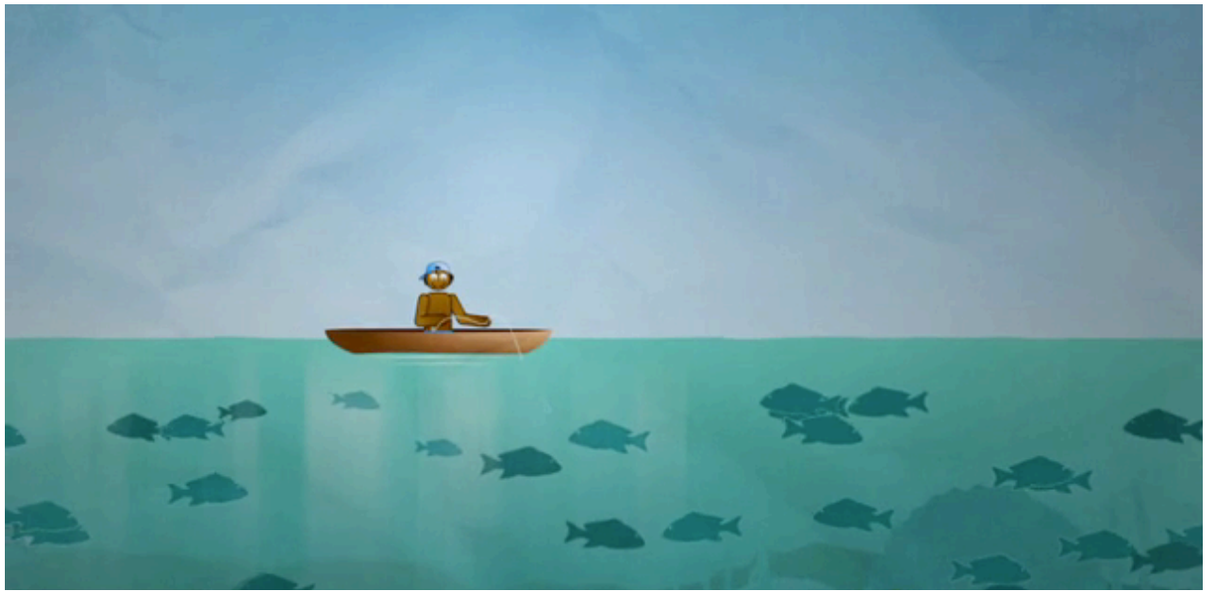

Designing a reproductive resilience index for small pelagic fish in the southern Humboldt Current Upwelling Ecosystem

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Resilience in ecology and fisheries science

- Ecological resilience is the magnitude of disturbance that a system can tolerate before it shifts into a different state (stability basin) with different controls on structure and function (Holling 1973, Folke 2006, Sheffer et al. 2009)
- Pope et al. 2014: “Resilience management consists of actively maintaining a diversity of functions and feedbacks, steering systems away from critical thresholds at which they would tip into undesired regimes, and increasing the capacity of systems to cope with change.”

