CaCu MICE update: Pacific sardine projections under environmental drivers and ecological uncertainty

Stefan Koenigstein

CCIEA-FutureSeas call Nov 10, 2020
MICE for Pacific sardine: Model structure

- **Model of Intermediate Complexity** (for Ecosystem assessment)
- Aim to assess environmental drivers of past sardine fluctuations and project into future, assessing uncertainty
- Based on biological processes

- Age-structured population model
  - ‘Stocks’ of individuals and ‘flows’ (life cycle, mortalities):
    - (finite difference equations solved in weekly time-step)
  - Early life stages have temperature-dependent development time and mortality
  - Consumption (and age structure) determines egg production

---

Ocean temperature
(10–40m, spring)

- thermal mortality
- development time

Food availability
(PL / ZM / ZL, summer)

- consumption

Egg production

---

- larvae
- juveniles
- adults

natural mortality
natural mortality
natural mortality

recruitment

fisheries

ELS mortality

eggs
Environmental drivers and spatial life cycles

- Output from downscaled ROMS-NEMURO runs in 24 zones (8x3)
- Sardine density distribution function along N-S and W-E axes, for feeding and spawning
- Approximating sardine spatial life cycle by simplistic migration rules
  - Spawning where temperature is best on N-S
  - Feeding occurs where best food availability is on N-S
Spawning location

- Assumption: Sardine migrate towards $\text{SST}_{\text{opt}} (\pm 13^\circ \text{C})$ for spawning

- CalCOFI sardine larvae data binned into latitudinal zones 1-8
  - Spawning location for fitting period

- Scenario for degree of compensation derived from correlation $\text{pOc-} \text{SST}_{\text{opt}}$ (ROMS nrt run, 2003-2018)
  - Adaptive annual spawning location for forecast
Early life stage survival

- Early life stages: Dynamic survival determined by T averaged over 10-40m depth (sardine spawning habitat)
  - thermal mortality and development time

Example:

\[
\text{Thermal mortality} \times \text{dev.time-dependent mortality} = \text{thermal response curve}
\]
Feeding

- Assumption: Sardine adults move to latitude of best food (PL) at peak plankton bloom time (fitting and forecast)
  - Check with adult data pending
  - Consumption determined by Type II functional response (3 food items PL/ZM/ZL)

![Graph showing latitudinal cell N-S with data from 1983 Jan to 2011 Jan. The graph includes lines for forage habitat N-S, plankton PL bloom, and sardine weighted food PL.](image)
Model fitting

- Fitted to stock assessment estimate of numbers-at-age and catch-at-age, 1980-2010 (Hill et al. 2019)
- Wide search of parameter space (8000+ runs / Latin Hypercube etc.)
- Picked 18 model parameterizations with diverging parameters among best fits to stock assessment
  - ‘ecological uncertainty’
Assessing different model parameterizations (overview)

e.g.

Run 2942

Run 1963

Run 4012

Run 296

Run 3340

**ELS thermal response**
(Recruits / ELS Temp)

**Stock-recruitment**
(Recruits / pop. no.)

**Feeding response**
(Diet / plankton biomass)

**Age structure**
(Mean age / pop no.)

**Egg production**
(eggs / food availability)
Environmental drivers in forecast scenarios

- ROMS-BGC (UCSC-NEMURO) downscaled from GCMs (CMIP5) → 2100 under IPCC RCP 8.5
- Combinations of driver trajectories differ among GCMs
- Slight adjustment by adaptation in spatial location (migration rules), differs among GCMs (interannual variability)

1980-2010 runs

2020-2100 drivers

GFDL

HAD

IPSL

Temp (10-40m) [°C]

PL

ZM

ZL

sardine location

Avg. over domain
Pacific sardine population trajectories

- Increasing population trends under all downscaled GCMs, due to general warming increasing ELS survival

- Range of future scenarios under different fitting scenarios (ecological uncertainty):
  - Projections forced by GFDL have lower uncertainty than HAD and IPSL
Catch-at-age projections

(Assuming one combined MexCal-PNW fleet with constant selectivity, and catch rules based on historical correlation)

- catches are proportional to population and age structure

Ecological uncertainty is
  - much higher for age1 than age2+
  - larger than variation among GCMs, but: divergent response among GCMs in final years of forecast
Conclusions

- Pacific sardine population projected to increase under all downscaled GCMs due to ocean warming – food availability secondary driver
- Ecological uncertainty in forecasts increased under greater departure from historical conditions, and diverging (positive-negative impact) drivers

Upcoming work
- More sensitivity analyses: uncertainty in sardine migration, catches and stock estimates
  - (first results: adds smaller amount of uncertainty to projections)
- Testing input from NEMURO-IBM (location, consumption…)
- Adding predators (California Sea lions, Brown pelicans, Humpback whales…)
Contributors

Mike Jacox
Mer Pozo Buil
Jerome Fiechter
Barb Muhling
Desiree Tommasi