"Using an Individual Based Model with four Trophic Levels to Model Fisheries Recruitment"

Fifth International Zooplankton Production Symposium
Pucón 14-18 March 2011

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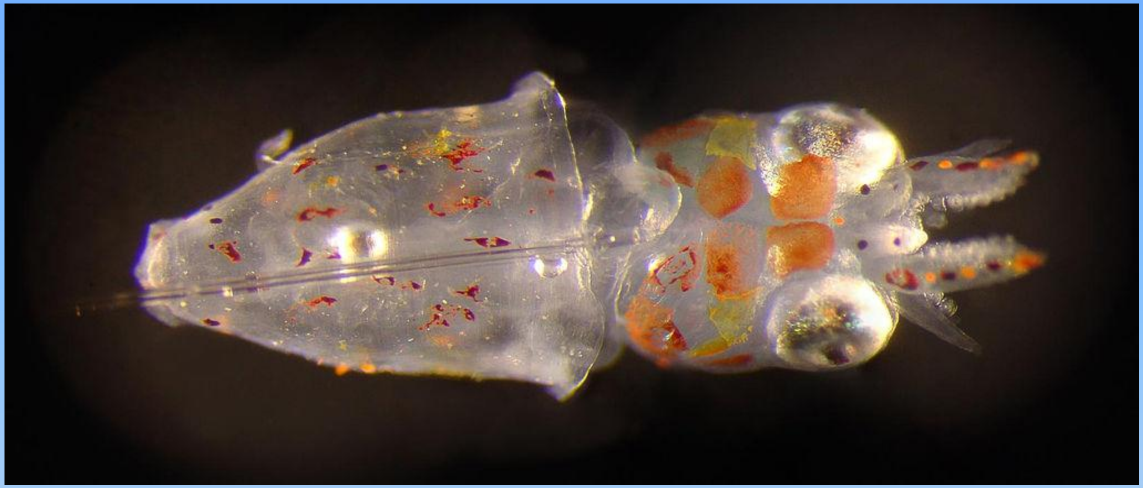
Outline

- Background
- Scientific challenge
- Strategy
- Model description
- Results from numerical experiments

Background

- Semelparous
- Fast growing
- Opportunistic



- The abundance of cephalopods in some areas has apparently increased relative to fish
- Highly variable recruitment

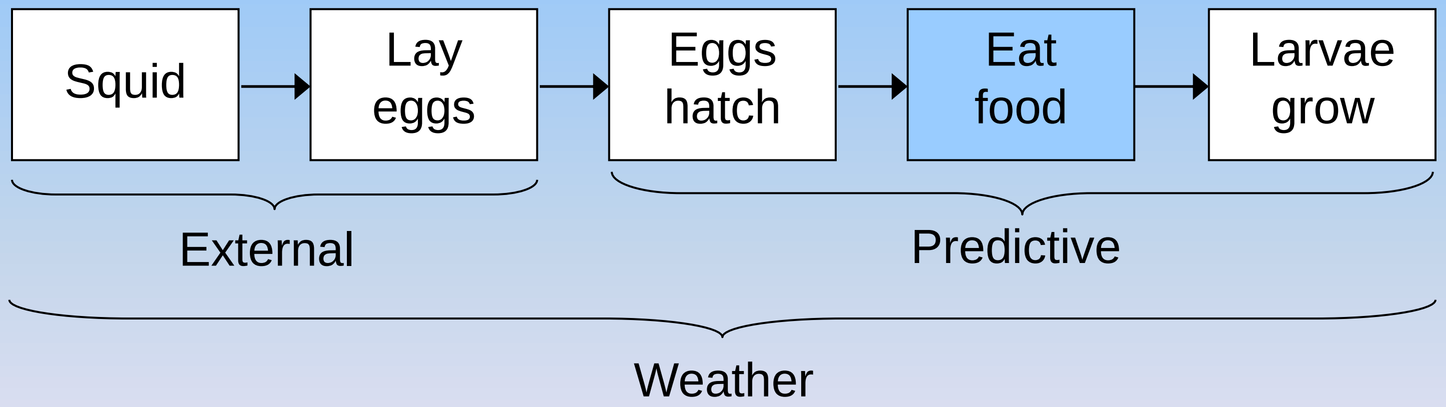
Scientific challenge

- Make predictions on squid recruitment
  - Phenotypic equations from reproducible laboratory experiments under controlled conditions
    - Behaviour
    - Physiology
- Model more realistically predator prey interactions
- Testing theories about the relationship between recruitment and ecosystem

Research strategy

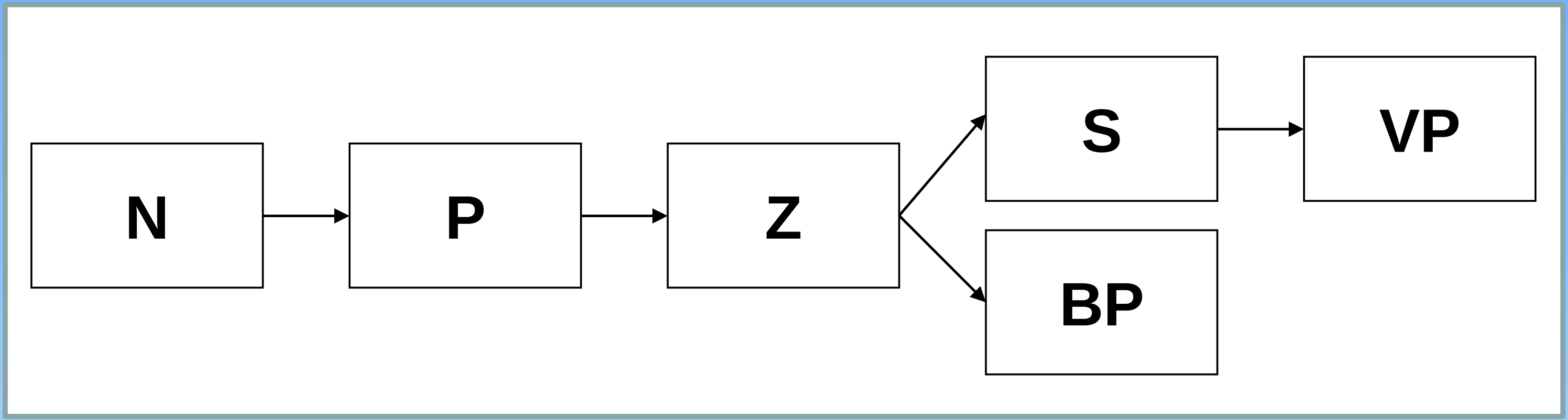
- Build a predictive ecosystem model based on the hard facts from marine biology
  - Lagrangian Ensemble Recruitment Model (LERM)