Resilience in ecology and fisheries science

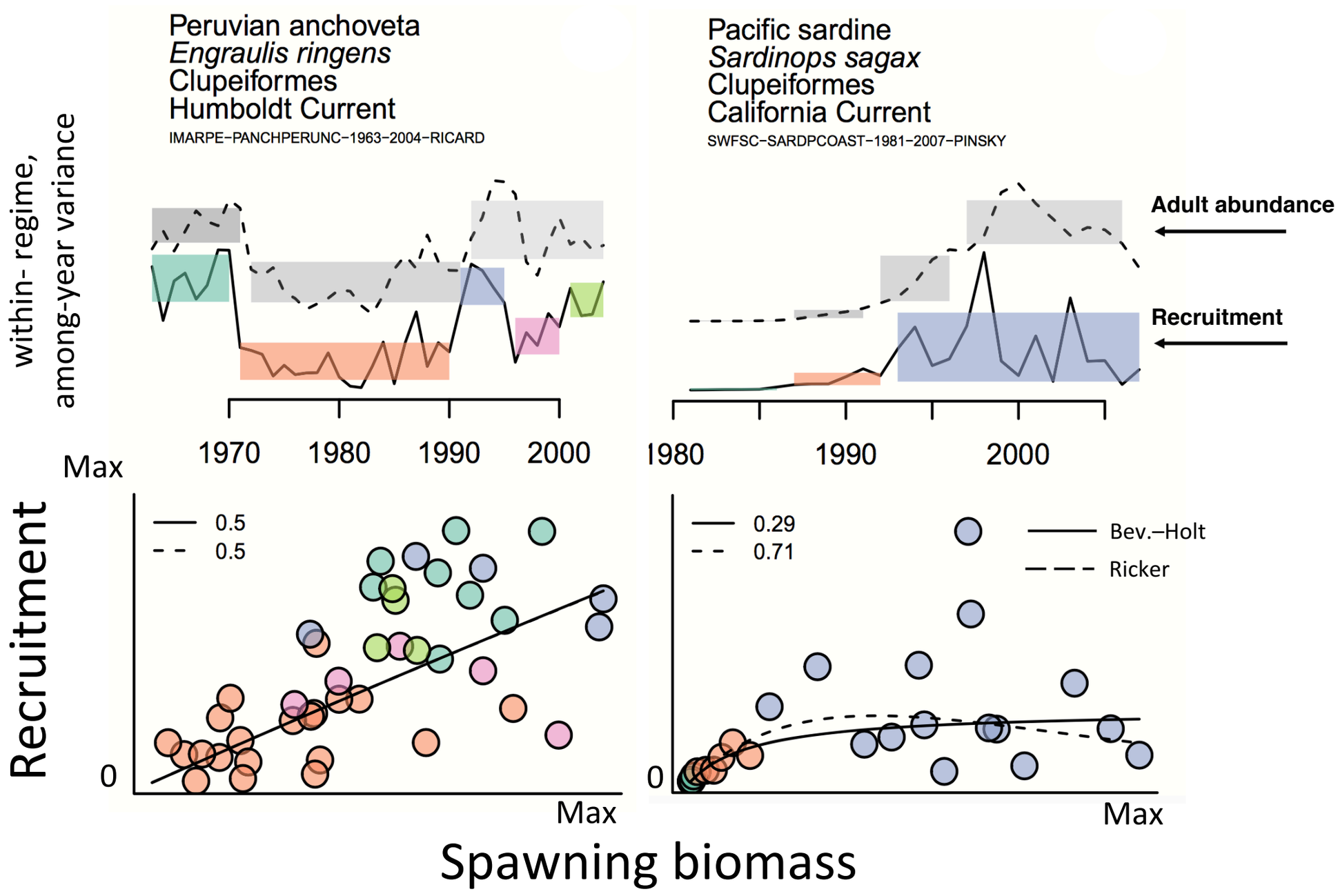
- For at least one decade, Fishbase has used an index of "**resilience to fishing pressure**" based on a series of suggested values for several biological parameters that allow to classify a fish population or species into categories of high, medium, low and very low resilience or productivity (Musick, 1999 & American Fisheries Society AFS).

Table 1. Values of selected life-history parameters suggested for classifying the resilience / productivity of fish populations or species (Modified from Fishbase).

Parameter	High	Medium	Low	Very low
Threshold	0.99	0.95	0.85	0.70
r_{max} (1/year)	> 0.5	0.16 - 0.50	0.05 - 0.15	< 0.05
K (1/year)	> 0.3	0.16 - 0.30	0.05 - 0.15	< 0.05
Fecundity (1/year)	> 10,000	100 1000	10 - 100	< 10
t_m (years)	< 1	2 - 4	5 - 10	> 10
t_{max} (years)	1 - 3	4 - 10	11 - 30	> 30

Cross-correlation and the relationship between spawning biomass and recruitment

Figure adapted from: Szuwalski, C. S., Vert-Pre, K. A., Punt, A. E., Branch, T. A. and Hilborn, R. (2015), Examining common assumptions about recruitment: a meta-analysis of recruitment dynamics for worldwide marine fisheries. Fish Fish, 16: 633–648. doi:10.1111/faf.12083



- Less than 20% of the stocks showed a pattern of productivity consistently driven by adult abundance (Vert-pre et al. 2013).
- Only 39% showed a positive relationship between recruitment and spawning biomass (Szuwalski et al. 2015).

