Another critical period: Physiological limits determine recruitment success during the post-larval stage of a temperate clupeid (*Sprattus sprattus* L.)

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Outline

1. Life-cycle in the Baltic Sea, key studies
2. 1-D growth model of seasonal cohorts
3. Growth performance in selected years
4. End-of-growing season condition & recruitment
Sprat life-cycle in the Baltic Sea
Sprat life-cycle in the Baltic Sea

Spatial

Depth
0 m

30-90 m

Temporal

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Sprat life-cycle in the Baltic Sea

Spatial

Depth
0 m
30-90 m

Temporal

Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec
Sprat life-cycle in the Baltic Sea

**Spatial**

- **Depth**
  - 0 m
  - 30-90 m

**Temporal**

- January
- February
- March
- April
- May
- June
- July
- August
- September
- October
- November
- December
Sprat life-cycle in the Baltic Sea

Spatial

Depth
0 m

30-90 m

Drift

Temporal

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Sprat life-cycle in the Baltic Sea

Spatial

Depth

0 m

30-90 m

Temporal

Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec

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Sprat life-cycle in the Baltic Sea

**Spatial**

- Depth
  - 0 m
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**Temporal**

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Sprat life-cycle in the Baltic Sea

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Depth
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Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec
Sprat life-cycle in the Baltic Sea

Spatial
Depth
0 m
30-90 m

Temporal

Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec

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Recruitment variability and critical life-stage

![Graph showing variability in spawning stock biomass and 1-year old recruits.](data from ICES WGBIFS 2015)
1a. Köster et al. 2003: **post-larval critical life-stage**

1b. Voss et al. 2012: **Act key mechanisms in coastal habitats of juveniles?**

2. Baumann et al. 2008: mismatch of peak spawning and peak origin of autumn-caught YoY/survivors:

Central Baltic Sea 2002
Recruitment variability and critical life-stage

1a. Köster et al. 2003: post-larval critical life-stage

1b. Voss et al. 2012: Act key mechanisms in coastal habitats of juveniles?

2. Baumann et al. 2008: „summer over spring born”

But why?

Our working hypotheses:

(1) recruitment strength is bottom-up regulated
(2) survival is the result of temperature * food interaction in the post-larval stage defining a successful „starting time“
(3) growth performance in the post-larval stage modulates survival and survival determines year-class strength
Growth model of seasonal cohorts

Spawning time

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Growth model of seasonal cohorts

Temperature dependent development of egg & yolk sac larvae (Petereit et al. 2008)
Growth model of seasonal cohorts

Temperature dependent length growth starting with 5 mm (first feeding)
(back-calculated length growth from otoliths of YoY-survivors, n > 400)

Growth model of seasonal cohorts

larval stage: fixed growth (temperature dependent)
Growth model of seasonal cohorts

post-larval stage: variable growth
upper limit ("optimal" growth)

larval stage: fixed growth
(temperature dependent)
Post-larval growth per day

\[ G = C - (R_{\text{routine}} + R_{\text{Feeding Activity}} + R_{\text{swimming}} + R_{\text{SDA}} + F + E) \]

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Post-larval growth – energy allocation

1. \( G < 0 \)
   - no growth
   - reduction of energy reserves

2. \( G > 0 \)
   - \( G - E_{\text{min}} < 0 \)
   - (reduced) growth
   - small increase of energy reserves

3. \( G > 0 \)
   - \( G - E_{\text{min}} > 0 \)
   - (optimal) growth
   - increase of energy reserves
Test run: Const. zero prey concentration

- no plankton
- no growth
- energy loss
- all cohorts die

Growth model of seasonal cohorts
Growth model of seasonal cohorts

Const. prey concentration
0.6 ind*l⁻¹

Low prey concentration
Growth (below „optimal“) and energy storage

Reduced growth
Small increase of e-reserves

Prey conc. (ind*l⁻¹)
Temperature (°C)
Energy reserves (J)
Length (mm)

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Growth model of seasonal cohorts

Const. prey concentration

2.4 ind*l⁻¹

"optimal" growth

increase of e-reserves

High prey concentration

Optimal growth and energy storage
Seasonal plankton time series

- coastal near location, vertical WP2 hauls (10-49 samples year\(^{-1}\))
- 2005 – 2015
- different energy contents per species and stage
- different capture success per species and stage

![Graph showing seasonal plankton time series](image-url)

- **Pseudocalanus**
- **Acartia**
- **Centropages**
- **Temora**
- **Eurytemora**
- **Cladocerans**

- - juvenile (IV-V)
- + adult

- Prey conc. (ind*l\(^{-1}\))
- Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec
A year resulting in high recruitment

Real plankton data 2006

“optimal” until September & strong increase of energy reserve

all cohorts survive

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Prey conc. (ind*l⁻¹)</th>
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<tbody>
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A year resulting in low recruitment

Real plankton data 2007

- Overall low length growth
- Depletion of energy reserves until all cohorts die
- Largest = earliest cohorts die first

Juvenile (IV-V) adult
Pse Ac Cen Te Eu Clado

Prey conc. (ind*l-1)

Temperature (°C)

Energy reserves (J)

Length (mm)
A year resulting in high recruitment

Real plankton data 2014

Early cohorts die, due to larger size & higher metabolic demand at high temperatures

No „optimal“ growth, for early cohorts

---

-200 -100 0 100 200

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

0 5 10 15 20

0 20 40 60 80

Prey conc. (ind*l-1)

Temperature (°C)

Energy reserves (J)

Length (mm)

-200 -100 0

juveniles (IV-V)

adult

Pse

Ac

Cen

Te

Eu

Clado

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A year resulting in high recruitment

No "optimal" growth, for early cohorts

early cohorts die, due to larger size & higher metabolic demand at high temperatures

Bigger is better is not always true!
Recruitment variability

Recruitment proxy: annual hydroacoustic survey from the Western Baltic Sea

early cohorts „suffer“
Recruitment variability and growth

**2006**

- Length (mm)
- Energy stores (J)
- Temperature (°C)
- Prey conc. (ind*l⁻¹)

**2007**

- Length (mm)
- Energy stores (J)
- Temperature (°C)
- Prey conc. (ind*l⁻¹)
Recruitment variability and growth

Year-class strength vs **length** (Dec)

\[ \text{no. sprat} = a \times e^{b \times \text{length}} \]

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<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-group</td>
<td>62</td>
<td>0.06</td>
<td>0.56</td>
</tr>
<tr>
<td>1-group</td>
<td>57</td>
<td>0.05</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Year-class strength vs **e-reserves** (Dec)

\[ \text{no. sprat} = a \times e^{b \times \text{energy reserve}} \]

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<tbody>
<tr>
<td>0-group</td>
<td>1229</td>
<td>0.0003</td>
<td>0.59</td>
</tr>
<tr>
<td>1-group</td>
<td>533</td>
<td>0.0003</td>
<td>0.83</td>
</tr>
</tbody>
</table>
Our working hypotheses:

(1) recruitment strength is **bottom-up** regulated

TRUE

(2) survival is the result of \textit{temperature} * \textit{food} interaction in the post-larval stage defining a successful „**starting time”“

TRUE \iff early cohorts suffer at low summer plankton conc. as their large body has high demands in summer temperatures

(3) **growth performance** in the post-larval stage \textit{modulates} survival and **survival determines year-class strength**

FALSE \iff survival of spring cohorts is not crucial for year-class strength

TRUE \iff \textit{growth performance in the post-larval stage determines year-class strength}