- Individual Based Model integrated by the Lagrangian Ensemble Metamodel (1D)



- Model food

Lagrangian Ensemble Recruitment Model
LERM



2 dissolved nutrients (N):

Nitrogen
Silicate

1 explicit diatom species (P)

1 explicit copepod species (Z)

1 explicit squid paralarvae species (S)

Droop pools
N,(Si), C
protein
lipid

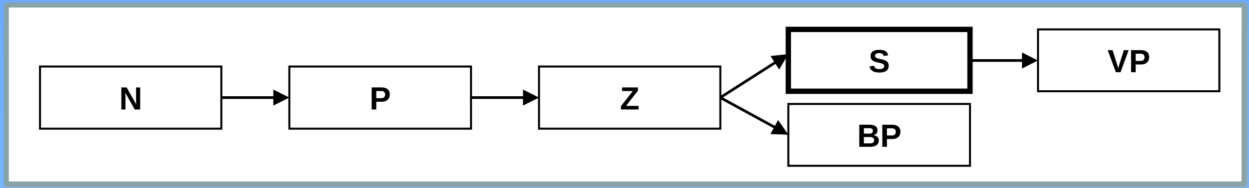
1 parametrised predator feeding on copepods (BP)

1 parametrised top predator feeding on squid (VP)

Lagrangian Ensemble Recruitment Model LERM

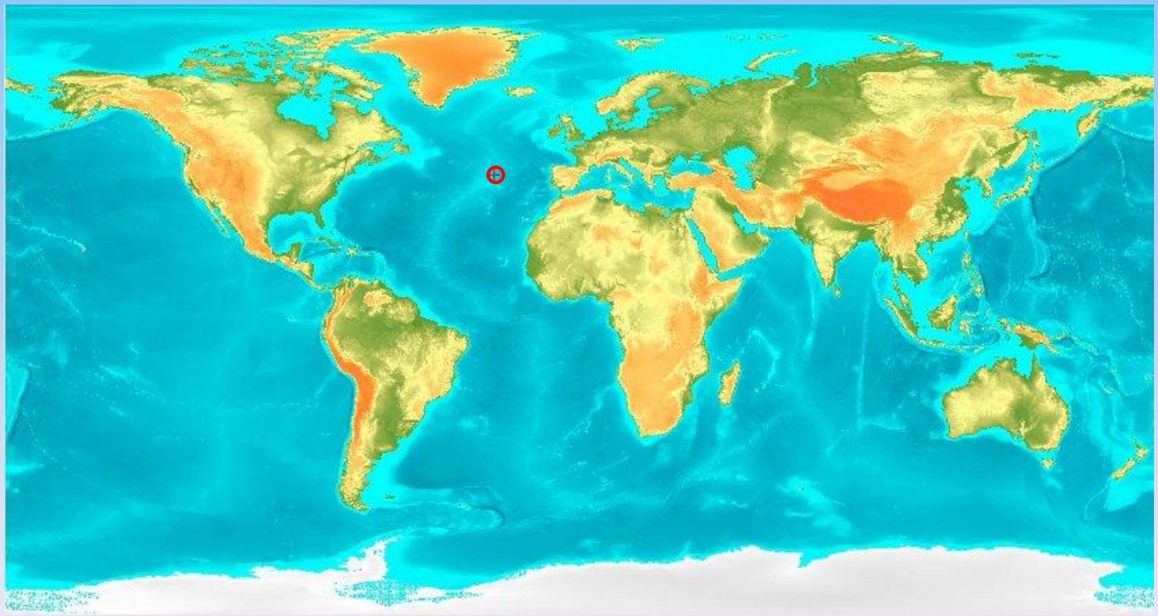
- Diatom
  - Based on a midsize diatom (cross-section diameter 20μm)
  - Photoadaptation
  - Cell division (C and Si)
- Copepod
  - Based on Carlotti and Wolf, 1998 model for *Calanus finmarchicus.*
  - Staged growth
  - Diel migration
  - Ingestion based on gut volume, digestion, gut passage time and assimilation
  - Dynamic allocation of C to protein and lipid
- Squid
  - Based on the physiology and behaviour of *Loligo*
  - Temperature dependent embryogenesis
  - Endogenous and exogenous feeding
  - Ingestion based on gut volume, digestion and assimilation
  - Dynamic allocation of C to protein and lipid
  - A squid recruits when it reaches 8mm in mantle length
- Top predators
  - Demography is set in the scenario using a series of exogenous equations
    - Abundance, size and vertical distribution
  - Trophic interaction is expressed by ingestion equations based on squid

Experiments



Experiments set at Azores site (41°N, 27°W)

- Annual surface heat budget is in balance (i.e. solar heating equals cooling to the atmosphere)



Stability – Convergence to a stable attractor

- The ecosystem is allowed to adjust to its attractor for 15 years:
  - Stationary annual cycle of external forcing (Bunker climatology)
  - Nutrients (NOAA Ocean Atlas)