Adult biomass

Fecundity

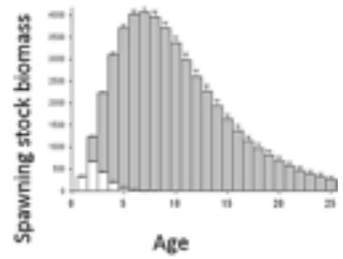
≠

reproductive success

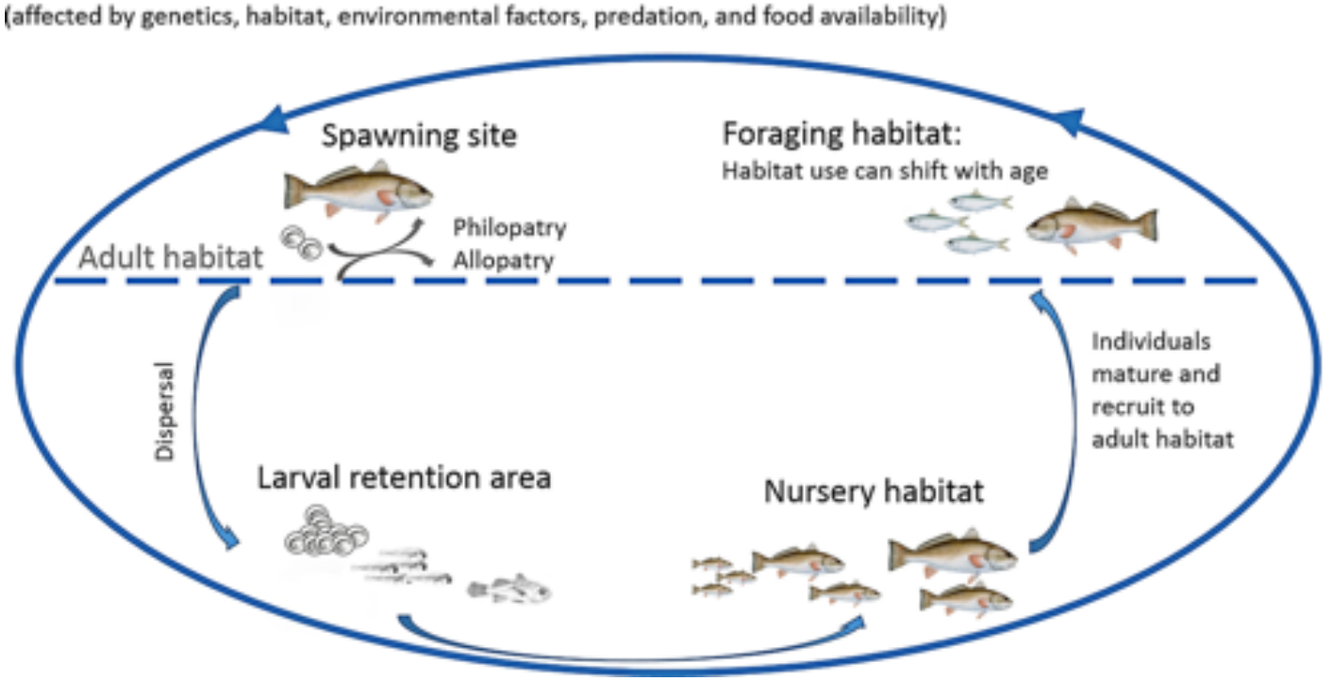
Reproductive potential is commonly based on spawning stock biomass, but in many marine species, spatial components of the life cycle may be more important to reproductive success.

