onshore vs. offshore).
- Environmental conditions favoring juvenile salmon growth.
- Mechanistic approach to understanding ecosystem variability.
Fully-coupled food web model?
Not quite there yet, but getting closer…