⇨ **Virtual ecosystem follows a stationary annual cycle**

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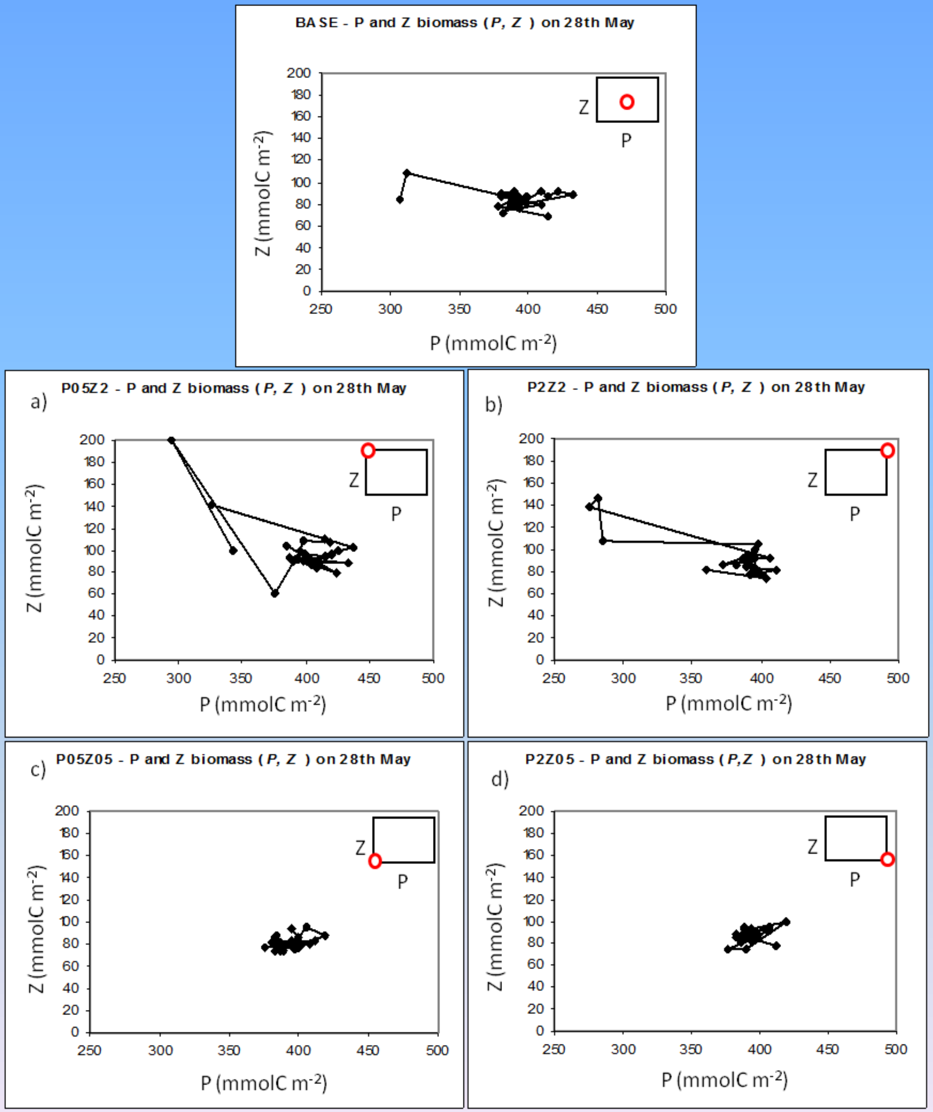

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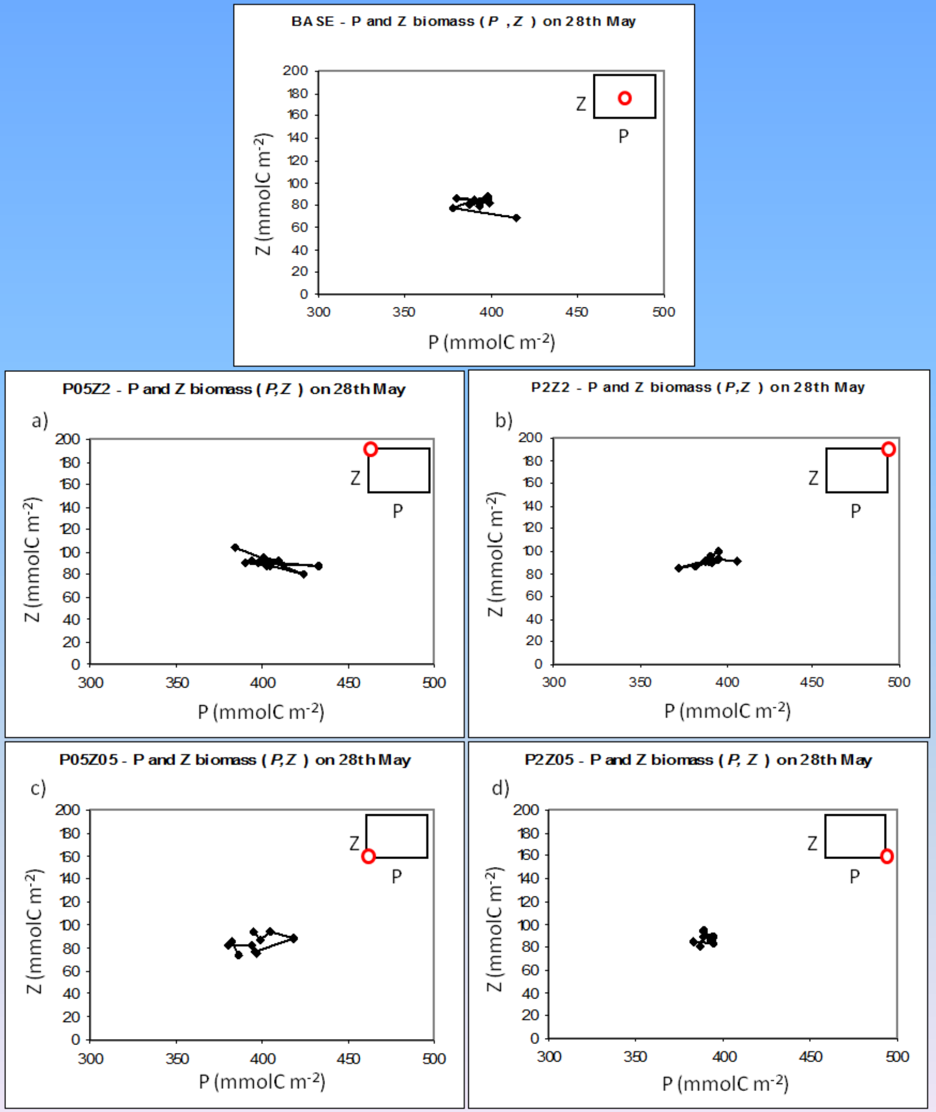