However, fisheries management remains predicated on the concept that mature biomass drives long-term population productivity and yield (Vert-pre et al. 2013).

Management context:
Harvest control rules=conserve some portion of mature females
(reproductive potential based on spawning stock biomass as a proxy)



Ecological context:
Reproductive success=an individual's offspring survive to reproductive age
(affected by genetics, habitat, environmental factors, predation, and food availability)



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FISH and FISHERIES

Original Article

Reproductive resilience: a paradigm shift in understanding spawner-recruit systems in exploited marine fish

Susan Lowerre-Barbieri[1,2,*], Greg DeCelles[3,4], Pierre Pepin[5], Ignacio A Catalán[6], Barbara Muhling[7,8], Brad Erisman[9], Steven X Cadrin[3], Josep Alós[6,10], Andres Ospina-Alvarez[11], Megan M Stachura[12,13], Michael D Tringali[1], Sarah Walters Burnsed[1] and Claire B Paris[14]

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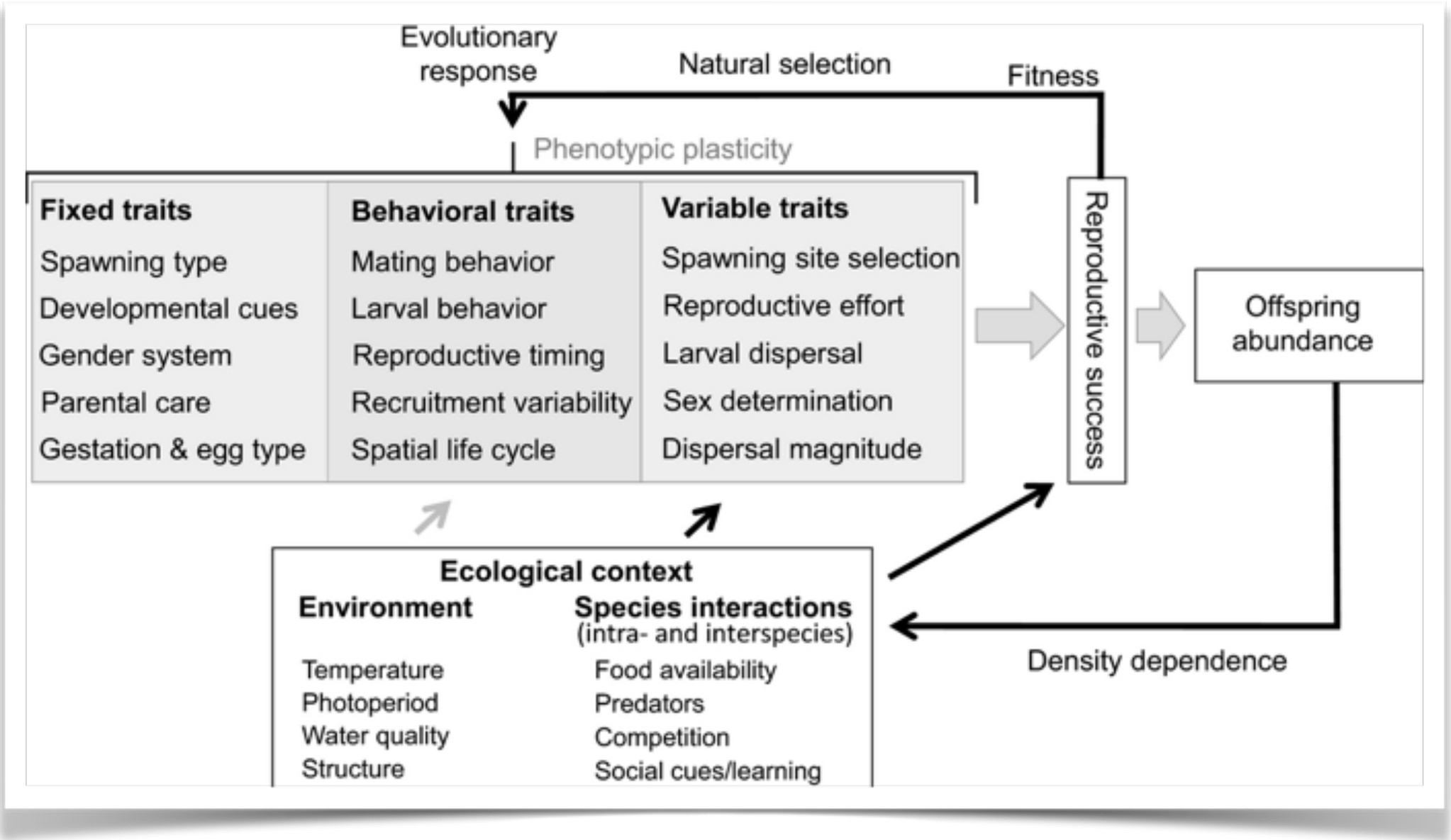
A new eco-evolutionary framework…

Reproductive resilience is the capacity of a population to maintain the reproductive success needed to result in long-term population stability despite disturbances (Lowerre-Barbieri et al. 2015)

A framework to better understanding of spawner-recruit systems



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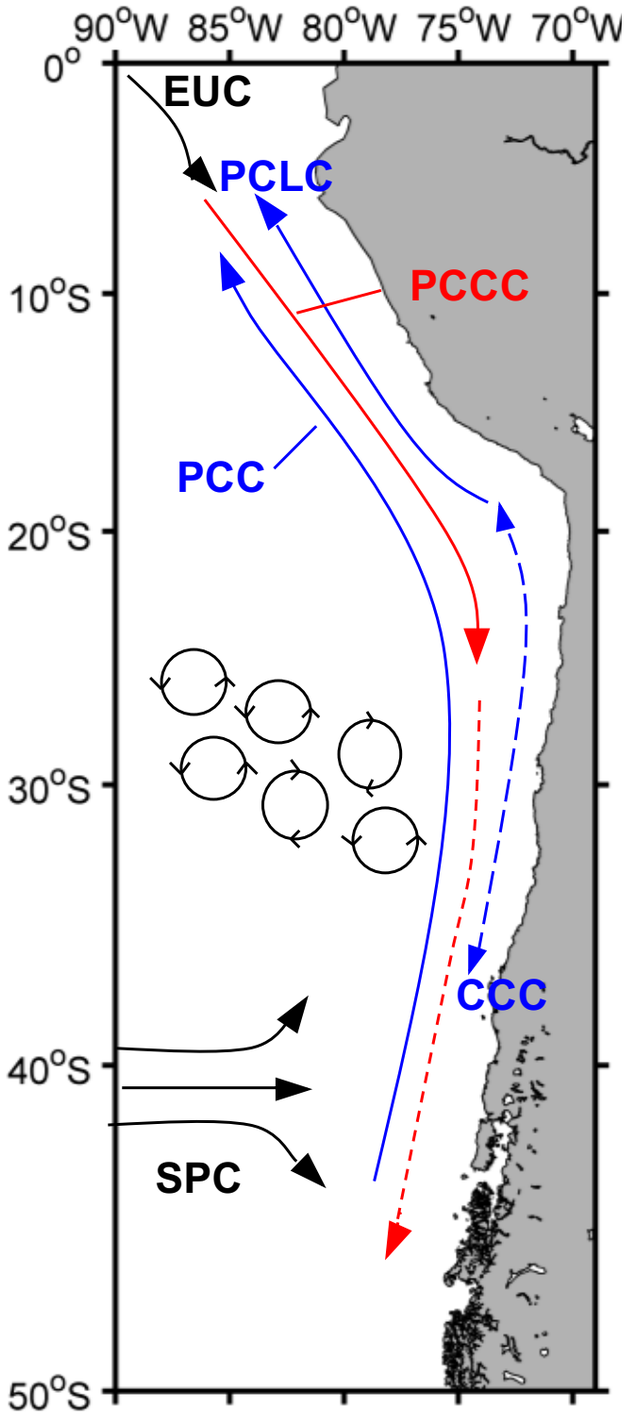
AIMS

- To design a reproductive resilience index for small pelagic fish in the southern Humboldt Current Upwelling Ecosystem as an alternative or complementary approach for fisheries management stock.