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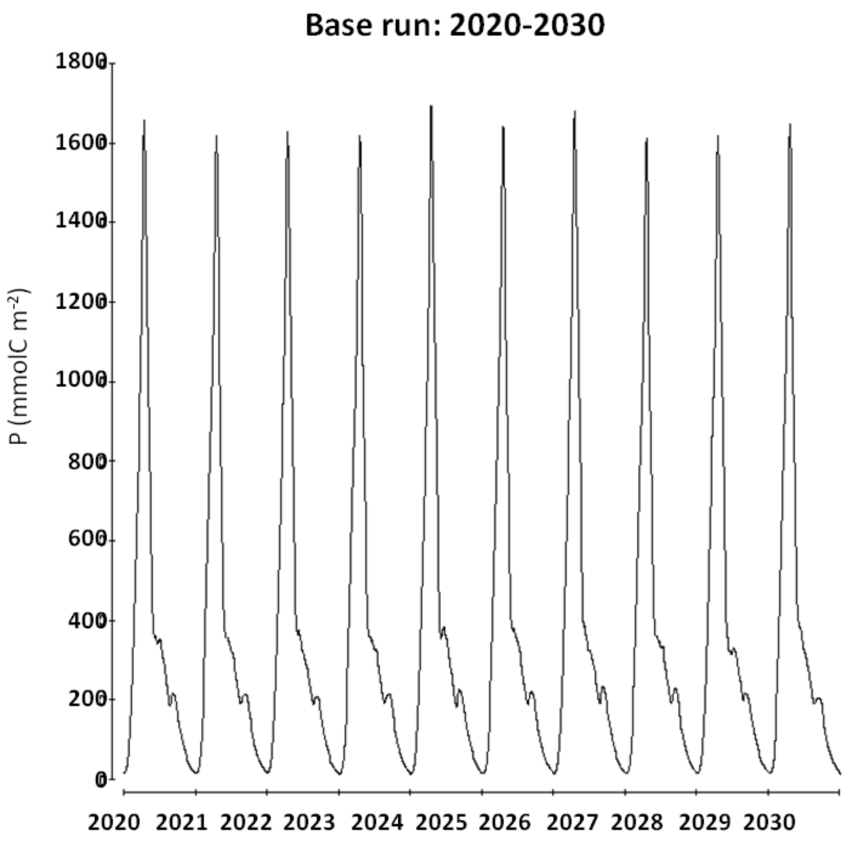
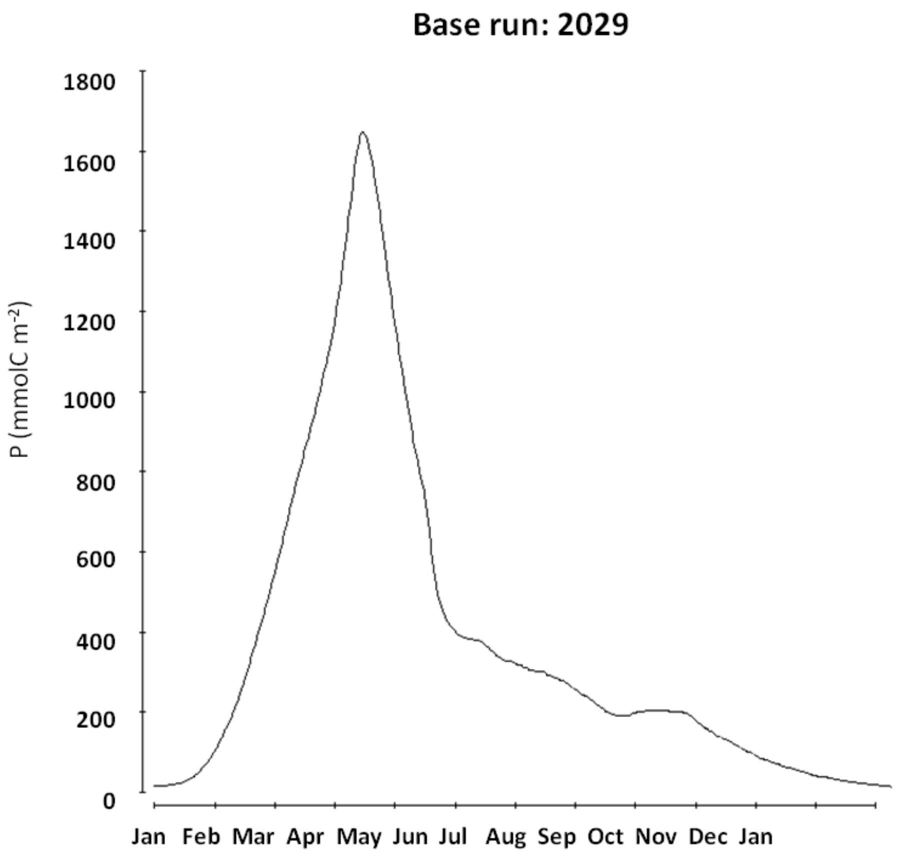
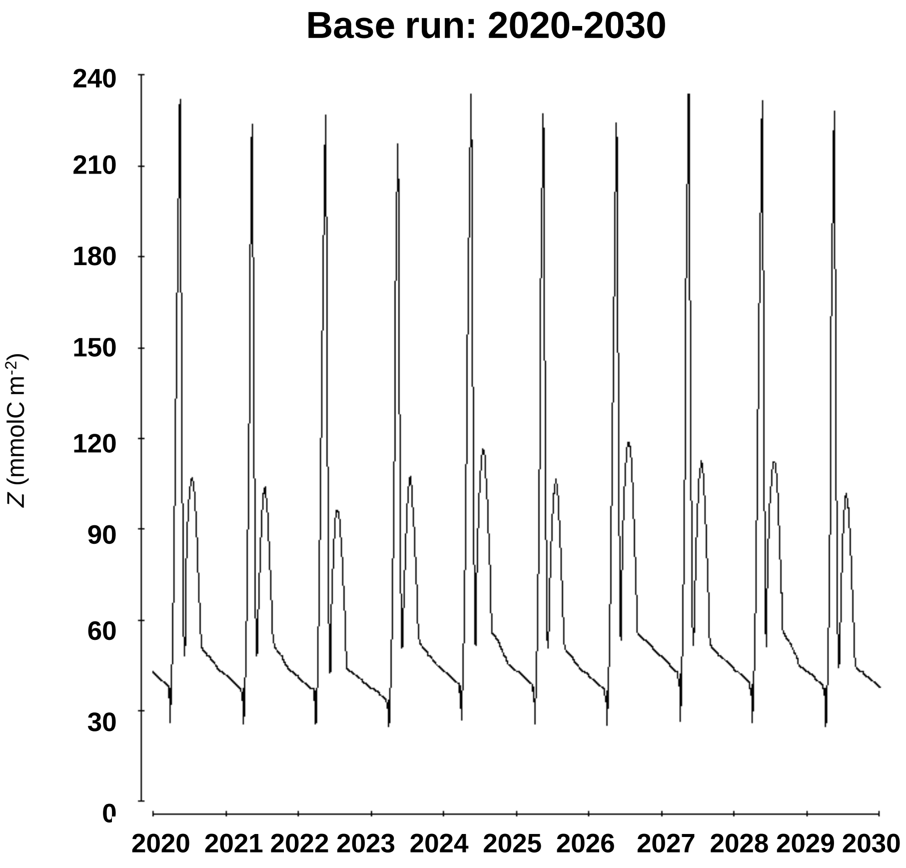
- The inter-annual variation from the multi-year mean is small
  - P, Z, S biomass on 28th May was 3.7, 8.6 and 11.3 % respectively
  - Inter-annual variation in squid recruitment was 12% of the multi-year mean