Study area and objective species



- Species focus of the study:
  - Jack mackerel (*Trachurus murphyi*)
  - Pacific sardine (Sardinops sagax)
  - Anchoveta (*Engraulis ringens*)
  - Common sardine (*Clupea bentincki*)
  - Patagonian sprat (*Sprattus fuegensis*)

Methods

- 17 traits of spawner-recruit systems was selected and classified in 6 main categories: Reproductive effort; demographic trends; reproductive timing; spawning site selection; larval dispersal potential & recruitment variability.

- Each of these 5 species was scored for its affinity to trait following the “fuzzy scoring” method using a scale of 0 to 5 (0 = no resilient to 5 = high resilient) (see Bremner et al., 2003 for further details).
- This assignment was based on available literature, experts' knowledge and information from the INPESCA database.
- When no information on a particular trait was available, information for closely related taxa (other species in the genus) was considered (Bolam and Eggleton, 2014).

Categories and traits

1. Reproductive effort
   - [A] Energy devoted to reproductive processes affecting skip spawning
   - [B] Reproductive migration

2. Demographic trends
   - [C] Growth rate
   - [D] Natural mortality

3. Reproductive timing
   - [E] Sexual maturity
   - [F] Reproductive lifespan
   - [G] Generation time
   - [H] Spawning seasonality

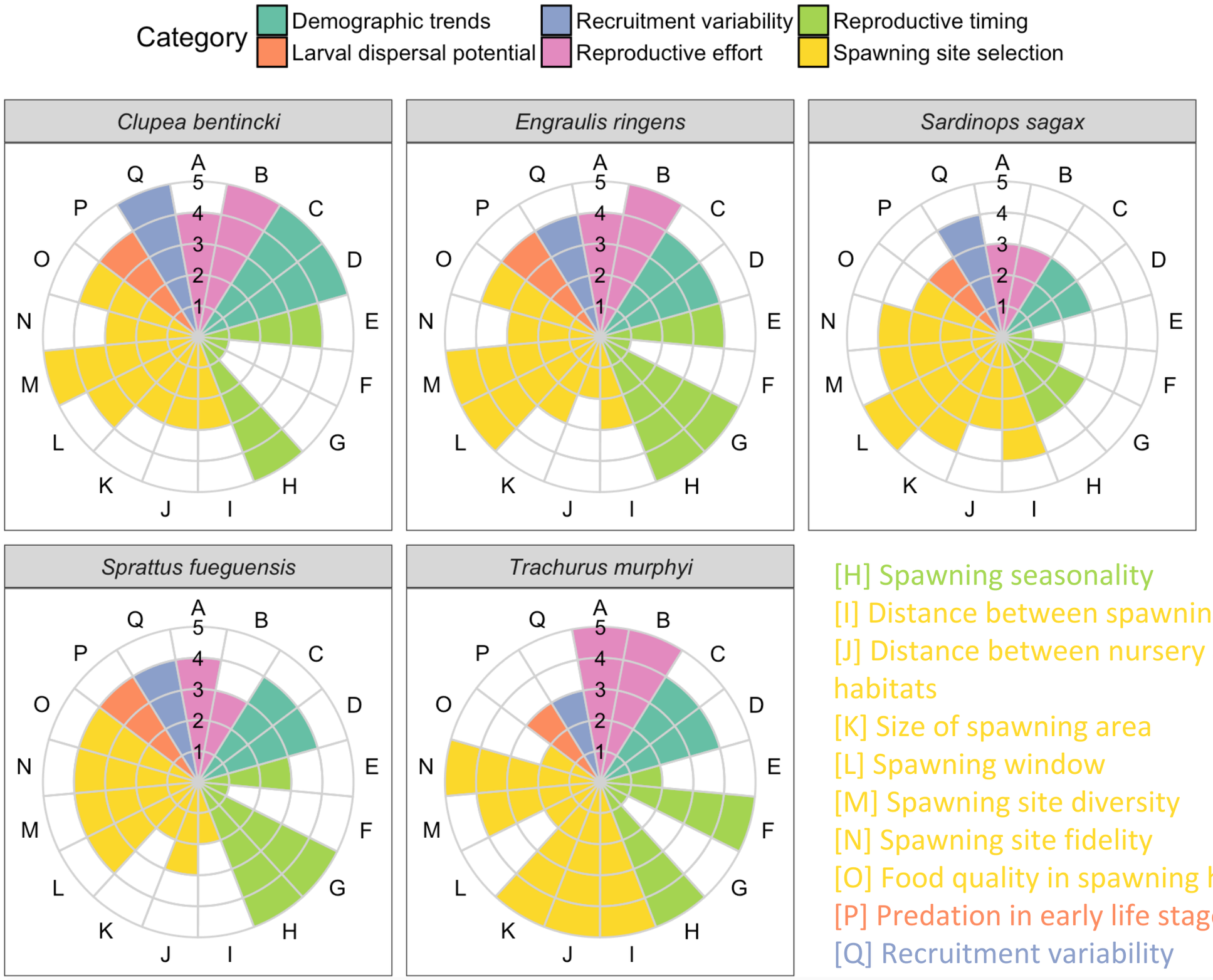
4. Spawning site selection
   - [I] Distance between spawning and nursery habitats
   - [J] Distance between nursery and adult foraging habitats
   - [K] Size of spawning area
   - [L] Spawning window
   - [M] Spawning site diversity
   - [N] Spawning site fidelity
   - [O] Food quality in spawning habitat