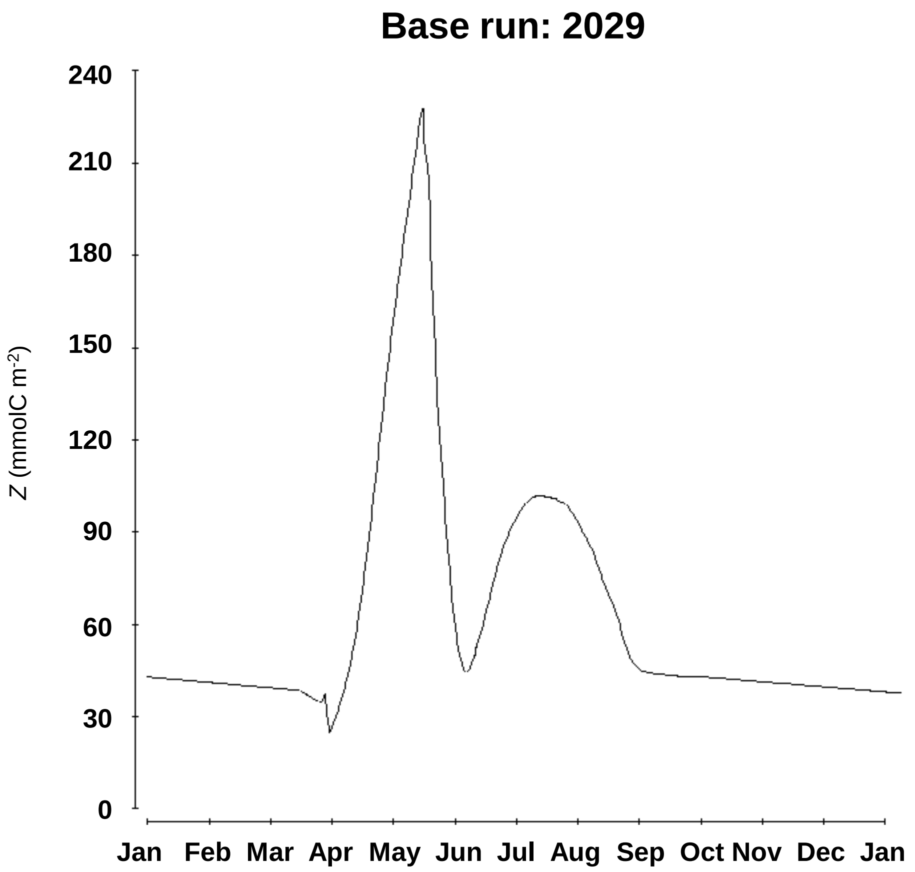
Phytoplankton biomass





Herbivorous zooplankton biomass



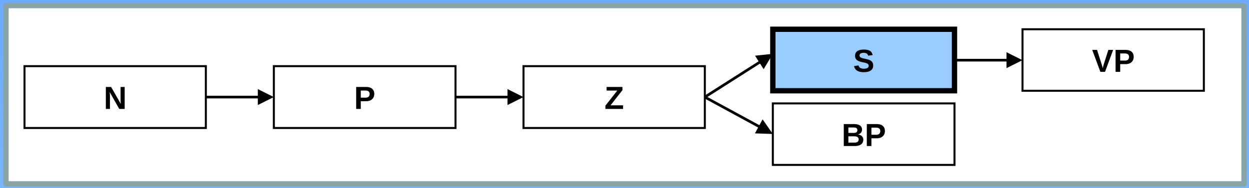


Herbivorous zooplankton biomass

- Sobrinho and Isidro (2001) measured Z biomass off Faial Island (38°N, 28°W) between February and June 1998.
- Single peak in Z biomass in May
- Comparable biomasses

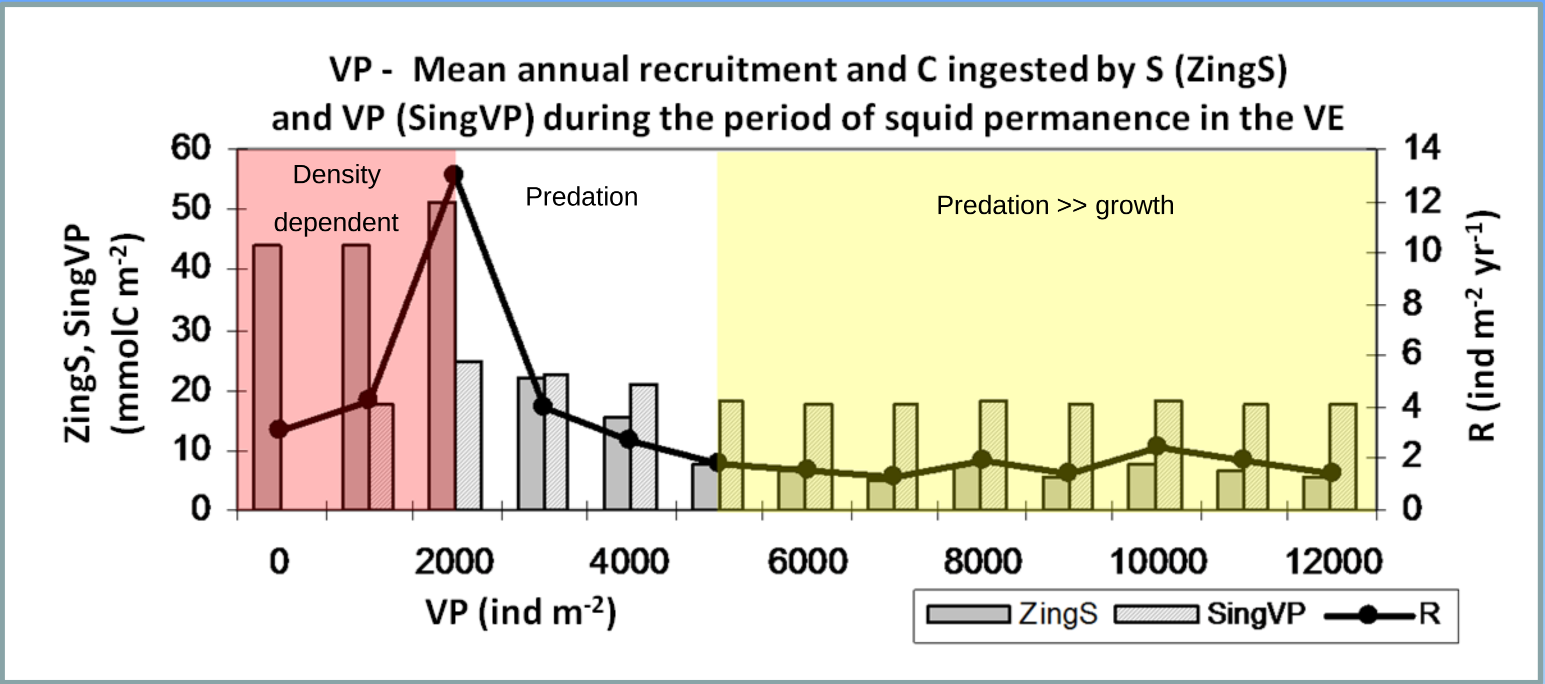
Month	OBS gC m^{-2}	LERM gC m^{-2}
Feb	0.57 ± 0.09	0.48 ± 0.03
Mar	0.79 ± 0.11	0.46 ± 0.03
Apr	-	0.84 ± 0.02
May	3.56 ± 1.63	2.72 ± 0.08
June	0.61 ± 0.09	0.87 ± 0.06

Experiments



- STABILITY:
- SENSITIVITY OF RECRUITMENT TO:
  - predation,
  - competition for food (basal predator),
  - **spawning magnitude**