5. Larval dispersal potential
   - [P] Predation in early life stages

6. Recruitment variability

Results

Important spawner-recruit system traits for pelagic fish in HCUE



Traits

[A] Energy devoted to reproductive processes affecting skip spawning
[B] Reproductive migration
[C] Growth rate
[D] Natural mortality
[E] Sexual maturity
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[N] Spawning site fidelity
[O] Food quality in spawning habitat
[P] Predation in early life stages
[Q] Recruitment variability

Results

Table. Spawner-recruit system resilience, summary of trait scores in categories

Category	*Clupea bentickі*	*Engraulis ringens*	*Sardinops sagax*	*Sprattus fueguengis*	*Trachurus murphyi*
Reproductive effort	5	5	3	4	5
Demographic trends	5	4	3	4	4
Reproductive timing	3	4	2	4	3
Spawning site selection	4	4	4	3	4
Larval dispersal potential	4	4	3	4	3
Recruitment variability	5	4	4	4	3
Spawner-recruit system resilience	**4**	**4**	**3**	**4**	**4**

Discussion

Table. Resilience to fishing pressure (from fishbase database)

Measure	*Clupea bentincki*	*Engraulis ringens*	*Sardinops sagax*	*Sprattus fuegensis*	*Trachurus murphyi*
K	0.6	0.6-0.9	0.45	0.7	0.09-0.11
tm	NA	1	2	NA	NA
tmax	NA	3	13-25	NA	NA
Batch fecundity	NA	>10000	10000	NA	NA
Resilience to fishing pressure	**High**	**High**	**Medium**	**High**	**Low**

Table. Spawner-recruit system resilience (this work)

Spawner-recruit system resilience	**4 (High)**	**4 (High)**	**3 (Medium)**	**4 (High)**	**4 (High)**

Perspectives

- Improve accuracy in fuzzy scoring to improve the definition of species affinity for each trait evaluated.

- Design an evaluation system to incorporate the knowledge of experts in the definition of the scores in each of the traits evaluated.

- Incorporate a greater diversity of species in the analysis to compare species that display different reproductive and ecological strategies.

- Discuss the incorporation of reproductive resiliency into the ecosystem-based fisheries management system.