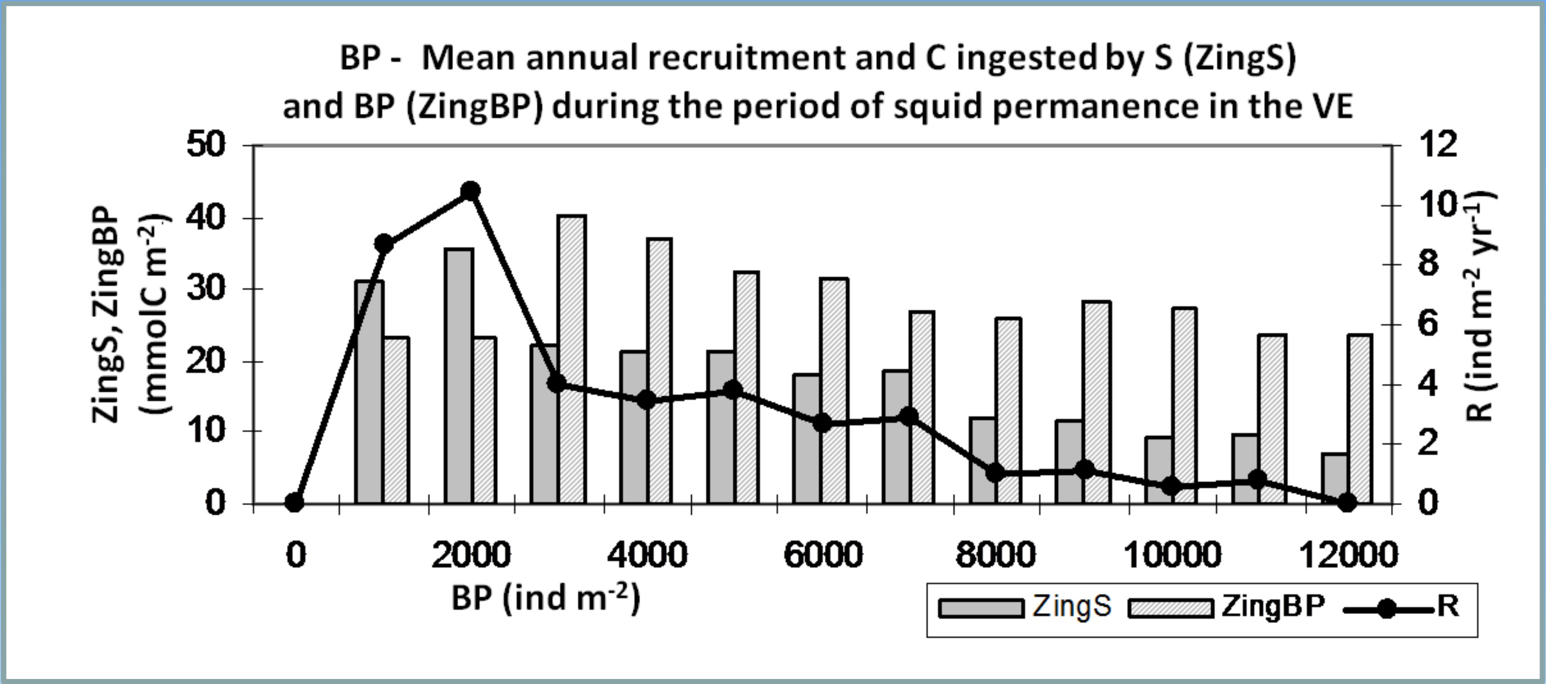
Predation on squid



(a)			
VP ×10^3	S	P	R
	ind m^{-2} yr^{-1}		
0	297.0	0.0	3.0
1	90.9	204.9	4.2
2	0.4	286.6	13.0
3	0.0	296.0	4.0
4	0.0	297.3	2.7
5	0.2	298.1	1.7
6	0.0	298.4	1.6
7	0.0	298.7	1.3
8	0.0	297.9	2.1
9	0.0	298.5	1.5
10	0.0	297.6	2.4
11	0.0	298.0	2.0
12	0.0	298.6	1.4

- Squid mortality due to predation was the most significant factor affecting annual recruitment
- effect of predation on the squid population especially on the more abundant and slower swimming newly hatched squid
- 3 regions:
  - Density-dependent
  - Predation
  - Predation much higher than growth

Inter-population competition



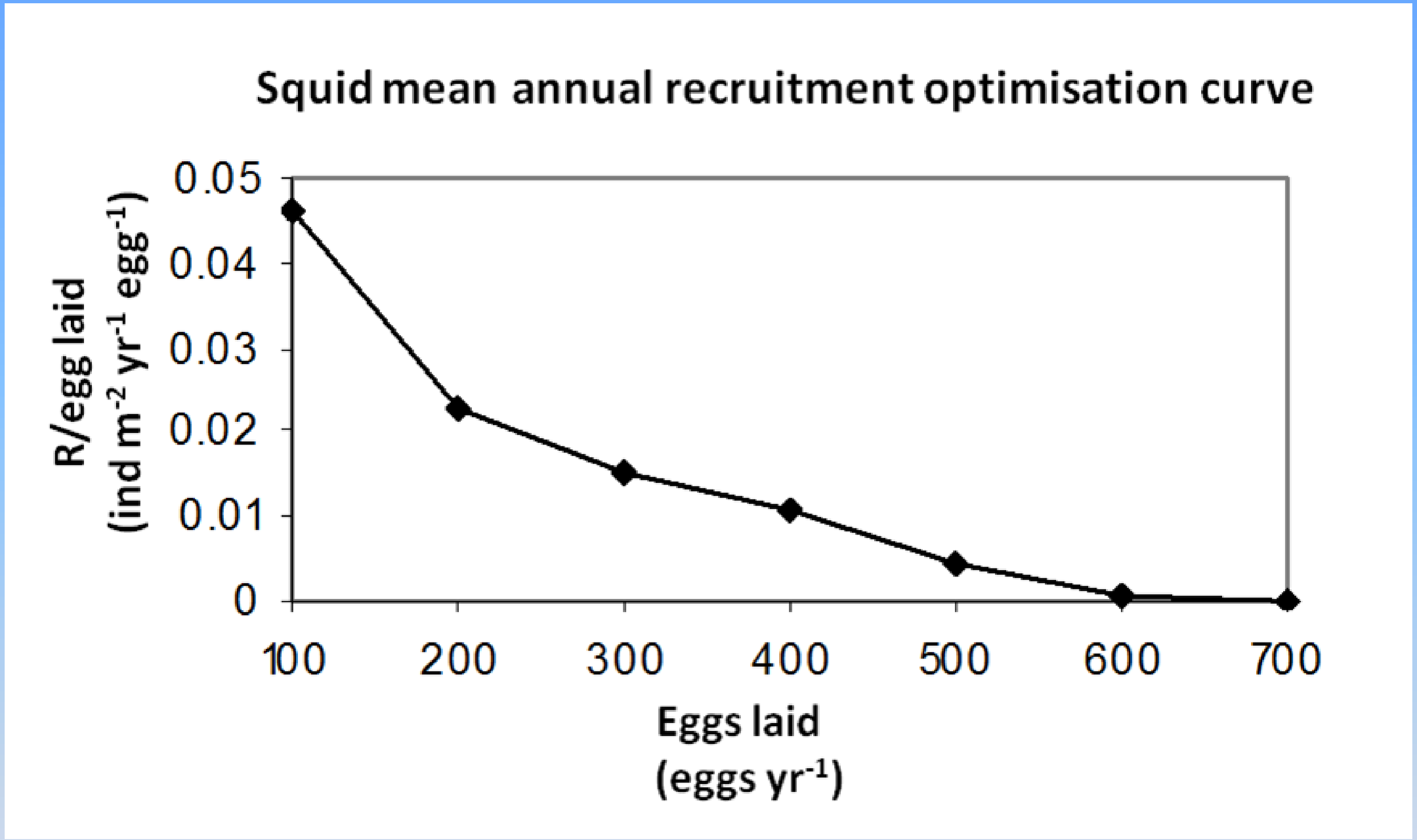
(b)			
BP $\times 10^3$	S	P	R
	ind m^{-2} yr^{-1}		
0	61.4	238.6	0.0
1	0.0	291.3	8.7
2	0.4	289.1	10.5
3	0.0	296.0	4.0
4	0.0	296.5	3.5
5	0.0	296.2	3.8
6	1.3	296.0	2.7
7	2.0	295.0	3.0
8	10.6	288.4	1.0
9	8.9	290.0	1.1
10	11.3	288.1	0.6
11	13.3	286.0	0.7
12	16.0	284.0	0.0

- Density-dependent reduction in Z at low BP concentration
- Direct effect of food limitation at BP > 2,000 ind m^{-2}
  - less carbon was transferred to the squid population → reduction in squid recruitment.
  - slower growth rate → squid more vulnerable to predation for longer (Ricker and Foerster, 1948)

Recruitment as a function of number of eggs laid

- Observation:
  - increased eggs production leads to decreased recruitment for *Loligo gahi* (Agnew *et al*., 2000).

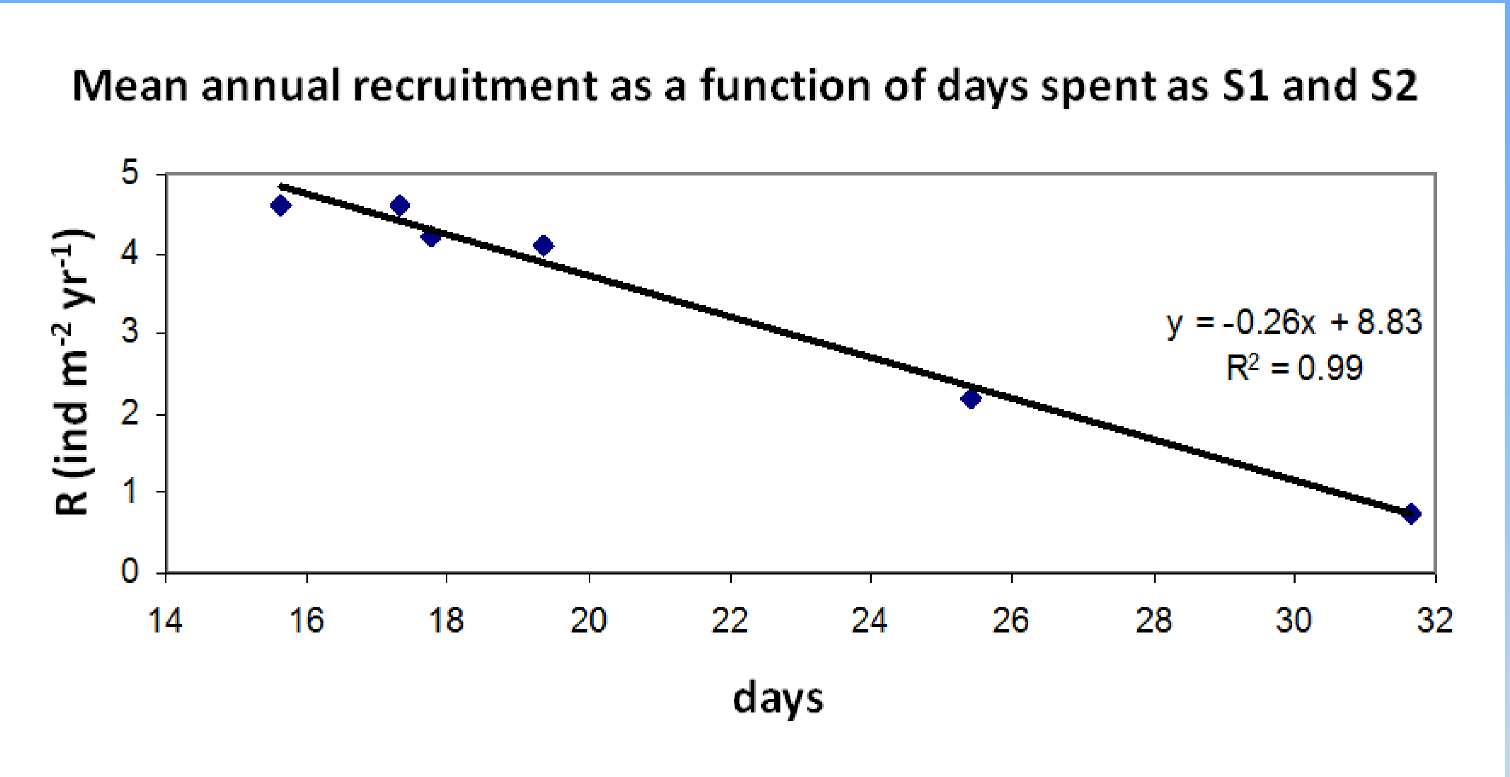
Recruitment as a function of number of eggs laid



(c)			
Eggs $\times 10^2$	S	P	R
	ind m^{-2} yr^{-1}		
1	0.0	95.4	4.6
2	0.0	195.4	4.6
3	0.0	295.8	4.2
4	0.0	395.8	4.1
5	41.4	457.4	2.2
6	14.8	584.5	0.8
7	39.5	660.4	0.0

- Lower survival with increased intra-population competition for food
- 100-400 eggs laid: mortality exclusively by predation,
- >400 eggs laid: combination of starvation and predation

Recruitment as a function of number of eggs laid



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Conclusions

- Annual recruitment was an emergent property of the silmulation:
  - Food availability and composition
  - Inter and intra-populations competition
  - Speed of squid growth
  - Predation
- Hjort’s critical period (Hjort, 1914)
- Interaction between density-dependent growth and predation determine density-dependent survival
  - (Ricker and Foerster, 1948; Cushing and Shepherd, 1980)
- The method proved successful in providing a plausible description of the mechanisms involved in determining squid annual recruitment